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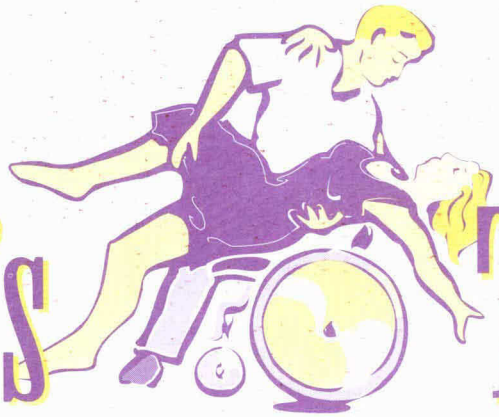

Let's Tango

PARTNERING PEOPLE AND TECHNOLOGIES

RESNA '97

June 20-24, 1997
David L. Lawrence Convention Center
Pittsburgh, Pennsylvania

PROCEEDINGS
of the
RESNA '97
Annual Conference

Let's Tango - Partnering People and Technology

June 20 - 24, 1997

David L. Lawrence
Convention Center

Pittsburgh, Pennsylvania

Stephen Sprigle, PhD
Editor

David Brienza, PhD
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Conference Co-Chairs

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Foreword

Let's Tango - Partnering People and Technologies

The RESNA '97 conference theme, Let's Tango: Partnering People and Technology, is symbolic of the RESNA membership's common goal to advance technology and make it work for people. The RESNA '97 conference theme are the common goals that unite our interdisciplinary membership. Individual approaches to achieving a partnership between people and technology are as different as our training and experience. We are people with disabilities, engineers, clinicians, suppliers, researchers and educators, and, like a superbly orchestrated dance, we work together to move the field forward, removing barriers and negotiating obstacles. To be effective we must share our knowledge and coordinate our efforts. There are many opportunities to participate--instructional courses, scientific sessions, concurrent sessions, commercial and scientific exhibits, social events, and tours of rehabilitation engineering and assistive technology facilities in the area. It is also an opportunity to participate in the "business" of RESNA and to find ways to become actively involved. Most important, there is time to partner with colleagues and friends.

On behalf of the Local Arrangements Committee, the RESNA Board of Directors, Meetings Committee, and Staff, we welcome you to Pittsburgh for the RESNA '97 Annual Conference.

We have come to Pittsburgh to Tango - Lets move together to partner people and technology.

David Brienza and Elaine Trefler
RESNA '97 Conference Co-Chairs

Al Cook
RESNA President

Preface

Welcome to RESNA '97. *Let's Tango: Partnering People and Technologies* is the theme for this year's conference. Instructional courses, concurrent sessions, exhibits, and the new "sneak previews" offer the best in educational opportunities. The scientific program continues this excellence with a diverse array of over 200 platform, interactive, and computer papers, presented by professionals from the United States, Canada and over ten other countries. Among these presentations are the two student competitions the "Whitaker Student Scientific Paper" which is comprised of research oriented presentations and the "PVA Student Design" which offers design concepts and practical solutions to assistive technology problems.

The Proceedings of the RESNA Conference attempts to capture and share a portion of the information that participants exchange during the presentations, activities and special events that make up RESNA '97. The many Special Interest Groups within RESNA provided opportunity for an in-depth focus on specific issues and concerns that cover almost all aspects of the rehabilitation technology field. We hope that you are one of the people actively involved in this exciting conference. These Proceedings and those from previous RESNA Conferences work to add important information to the growing body of professional literature on rehabilitation engineering and assistive technology. If you are interested in accessing content from the Proceedings from this conference electronically, you are invited to visit the RESNA Home Page on the World Wide Web
<http://www.resna.org/resna/reshome.htm> for information.

The Annual RESNA Conference represents the culmination of the efforts of many people. Over the past year, Conference Co-Chairs David Brienza and Elaine Trefler, have led an active local group who have helped make the conference in Pittsburgh possible. Special thanks go out to the continued work of the Meetings Committee, under the direction of Mary Binion, for their excellent efforts. Finally, the RESNA Office staff have worked hard throughout the year to support the conference and all the other RESNA activities.

We hope that you enjoy RESNA '97!

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SIG-01
Service Delivery and Public Policy

USING A TECHNOLOGY CONTEST TO INCREASE AWARENESS OF ASSISTIVE TECHNOLOGY

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ABSTRACT

This paper will highlight a technology contest that was open to consumers and staff of the agency to submit their best technology solution from the past year. The two outcomes we were striving for were: 1. Gain a better understanding of which technology solutions were most important to the consumers, and 2. Increase awareness of various assistive technology interventions that could benefit consumers.

BACKGROUND

Our agency provides transdisciplinary assessments for various types of assistive technology interventions. These assessments include mobility, seating and positioning, computer access, worksite modifications, environmental control units and augmentative communication devices. Each assessment is conducted by a team that may include any or all of the following: the consumer and family, rehabilitation technologist, physical therapist, occupational therapist, speech therapist, teacher, nurse, job coach, social worker.

OBJECTIVE

As professionals in the field of assistive technology, we are exposed to many different technologies and use them to meet the needs of the consumers we work with. Once these needs are met we seldom ask the consumers themselves which of these interventions they felt were most important to them and why. In addition to this, consumers may only be familiar with technology that is similar to their own and may not know the other types of assistive technology devices that are available today.In developing this contest, we hoped to learn which technologies were most important to the consumers we serve, as well as, use the data we collected to create a video tape that can be used to educate consumers and professionals about assistive technology and how it could increase independence.

METHOD

Entry forms were provided to consumers and staff which asked them to state the problem, the technology solution, and the members of the transdisciplinary team that were involved. There were no restrictions on the types of entries that could be submitted or the number of entries submitted from each consumer or team. The entries could consist of a commercially available device or devices, commercially available devices that were modified, or custom made assistive technology devices. Once all the entries were collected, they were videotaped and each one was summarized. Each presentation audience member is presented with a "ballot" to select the technology intervention of their choice.

RESULTS

Eleven entries were submitted for the contest and were as diverse as the field of assistive technology itself. Of the eleven entries, eight were technology interventions completed for specific consumers and three were completed for multiple users. Out of the group of eight individual

solutions, the age range was 9 years to 58 years of age. Two of the respondents were male and six were female. Seven of the consumers had a diagnosis of cerebral palsy and one consumer had a diagnosis of spina bifida.

The following is a brief description of each entry:

Universal Switch Mount - Commercially available device that was used to position a single switch near a user's head for computer access.

Access Utilities for Windows software - Free software, available from Microsoft, that enables the user to access Windows programs through the keyboard.

Proximity Switch Head Array for Power Wheelchair Control - Power wheelchair control that consists of switches mounted in a headrest to control the direction of the wheelchair.

Age Appropriate Multisensory Activity - T-Ball - Modified game of T-Ball that includes use of computers, adapted balls and bats, and various other pieces of assistive technology.

Adjustable Mount for Latch Hook Loop - Custom made device which enables consumer to independently complete a latch hook rug.

Sensor Switch for Augmentative Communication Device and Computer Access - Commercially available switch which enabled child to access computer and communication device.

Sliding Shelf on Work Table - Custom worksite modification to enable woman to access food preparation area in fast food restaurant.

Switch Adapted Personal Call Button - Modifications made to commercially available emergency call button to allow consumer to access it with larger, commercially available single switches.

Electric Razor Holder - Custom made fixture to enable man with severe spasticity to shave independently.

Tactile Mat - Eight foot long mat with various textured materials to assist therapists working with children with tactile defensiveness.

Adapted Shoulder Cuff - Custom made device to enable consumer to paint using the movement of her shoulder.

DISCUSSION

After all the entries were collected and documented, an interesting pattern arose. Several of the entries that were submitted by various consumers were surprising for the fact that the most important assistive technology device for them was not the device that the team would have initially selected. Instead of selecting the more expensive, commercially available device that the team may have felt was the most important intervention of the year, several consumers selected custom made fixtures that were designed to help them complete a designated task.

One woman has received many devices throughout the past year, including a power wheelchair with power tilt in space features, custom molded seat and back cushion, and a custom molded leg positioning system. While we felt she may submit this technology intervention because of the increased independence it afforded her, she instead submitted a custom made adjustable mount for a latch hook rug. This device consisted of several pieces of hardware mounted together in a unique way that enabled her to complete a latch hook rug that she was

making as a Christmas present. While she still needed minimal assistance from staff, she was excited about being able to independently complete this task.

Another gentleman has had many modifications completed throughout the year to enable him to access the computer independently and complete word processing training. His entry into the contest was another custom made device that allowed him to shave with his electric razor independently. This was another device that was designed using various pieces of hardware that were used in a creative way to allow us to mount the razor to his table and allow it to swivel to enable him to reach his entire face.

The video tape has also proved to be an excellent tool to raise awareness about assistive technology both in the community and within our own program. The video has already been presented at several local conferences and drawn rave reviews. Each audience member is provided a "ballot" to select the technology intervention of their choice. The video tape has also been used at staff meetings to showcase the different types of technology used by the consumers at our agency. Another positive consequence of this contest is that it has made the consumers we serve more aware of the assistive technology they are using and they are excited about submitting entries for next years contest.

ACKNOWLEDGMENTS

We would like to thank all the staff and consumers of Cerebral Palsy of Monmouth and Ocean Counties that submitted entries for the contest because without them this paper would not have been possible.

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USU Automatic Rocker

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ABSTRACT

For centuries, the positive relaxation effects for a rocking motion have been proven with children and elderly individuals. A repetitive rocking motion relaxes muscles and reduces stress. It can also provide sensory stimulation for less active people. Some individuals need assistance to rock in a rocking chair because they lack the necessary muscle control.

BACKGROUND

Sunshine Terrace Nursing Home in Logan, Utah requested an automatic rocker for their clients. They have expressed the need for a chair that would provide this type of relaxation and stimulation for those individuals without the ability to access it on their own. The rocker is intended for use at retirement centers, rest homes, or for any individual that wants the benefits of an automatic rocking chair

STATEMENT of the PROBLEM

Early in our design process we contacted the Adult Day Care Center at Sunshine Terrace who first asked us to design this type of chair. Several client needs were presented to us by the staff of this facility. Considering these needs we listed the following design constraints.

1. The chair must have a smooth continuous motion.
2. The rocker should have variable speed control.
3. When on, the rocker should stay in one place on the floor.
4. The device should be self-contained, without protrusions.
5. The controlling mechanism should be easily accessible.

RATIONALE

The automatic rocker design serves three purposes. First, it gives the user passive exercise because they have to gently adjust their head and upper body to account for their rocking. Second, it stimulates the vestibular system which provides critical input to the reticular activating system acting to arouse or inhibit the central nervous system. Third, the rocking motion is relaxing for many people. This automatic rocking chair will provide the necessary relaxation therapy and vestibular stimulation in an appropriate cost-effective manner.

DESIGN

The entire automatic rocking system consists of four main parts:

1. The rocker
2. The mechanical design and motor
3. The electrical design and speed control
4. The mounting system for the motor

1. The rocker

We purchased a standard sized glider/rocker that was sturdy because of our long hours of testing. Our intention was to develop a universal design so this automation could be used on all sizes and chair structure constraints. Three different type of rocking chairs have now been fitted with motors so the design is easily adapted to any type of rocking chair.

2. The mechanical design and motor
A 90 volt DC gear motor with 1/8 hp, 224 in-lbs of torque, and operating speed of up to 31 rpm's was chosen for the desired speed.
The motor is connected to the chair with a 1 1/4" crank arm attached to the motor shaft. The motor is placed upright underneath the chair allowing the crank arm to be positioned so the arm is attached to the bottom of the seat, thus reducing the torque requirements for proper performance. The attachment arm uses two swivel ball socket type connectors so the motion is smooth.

3. The electrical design and speed control
The rocker unit will be made to plug into any 110 volt standard electrical outlet. The speed controller has a AC/DC converter with a potentiometer for controlling the electrical current to the DC motor thus allowing the user to complete control of the speed of the chair.

4. The mounting system for the motor
The mounting system consists of 2 - 8 1/2" long pieces of 1 1/2 " X 2 1/4" slotted angle iron, chair attachment bracket 1 1/4" X 3" X 1/4" steel with 1/4" bolt, actuating arm made from 5/16" fine threaded steel screw stock with 2 - 5/16" swivel ball socket connectors on both ends. The motor is attached to a 10 1/2" X 8" X 1/2" plywood board with 4 - 1/4" X 3/4" lag bolts, as well as the chair attachment bracket.

DEVELOPMENT

This Automatic Rocker design needs only to incorporate past applications in design, and invert them so the motor and rocker arm is within the chair's framework. With our design the linear motion is the same, except that we have eliminated some torque requirements by reducing the stroke of the rocking mechanism. By having the motor placed in a vertical position with the rotating shaft up, it will easily attach from the motor to the seat frame through the linking arm assembly. This placement of the motor will require less torque to operate than from the lower swing arm position.

EVALUATION

Three chairs fit with different motor configurations have been used at this facility for the past year with much success. It has been found that the different rocking speeds benefit people in different ways, so our variable speed chair can be used with any type patient.
I do not foresee any problems with the combination of this chair and the motor setup, or any difficulties with this design. There are slight variances with other models of rockers so I can see changed needed only in the mounting plate and the linking arm. The dimensions of all of the chairs are nearly identical as far as the width, height, and length, the major problem is the bracing, and supports, for the chairs are slightly different, requiring minor changes.

DISCUSSION

The Automatic Rocker with its' desirable rocking motion, and comforting movement, shows a real potential. By the incorporation of the electric motor, and mechanical arm within the unit, makes this a unique rocking chair. The staff at Sunshine Terrace has been very positive about the different chairs we have developed and believe there is great potential for its use in many different type of settings such as adult living centers and rest homes. The cost of all parts, including the chair, was approximately $750.00. Several people have also shown interest in using the rocking chair with their young children to help induce sleep.

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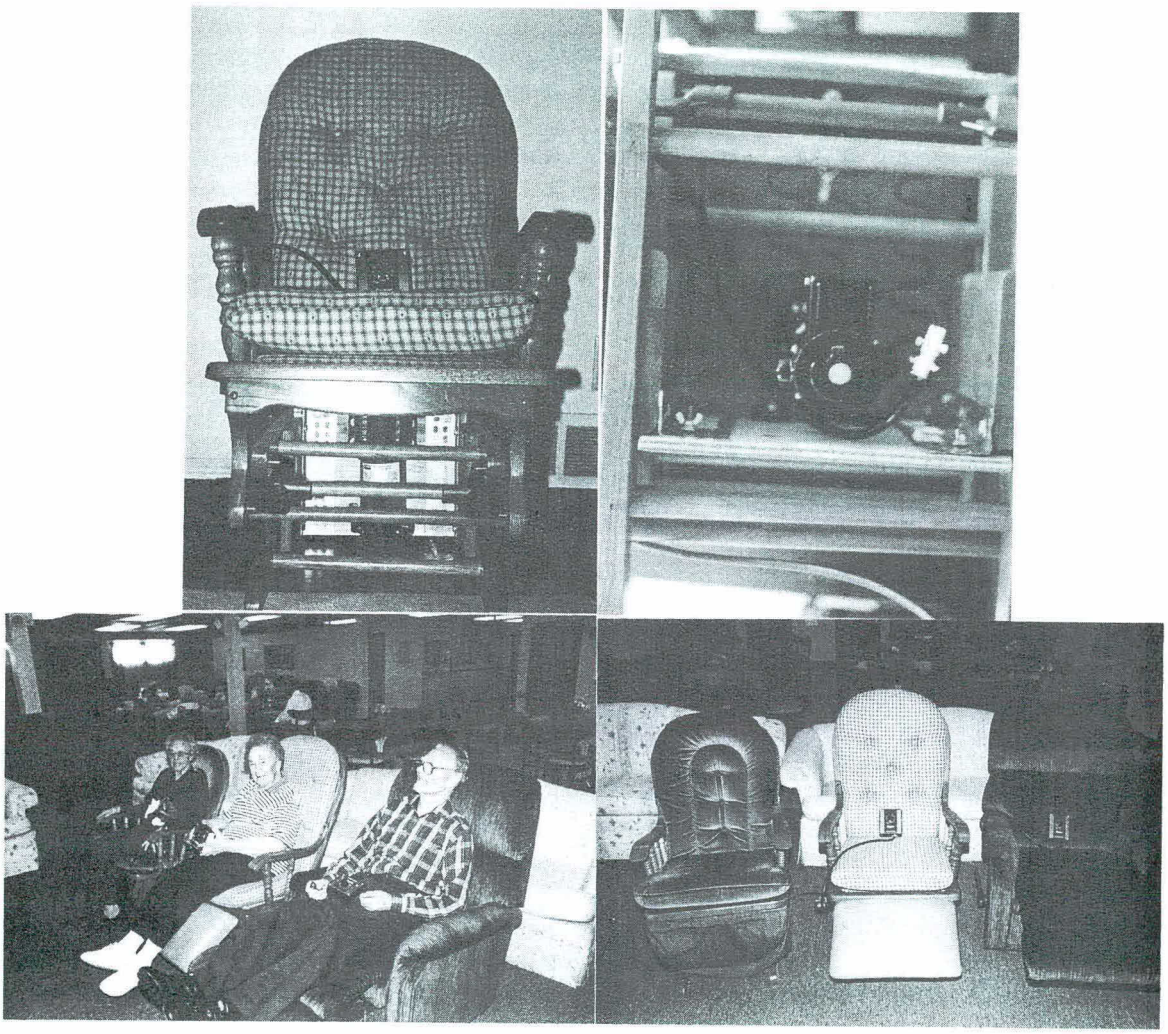

A LOOK AT REHABILITATION TECHNOLOGY SERVICES IN VOCATIONAL REHABILITATION AGENCIES

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ABSTRACT

Rehabilitation technology services in vocational rehabilitation (VR) agencies have reportedly grown in acceptance and utilization, yet relatively little is know about current trends or patterns of usage. A survey of VR agencies was conducted to develop a profile of current activities, identify existence of trends and estimate the (perceived) impact that rehabilitation technology (RT) has had on rehabilitation outcomes. Findings report use of RT services, important factors in technology utilization by counselors, and estimated impact that RT has had on VR services.

BACKGROUND

Rehabilitation technology has been mandated as a core service that should be considered for all individuals receiving vocational rehabilitation services (RSA, 1993). Despite indications of increased use and acceptance as an important service component, relatively little is known about trends and patterns of RT services.

The most comprehensive review of RT activities in VR agencies completed was the survey conducted by this RERC in 1994. The *General Report of Findings* (Flynn, 1994), which is available from CRTS, provides an in-depth look at multiple aspects of technology utilization in the VR process. Since collection of data for this survey occurred in 1993, RT requirements in the 1992 Rehabilitation Act Amendments have been enacted. Systematic monitoring and reporting requirements for RT have only recently been implemented however, therefore only limited information is available on changes or recent activities.

OBJECTIVES

Rehabilitation technology application and practice in VR agencies was reviewed to estimate current levels of activity and gather information which could assist in planning and program development by: (1) developing a general profile of RT use; (2) determining if there are any apparent trends in RT use; and (3) estimating the perceived impact of RT.

METHOD

A 14 item mail survey, with a cover letter, was sent to all 81 vocational rehabilitation agencies, which includes 23 General, 22 Blind and 36 Combined agencies. As of 12/1/96, 31 agencies submitted completed survey forms for a response rate of 38%.

APPROACH

Responses were analyzed by type of agency (General, Blind, and Combined) and as a total data set. Due to the relatively small numbers, analysis by type of agency will be reported only to respective VR agencies in individualized reports for internal planning only. The total data set was used in this analysis since it offers a more reliable indication of RT trends and practice.

RESULTS

Profile of RT Services

Considering all RT activities in the past year, VR agencies estimated that they spent the greatest time in work site (34%) and training/school site modifications (16%) followed by home access/IL (14%) activities. Information in Chart 1 illustrates how the total estimated time was spent.

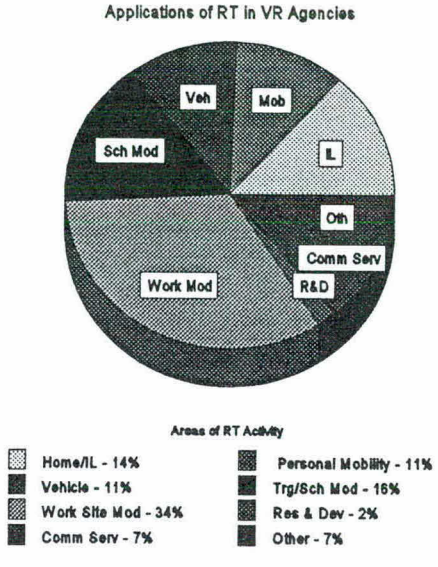

Chart 1: Applications of RT in VR Agencies.

How these technology services are delivered varies significantly between VR agencies. Although a detailed analysis of service delivery practice was not completed, some interesting patterns were noted. VR agencies use slightly more external sources of personnel (54%) than VR employees (46%) to provide technology services. A large number of agencies (61%) reported that they increased use of outside technology providers, on average, 36%. Vehicle-based services remained essentially the same in most agencies (68%), however 19% indicated increases from 10-100%. Most agencies (77%) indicated that they have had no significant capital improvement projects for technology activities.

Since access to rehabilitation technology services in VR agencies usually depends on decisions made by VR counselors, their perceptions as to what was most important about RT is interesting. Table 1 ranks their responses, from *most* (5) to *least* (1) important].

Technology-related Activity	*importance*	M
Obtain timely RT services	*very imp* (4)	4.26 Range 3-5
Order/receive AT equip in timely manner	*very imp* (4)	4.06 Range 3-5
Easy access to reliable vendors	*very imp* (4)	4.00 Range 3-5
Involving consumers in selection of AT	*very imp* (4)	3.82 Range 2-5
Sufficient opportunity for RT training	*important* (3)	3.42 Range 1-5
Having access to custom fabrication resources	*important* (3)	3.13 Range 1-5
Identifying funding to purchase AT devices	important (3)	2.96 Range 1-5

Table 1: VR Counselor Ranking of the Importance of Technology-related Activities.

The most consistent pattern stressed basic aspects of good technology-related customer service: timeliness, easy access and consumer involvement. It was somewhat surprising to see that funding was the lowest ranked factor.

Trends in RT Use

Overall, significant increases were reported in almost all aspects of rehabilitation technology use since implementation of the 1992 Amendments to the Rehabilitation Act. The following estimates of RT activity recognize several possible trends:

- **More individuals are being referred for RT services;**

Over 3/4 of VR agencies (77%) reported, on average, 28% increase in number of referrals for

RT. Individuals actually receiving RT services increased, on average 33%, in most agencies (87%).

- **More dollars are being channeled for technology-related activities;**

Funding allocated for RT increased, on average, by 60% in most agencies (68%). Increases range from 10-200%.

- **RT services appear to be better integrated into the rehabilitation process;**

Most VR agencies (between 46-86%) reported increased use of RT in key segments of the rehab process: evaluation-related activities (46% average gain); planned services (23% average gain); and placement-related activities showed a 24% average increase.

Estimated Impact of RT

Using a 5 point likert scale [*minimal* (1) to *significant impact* (5)], Agencies reported that RT has had a ***moderate impact*** (4) on rehabilitation outcomes. Expanding employment options for persons with severe disabilities (M=4.13), increasing the number of (job) placements (M=4.10), increasing the level of job placement (M=4.07) and opening new job areas (M=3.94) are all key issues which benefited when RT was used.

When questioned as to the response that VR agencies have received from employers toward participation in the purchase of assistive technology (AT) work aids or the modifications to work stations, employers seem to have been only ***somewhat receptive*** (M=3.22, range 2-5, on 5 point scale). Although this suggests that employers have been hesitant in their willingness to provide AT devices and make accommodations, the wide range of responses indicates that some agencies have experienced greater success since 39% (12) felt employers were ***very receptive***.

DISCUSSION

The number of individuals receiving RT services has apparently increased significantly. Since internal technology staffing levels remained the same in most agencies, increased RT activity may be attributed to the larger increases noted in use of external tech providers (contracts and consultants). From the information collected it was not possible to ascertain what specific services were used nor who provided them. Although not all aspects were analyzed, there does appear to be an overall increase in RT-related activities in almost all VR agencies.

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REHABILITATION SERVICE TRIALS VIA TELEVIDEO TECHNOLOGY: ISSUES AND COST-BENEFIT VARIABLES

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ABSTRACT

Trial use of videoteleconferencing technology for remote rehabilitation service delivery is described. Multi-line ISDN systems (384Kbps) were considered useful for education, consultation, and for some forms of assessment. Professionals did not consider the desktop versions of single-line (112 to 128 Kbps) ISDN-based videoteleconferencing useful for clinical applications. The cost effectiveness of the multi-line systems hinges on a number of variables which are identified. Variables and factors affecting the cost-benefit of this technology are discussed.

BACKGROUND

Telecommunication technology is evolving rapidly. Applications include teleworking or telecommuting (Milpied and Grandjean, 1995), teleconferencing, video-conferencing, multimedia conferencing, computer-supported co-operative work (Grudin, 1994), telemedicine (Bashshur, 1995), telelearning and distance education (Wells, 1993). Many of these applications have potential uses in the field of rehabilitation. Each of the above fields also has an R&D history and literature of its own, so that we can benefit from the work that has already been carried out in these areas.

OBJECTIVE

To determine the usefulness of multimedia televideo technology for use in the delivery of rehabilitation services to remote areas in Ontario we have over the past two years evaluated videoconferencing technologies for and in a number of different applications. Specific questions addressed were: which of the currently available technologies provides satisfactory image, motion and sound quality to allow clinicians to perform an extensive evaluation of this technology, and what cost-benefit models describe this technology.

METHOD/APPROACH

Two desktop video systems (VISIT and ProShare) and two Group or Boardroom systems (PictureTel's Concorde and Venue systems) were evaluated for clinical and R&D purposes. As a result of the merger of two organizations, our new institution exists on two sites 10 miles apart. This physical arrangement was well suited to the exploration of video technology for a number of intersite activities and for experimental applications. Demonstrations, educational sessions, meetings and interviews were conducted during the first month of use of the group systems. Client prescription reviews, assessments and more meetings and interviews are scheduled for the second month of operation.

All participants in the televideo activities were asked to fill in a questionnaire to help evaluate the system, its performance, and the participants' assessment of the usefulness of this technology.

RESULTS

Before installing the group video conferencing systems, we successfully used televideo desktop technology for cross-Canada meetings in a one-year software design and development project. However, the desktop systems fell short in our professionals' expectations of relevant clinical applications. These shortfalls were due to the limited screen size and image quality of the desktop systems.

Staff and a small number of parents and clients participated in the evaluation of the large screen group systems for clinical and meeting purposes. A total of 53 evaluations were completed. All but five gave very positive responses from professionals, clients and parents

(a rating of 4 or 5 on a scale of 1 to 5). Average ratings, on a scale of 1 (very poor) to 5 (very good) were:

Picture quality:	3.9
Audio clarity:	4.2
Ease of camera control:	4.0
Overall effectiveness:	4.3

The top perceived uses for the system were:

Consultation (incl. meetings):	28%
Education:	25%
Research proposals:	16%
Observation:	15%
Assessment:	14%

Our results with this technology matched research carried out elsewhere. These evaluations of ISDN-based video technology report tremendous potential for its use in rehabilitation and medical applications for direct service provision in outlying or remote areas and anywhere in the community.

DISCUSSION

A number of issues remain to be resolved. They are the choice of technology, jurisdiction and payment for services, and standards. Each of these will be discussed briefly.

Technology choice: The question of choosing a technology to use as a platform is likely to continue to exist for some time. At the moment, the best and most cost effective technology appears to be systems based on multiple ISDN (Integrated Services Digital Network) lines. As newer technologies such as ADSL (Asymmetric Data Subscriber Line) become more widely available with appropriate televideo systems, substantial improvements to the quality of information transmission and cost reductions can occur.

Jurisdiction and fee-for-service: Who can provide services, to whom, and how is one to be paid for this? Can a therapist or rehabilitation engineer provide services to people who live out-of-province or out-of-state? and under what conditions? An equally important question is who will pay for services via televideo conference, consults, assessments or prescriptions? In Canada these are not simple questions. They give rise to visions of, for example, a few computer applications technology gurus whose services are spread all over North America. Similarly, a small number of cognitive retraining experts, or head injury experts could serve all of continental America. These are not idle speculations. In effect the vision comes from one of RESNA's own institutions, the RESNA LISTSERV in which a small and highly informed handful of experts respond to the 30 to 50 clinical questions that appear on the LISTSERV each month.

Standards. Whether we are able to resolve the jurisdictional and funding issues or not we must look at the issue of standards for providing service over the information highway. The information transmitted, the names, composition and definition of procedures, AT devices, access software programs, treatments and services, should be comparable and standardized across different sites, states, provinces, and probably countries.

COST BENEFIT VARIABLES

The variables that are relevant in the use of televideo rehabilitaton services are: systems, application, travel (or travel substitution both in terms of cost and time, and accommodation), loss of work, loss of schooling, occupancy, media or line costs, staffing, fees or reimbursement.

The kind/type of system has a bearing on the number of applications. A small screen video conferencing system (desktop) using ordinary phone lines or single ISDN lines (112K or 128K) is cheaper to purchase and maintain but allows fewer useful applications and thus has less opportunities for return on investment. The system variables may include hardware, software, part-time staff, and space or a special room.

Another major variable is travel or travel substitution cost. This variable clusters with the duration of the application. A one hour device demonstration or training session can be accomplished in a single morning or afternoon whereas some multidisciplinary assessments may take two or more days. Many of our clients travel

hundreds of kilometres with their families to the centre and remain in the city for several days. In this case, accommodation costs must be added as well as the cost of lost time at work or school for the clients, parents and siblings.

Another cost differentiation comes from the kind of transmission medium used. The cheapest at the moment is the ordinary phone or fax line. For the moment the phone line does not yet support high quality video transmissions but will likely do so in the near future. Currently the most effective and available technology is ISDN (Integrated Services Data Network).

Occupancy or the number of hours per day that the system is in use and the number of persons who participate make an obvious difference to the cost effectiveness of this technology. Another factor that is important is that of fees or reimbursements to clients and clinicians.

Model I (from the client's point of view)

The simplest model from the parents' perspective include travel, accomodations, and time away from work and school. We can calculate costs using distance in kilometres, reimbursements of 32 cents per km, average accommodation, daily salary and tutoring rates to arrive at a value here.

Model II (from the rehab. centre's perspective)

The variables that play a role for the Rehabilitation Centre are: Cost of the system, number of valid applications, and occupancy or the number of hours and number of persons using the video system per month and the fee and/or reimbursement structure.

In our particular case the group system was used for meetings of staff between the two sites of our merged institutions. According to the merger plan the amalgamation process would require from 3 to 5 years. A simple calculation of the travel savings (in staff salaries) enabled by the televideo-based meetings showed that the purchase price of two group systems could easily be recovered in a single year.

CONCLUSIONS

From our limited experiences with the large screen videconferencing or "group system", it is clear that a number of current rehabilitation services and educational activities could be carried out using this technology. So far the applications selected appear to remain very close to the things professionals have been doing all along. Face to face meetings have become screen to screen meetings. The challenge for the next few years will be to realize the surplus value of the information and knowledge tools that can now be made available to clients and clinicians. We believe that it is possible to use this technology as a catalyst for an entirely new and more efficient means of service delivery.

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UTILIZING A REHABILITATION TECHNOLOGY TRAINING PROGRAM TO ASSIST COLLEGE STUDENTS WITH DISABILITIES

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ABSTRACT

SFSU has integrated two projects which together greatly enhance the training of assistive technology students and which facilitate retention and graduation of college students with disabilities. A series of Problem Solving Teams brings together students in our Rehabilitation Engineering Technology Training Project with students with disabilities entering the university. The focus is on utilizing rehabilitation technology students to assist in addressing the non-academic obstacles to success so often encountered by students with disabilities. The students with disabilities develop skills through team leadership. The students of assistive technology gain a deeper appreciation of the realities of living with a disability.

BACKGROUND

Several concurrent problems and needs exist at colleges providing training in assistive technology and at college campuses in general:

Needs of Assistive Technology Students:

- Rehabilitation technology students need opportunities for hands-on problem solving, working directly with consumers with disabilities.
- Assistive technology students need to understand that when the decision maker does not have to live with the technological devices the decisions that are made can lead to inappropriate choices and technology abandonment. For effective service delivery, students need to learn a consumer driven model which promotes the disabled consumer as the leader of the design team. (Nemon, Hotchkiss, & Pfaelzer, 1991)
- There is a need to increase the number of people with disabilities in the rehabilitation technology field.
- There is a need for increased exposure of rehabilitation counseling students to assistive technology principles and practices.
- There is a need among professionals in allied fields—OT, PT, special education, universal design, and independent living center staff—for focused education in assistive technology.

Needs of Students with Disabilities:

- Students with disabilities often have difficulty in transitioning from a home/high school environment to that of a university, with its accompanying expectation that students live and work independently. Even older students who transfer from other schools or re-enter college as independent adults often have trouble negotiating the unfamiliar terrain of university life.
- Students with disabilities need assistance with non-academic issues, which limit academic success. While most campuses have programs offering supports to students with disabilities, these programs overwhelmingly focus on classroom-related issues. Assistive technology services, such as adaptive computer labs, have also been oriented toward academic activities. Lacking are programs which comprehensively address the range of non-academic needs which can range from locating devices for self-care, to making a living space more accessible, to developing skills in self-advocacy and in managing assistants and service providers.

OBJECTIVE

The objective of this project is to develop a model for utilizing the existing resources on a college campus where some level of assistive technology training or services is available in order to increase the access by students with disabilities to these services. This model utilizes their knowledge and experience as consumers and promotes their own skills in research, problem-solving, and self-advocacy.

METHOD

We have designed two separate projects that complement and reinforce each other. One

project is our graduate training program in Rehabilitation Engineering Technology (RET), funded by the Rehabilitation Services Administration. This project offers course work towards a graduate certificate (or masters degree) in rehabilitation technology for rehabilitation counseling students, technologists, engineers, and allied professionals, while providing in-service training opportunities to state vocational rehabilitation counselors and local independent living centers staff. A companion goal of this project is to recruit people with disabilities to become qualified to work in the field of assistive technology, thereby promoting a model of service delivery by peer professionals.

Our second project is aimed at increasing the retention rate and academic success of incoming students with disabilities at SFSU. Entitled START (Solutions Through Advocacy and Resource Teams), it is supported by the Fund for the Improvement of Postsecondary Education (FIPSE), and focuses on addressing the non-academic issues of living with a disability which can impede a disabled student's academic progress.

The two programs have been designed so that technology students in the RET training program will gain hands-on experience with the technology needs of "real-life" consumers who are students like themselves. The students with disabilities in the START program interact with technology students from the RET project in a context which actively promotes the leadership role of the consumer and which discourages professional distance on the part of the technologists.

APPROACH

The SFSU rehabilitation technology program was founded in 1987. Its hallmarks are the use of a consumer driven model, an interdisciplinary framework, and the utilization of a problem solving methodology. Central has been an approach in which students from different disciplines and consumers with disabilities form teams which give participants experience in working together under consumer direction. A specific problem solving methodology is taught which enables the consumer to understand the professional's perspectives, thus allowing the consumer to participate more fully in the process. (Nemon, Hotchkiss, & Pfaelzer, 1991). The new project incorporates and builds upon the use of these basic principles.

In the past, our assistive technology students typically worked in teams with volunteer consumers from the community to gain hands-on experience with evaluation and service delivery. Some disabled students on campus were volunteers, but there have always been many more students with disabilities who could benefit from these efforts. Until now there has not been a systematic way to link the two groups.

Drawing from the last eight years' experience with the RET training program, the students in the START project are organized into problem solving teams composed of several disabled students and one or more technology students. The task of the teams is to identify and address individual participants' needs in living with a disability. Consumer students are grouped as much as possible in teams with others having similar disabilities or functional issues, in order for them to share relevant knowledge and skills.

Students in the START project are expected to take responsibility for coordinating the team's process of identifying problems and arriving at and implementing solutions. They draw on the technology students as collaborators and technical assistants. Rather than rely solely on the technologists for answers, they too learn about assistive technology concepts, problem-solving strategies, products, and service delivery resources.

Many of the issues addressed in the teams relate to assistive technology. An Assistive Technology and Resource Lab is being developed for consumer students to explore high- and low-tech options side-by-side with RET students. Students utilize printed and computer-based lab resources to search for information on products, vendors, and funding.

While a goal for the technology students in the teams is to gain an understanding of the factors surrounding the acquisition, acceptance, and use of assistive technology, it is expected that they will also learn about the non-technological issues which can promote or hinder a person with a disability's success in achieving his or her life goals. A number of the issues addressed by the teams are only peripherally technology-related, and some are

not technology related at all. RET students are expected to assist with these matters as well.

Students with disabilities are recruited into the problem-solving teams through a three-unit course entitled "Problems and Solutions in Living with a Disability." In addition to the team activities, the course covers a wide range of topics including: Introduction to a Creative Problem Solving Methodology; Finding, Hiring and Managing Personal Care Assistants, Tutors and other Aides; the State Department of Rehabilitation and other Sources of Financial and Material Aid; Negotiating for Reasonable Accommodations and Conflict Resolution; Issues in Independent Living; and the History of the Independent Living Movement.

PRELIMINARY RESULTS

In the course of working on the problem solving teams, RET students are learning that the students with disabilities have had significant life experience with issues and solutions relating to physical and programmatic access and assistive technology options. Many have also dealt with personal and social issues such as discrimination, stereotyping, low self esteem, and passivity. In helping explore non-technical issues, the RET students are gaining a greater depth of sensitivity and a more realistic understanding of what assistive technology can and cannot do to overcome barriers to success.

Rather than the typical two to four technology students working with one consumer, two or three RET students work with two to three students with disabilities. This approaches a more realistic multiple-project situation typical of real-world service delivery settings.

The interaction between disabled consumer students in the START class and RET students with disabilities provides additional role models and introduces assistive technology as a potential career path for the consumer students.

The project fosters development of peer relationships which should help in the integration of disabled students into campus life and which increase the comfort level of technologists and counselors in working with people with disabilities.

DISCUSSION

This is a new project with a variety of challenges. Outreach and recruitment of students with disabilities, particularly students from culturally diverse backgrounds, is an important task which is being addressed. Reaching students with hidden disabilities, many of whom never self-identify to the university's Disability Resource Center is an ongoing effort. Coordinating the needs of both the assistive technology students and the students with disabilities is another challenge. Many of the students have learning disabilities. However, for training purposes, it is important that technology students are exposed to a wide diversity of physical and cognitive disabilities, and opportunities for additional hands-on experience are created as needed.

Evaluation is being conducted to study the impact of our program on retention and graduation rates of students with disabilities, although it is often difficult to attribute change directly to participation in the problem solving teams. We are now involved in the first year of this three year effort and anticipate that programmatic changes will occur over the life of the project.

FIPSE funds demonstration projects which can ultimately be replicated in other settings. It is expected that campuses which engage in any kind of assistive technology training, such as an occupational therapy training program, could utilize a similar methodology.

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EMPLOYERS WHO HIRE ASSISTIVE TECHNOLOGY USERS: A CASE STUDY

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ABSTRACT

This is excerpted from a case study of employers who have successfully hired assistive technology users. Basic information was gathered on these employers, on their interactions with vocational rehabilitation (VR) employees, and on their levels of satisfaction with technology users and VR personnel. The targeted employers were selected based upon their policies and histories of actively seeking out and hiring persons with disabilities. Why do they hire technology users? What are the advantages to the company, and why do they feel it is advantageous? The current paper highlights one employer from this case study, examining a successful employment strategy for recruiting and hiring technology users.

BACKGROUND

In 1995, the National Organization on Disability commissioned a Louis Harris survey on employment of people with disabilities. According to this survey (Harris, 1995), there is a misconception that corporate America is not supportive of the Americans with disabilities act (ADA). They found the reverse to be true, that large corporations strongly support the ADA and the policy of allowing equal access to employment for persons with disabilities. They found that 81% of companies of all sizes have increased the number of accommodations they have made in the work place as opposed to 51% of companies as found in a 1986 Harris poll.

Assistive technology aids and devices are often credited with opening the doors to diverse job opportunities for people with disabilities (Kirchner, McBroom, Nelson, & Graves, 1992). While assistive technology may enable people to work in various jobs, evidence is mixed to whether or not employers are willing to hire people who need assistive technology.

OBJECTIVE

The objective of this case study is to share stories of employers who successfully and consistently hire persons who use assistive technology aids and devices. It is hoped that other employers will be encouraged to offer job opportunities to persons with disabilities who use assistive technology to complete their tasks.

METHOD/APPROACH

V R counselors were contacted across the country and asked for employer contacts. The counselors were specifically asked for employers who hired their clients who were assistive technology users. The employer contacts were then screened with a brief interview; employers who seemed to have a history of hiring device users were selected for a more in-depth interview. The employer highlighted in this case study is NOVUS Services in Sandy, Utah.

RESULTS

NOVUS Services had tried with limited success to actively hire persons with disabilities. In spite of their efforts to advise applicants that they were an equal opportunity, affirmative action employer, they were not receiving a significant

number of applications from persons with disabilities, even though the work could be performed by individuals with severe disabilities provided they had the proper training. Furthermore, the company was willing to provide the necessary training and worksite accommodations. To help implement their strategy for hiring people with challenges, NOVUS invited input from volunteers in the disability community.

When the volunteers were asked how NOVUS could meet the needs of people with disabilities, Debbie Inkley stated the need for meaningful employment with competitive pay. Debbie agreed to pilot a training program for a year as a volunteer to see how well it would work; in return, the company committed to providing the necessary resources. After a year, Debbie was asked to continue as the director of the training program (known as the B.O.O.S.T. program) as a paid consultant.

The B.O.O.S.T. program teaches Rockwell phone procedures, telephone communications skills, OS/2, Lotus, and Ami Pro computer skills; office equipment handling; customer services skills; problem solving skills; job interviewing skills; and quality training. While the program seeks to qualify trainees in all areas, each module is a standalone; therefore, it is possible for most individuals to pass at least some of the modules, so it is not an "all or nothing" situation.

The B.O.O.S.T. program is provided free of charge to individuals with disabilities. Although they seek to hire as many of the B.O.O.S.T. graduates as possible, there is no obligation on the part of NOVUS Services to hire them; on the other hand, if a graduate gets a job offer from another employer, the graduate is free to accept this offer and is in no way obligated to NOVUS Services.

The B.O.O.S.T. program is essentially a partnership with VR. Counselors often call asking about openings in the training program; when necessary, the B.O.O.S.T. director solicits participants from VR and other sources. NOVUS Services provides training and worksite accommodations; VR provides assistive technology devices, rehabilitation engineering services, and technical expertise in worksite accommodations.

As a direct result of the B.O.O.S.T. program, NOVUS Services currently employs approximately 41 individuals with disabilities, including 15 assistive technology users, and this number is gradually growing. NOVUS Services facilitates the B.O.O.S.T. program in Sandy, Utah; Phoenix, Arizona; and New Castle, Delaware. This attests to the success of this program, both for the employer and for potential employees with disabilities.

DISCUSSION

The question of cost-effectiveness is often asked when assistive technology and worksite accommodation are discussed. While assistive technology is sometimes thought to be less cost-effective than other strategies, there may be other benefits to introducing employers and employees to assistive technology. Some initial questions include:

- Are assistive technology devices being used effectively and efficiently on the job to the satisfaction of the employer and the employee (i.e., has the device permitted the employee to perform up to standard in competitive employment)?

- Are employers who hire device users more likely to seek out Vocational Rehabilitation when they have job openings? As a result, may we expect more job opportunities for persons with disabilities?

Employers who Hire Technology Users

- Has the purchase of assistive technology impacted on their total operation (i.e., has the accommodation benefitted the business in any way other than permitting the technology user to perform a job)?

Research is needed in the area of direct and peripheral benefits of providing assistive technology to persons with disabilities.

An issue of importance to consumers is that of meaningful employment. If an individual with a disability can be returned to an occupation in which he or she has years of experience and expertise following illness or injury through the provision of assistive technology to compensate for a functional limitation, it seems intuitive that we may expect the person's earnings to be higher than if the person was placed into an unskilled, entry level position. Also, if a person is entering the job market for the first time, it is possible that he or she will be able to find a higher paying position if the number of occupational options were increased. Can the use of technology lead to increased occupational options, and to higher paying positions? CRTS is making initial overtures into this area by gathering case study data. However, in order to make a determination as to the contribution (and worth) of assistive technology, further research is needed to gather hard data.

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A MODEL BS PROGRAM IN REHABILITATIVE SCIENCE & ASSISTIVE TECHNOLOGY

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ABSTRACT

A proposed model Bachelor's Degree program in Rehabilitative Science & Assistive Technology is described. The program described is interdisciplinary, with course work taken from existing offerings out of health sciences programs, the Physical Therapy program, the Engineering Technology program, as well general college distribution requirements for B.S. degrees at the College of Staten Island. Nine new courses in rehabilitative science and technology will be offered for majors in this program.

BACKGROUND

Innovations in the field of rehabilitation and assistive technology have made major advances in recent years. These advances are partly due to relatively generous funding that has been available in the health-care field, and the social need to improve the quality of life of people with disabilities. Proliferation of private industry has allowed untrained persons to enter the field as suppliers of rehabilitation tools or assistive technology devices. With the move towards managed health-care and the need for efficient and competent delivery of services, the benefit of certification and well defined educational programs for providers of rehabilitation tools and assistive technology is clear. The authors therefore believe that there is a need for a well designed four year college curriculum to academically prepare professionals who wish to work in the area of rehabilitation and assistive technology.

OBJECTIVE

The authors propose to establish a new B.S. program in Rehabilitation Science and Assistive Technology. The new program will cater to the changes in the health field and the move toward managed care. The new Rehabilitation Science and Assistive Technology program will be interdisciplinary, and will involve physical therapy and engineering technology. New courses will be developed and refined by faculty teaching in these areas guided by recommendations resulting from curriculum development seminars. At first, a minor in rehabilitation science and assistive technology will be offered. Further development of new courses will allow a degree in Rehabilitation Science and Assistive Technology to be offered. The degree of B.S. will be available to entry level students as well as those already awarded an A.A.S. in Physical Therapy (PTA) or Engineering Technology. No program of this type is presently offered at any unit of CUNY, and therefore it our objective to provide such a program in the near future.

APPROACH

Planning a new program in Rehabilitation Science & Assistive Technology requires a multi-disciplinary approach. An interdisciplinary team of faculty, providers, and consumers will be assembled to determine the requirements of the program and design the course work. The faculty component of this team is from the programs of Physical Therapy and Engineering Technology at CSI.

The team will determine common core areas of

understanding essential to Rehabilitation & Assistive Technology. The team will identify the most common real world problems a rehabilitation scientist might be required to solve, and will design course work appropriate to provide students the skills necessary to solve these problems. To facilitate the program development, three faculty development seminars are planned. In the first, the team will meet with outside consultants to explore core areas of knowledge and skills sets needed in Rehabilitation Science & Assistive Technology. In the second seminar will team participants from the multi-disciplinary departments involved will meet to refine the preliminary curriculum for Rehabilitation Science & Assistive Technology. Broad requirements will be discussed followed by focus on key areas requiring collaboration between the disciplines. Team members will fully develop specific subject areas. The third faculty development seminar proposed will bring together all participants, including outside expert consultants for a panel discussion of the implementation of the program. Work done thus far will be critiqued and revised by the group. A complete and detailed academic curriculum in Rehabilitation Science & Assistive Technology will then be submitted to the College of Staten Island for approval.

RESULTS

A preliminary curricula for a Bachelor of Science degree program in Rehabilitation Science has been proposed. This curriculum is designed to conform to general academic requirements for four year programs in the sciences. The program attempts to maximize the use of existing courses. Courses identifiers prefixed by a * indicate a new required course that must be developed. Full descriptions of existing courses are found in the 1996-1997 CSI Undergraduate Catalog.

Pre-Major Requirements

Bio 150,160	Anatomy & Physiology	8cs
Bus 100	Introduction to Business	3cs
Chm 106,108	Chemistry I, II	6cs
Chm 107,109	Chemistry Lab I, II	2cs
Elt 102	Intro. to Elec. Technology	4cs
Mth 113	Intro to Prob. & Statistics	4cs
Mth 130	Pre-Calculus Math	3cs
Phy 116,156	Physics I,II	8cs
Psy 100	Psychology	3cs
Psy 242	Developmental Psychology	4cs

Major Requirements

Ent 100	Basic Technical Skills	2cs
Ent 101	Intro to Meas. & Inst.	2cs
Elt 213	Electronic Fab. Techniques	1cr
Elt 240	Prin. of Digital Circuitry	3cs
Elt 241	Digital Circuitry Lab.	1cr
Ent 261	Intro to Robotics	3cs
Csc 126	Intro. to Computer Science	4cs
Phl 130	Intro. to Ethics	3cs
Haa 107	Intro to Dev. Disabilities	3cs
Pht 608	Health Care Admin.	3cs
*Ent 5xx	Sensor Tech. & Cont. Inst.	4cs
*Prt 3xx	Principles of Biomechanics	4cs
*Ent 3xy	Applied Materials Tech.	4cs
*Prt 4xx	Rehab. Equip./ D.M.E.	4cs
*Prt 4xz	Rehab. Equip./Computer	4cs
*Prt 4xz	Innovations in Rehab. Sci.	4cs
*Prt 270	Clinical Practicum I	3cs
*Prt 300	Clinical Practicum II	3cs
*Prt 5xx	Accessibility Engineering	3cs

Basic Requirements & Electives 18crs

DISCUSSION

Changes in the current health care system will demand training of professionals in the field of Rehabilitative Science. The academic program proposed will be attractive to students who enroll in Engineering Technology, Engineering Science, as well as the Physical therapy program, where currently hundreds of students apply for only a small number of spaces.

Other units of the CUNY have related two year programs, some of whose graduates wish to continue their studies. Initially, the program will have enrollment of 15 to 25 students selected from the groups described. The program may be divided into two major areas of emphasis. Rehabilitation Science, and Assistive Technology. The Rehabilitation Science program will attract some practicing physical therapists who earned a baccalaureate degree before the masters entry level requirement was instituted, the majority of whom graduated before 1990 and are interested in upgrading their credentials. The other area of emphasis is Assistive Technology, which will be suitable for AAS degree graduates of programs such as PT Assistant, or Engineering Technology. These students will wish to complete remaining requirements for a B.S. degree. Laboratory space compatible with the requirements of this new program already exist at CSI as part of the facilities serving programs in Engineering Technology, Physical Therapy and Applied Sciences. Advancements in computer software now allow multiple uses of existing instrumentation, and therefore this instrumentation can be used for the newly designed laboratory component of this program. It is expected that durable medical equipment, such as powered wheel chairs, will be provided by the health care industry. A large capital investment is therefore not immediately needed.

Internships at health-care and rehabilitation technology providers are also an essential part of this program and must be made part of the curricula. Internships will serve the dual purpose of affording students the opportunity to experience the real world work place, as well as develop job opportunities. The College of Staten Island, with its existing Physical Therapy and Nursing programs is well positioned in the health care field, and has the contacts necessary to establish such internships. These internships will be on-site at health-care facilities in the area.

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IMAGINE SPENDING A DAY WITH YOUR MOUTH TAPED SHUT.

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ABSTRACT

This paper proposes the use of a contracted AAC distribution service for the administration, management and delivery of augmentative and alternative communication (AAC) systems in Minnesota. Findings from a 1997 study conducted by the STAR Program suggest that inaccessibility to AAC has multiple components: lack of funding for a full range of needed AAC systems, limited number of knowledgeable service providers, restricted availability of AAC for trial and short-term use, and limited access to unbiased expertise. The development of an AAC Distribution Service will improve access to needed AAC systems, build capacity in communities, and help to control costs through availability of low-to-moderately priced AAC systems and the reuse of used AAC devices and system components.

BACKGROUND

In two decisions in 1985, the Minnesota courts compelled Medical Assistance (Minnesota's Medicaid program) to consider AAC "medically necessary". When only two or three manufacturers or distributors enrolled in MA, the Department of Human Services created an informal agreement (1987) allowing two service providers to serve as "pass-through" vendors in order to provide access to other AAC products. These products were largely the low-to-moderate cost AAC that were less complex devices or devices requiring a combination of components such as mounts, switches, wheelchair trays, keyguards, etc. "Pass-through" vendors acted as purchasers and billed MA using their own number to garner reimbursement for AAC systems not otherwise available. Reimbursement was at 120 percent of wholesale providing full remuneration for the cost of the device plus 20 percent for administrative costs. This system worked well for the consumer until August 1995, when DHS "corrected" this practice saying it did not comport with federal rules thereby reducing reimbursement to 80 percent of the actual cost to the "pass-through". Access to low-to-moderate cost AAC, relatively simple devices, lightweight but complex devices, and computer-based systems was immediately cut off. Consumer complaints supported by reports from agencies and professionals came in to STAR. STAR was successful in getting a short-term amendment adopted establishing payment for "pass-through" vendors at 100 percent for the cost of the device until December 31, 1996. The amendment also directed STAR to study alternative payment methods. STAR submitted a report of its findings to the 1997 Minnesota State Legislature. That report is entitled, *Imagine spending a day with your mouth taped shut.*

OBJECTIVE

STAR's report presents an innovative approach to providing access to a full range of AAC devices and system components through Medicaid programs. Considerations were given to prior authorization procedures and meeting the requirements to recoup federal share.

METHOD OR APPROACH

STAR conducted surveys of manufacturers of AAC and Minnesota speech language pathologists, met regularly with staff from the Department of Human Services, discussed legal barriers with the Minnesota Disability Law Center, spoke with representatives of AAC manufacturing companies, and listened to concerns of consumers, families, and other professionals.

RESULTS

Of the 115 surveys sent to manufacturers of AAC-related products. Seventeen surveys were returned and STAR staff made phone contact with several others. Companies not enrolling in MA stated concerns about the cost of managing the paperwork and tracking payment in addition to receiving only 80 percent of their retail price. Manufacturers of low-to-moderately priced AAC

report that they have priced their products with a small profit margin in order to be affordable for those purchasing AAC out-of-pocket. Manufacturers who were enrolled in MA tended to be larger companies who had published list prices with room for a 20% discount.

Surveys were sent to 460 speech language pathologists (SLP) in Minnesota since reimbursement for AAC devices and services fall under their MA codes. Twenty-one surveys were returned. An additional 25 SLPs were contacted by phone; all of whom said that they did not know enough about the subject matter to return the survey. Their comments support our belief that the low return rate was not due to lack of interest but rather lack of experience.

DHS provided STAR with data on 282 MA recipients who had requests for purchase, repair, or lease/rental transactions during a 31-month period. Approximately 60 AAC systems are purchased each year through MA. Recipients reside in 62 of Minnesota's 87 counties, with many of them living in Hennepin and Ramsey counties. Twenty-nine percent of Minnesota's counties did not have any transactions. These findings suggest a significant underutilization of access to AAC technology. Restricted access to AAC in MA, the newness of the AAC technology itself, and limited access to expertise in communities all contribute to this situation.

One of the complications in dealing with this issue is that no one has good hard data about the number of MA recipients being underserved, not being served appropriately or not being served at all.

DISCUSSION

The STAR report is a vehicle for educating legislatures and other decision makers about AAC while presenting an innovative alternative. The report highlights individuals whose lives have been impacted by AAC to remind decision makers that there is a human cost to not providing adequate funding or access to services. The Department of Human Services opposes any changes despite recognizing that some people do not have access to the appropriate devices. They anticipate the movement of individuals with disabilities into managed care within the next couple of years as the eventual solution to this problem.

STAR works to gain timely access to appropriate assistive technology for all people with disabilities through systems change activities. The response of the Minnesota State Legislature will be discussed in the presentation but is not known at the time of this writing. STAR expects to be able to discuss further the process, what worked and what did not, and who the proponents and opponents of the report's recommendations were.

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SIG-02
Personal Transportation

BICYCLE MODIFICATIONS FOR AMPUTEES

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ABSTRACT

In this day of heightened awareness of health and exercise, people have begun to realize the importance of participating in some form of athletic activity to promote a healthy lifestyle. Bicycling has long been known to provide a good workout with low impact, with the additional benefits of being outdoors, fresh air and scenery. For those cyclists with above the knee amputations, cycling presents some unique challenges for safe and efficient riding.

BACKGROUND

The design group was approached by two cyclists with above the knee amputations (AK) of the left lower limb, each with different goals concerning their cycling. Client #1, Andrew, had a left hip disarticulation and was concerned about low speed balance. Client #2, Scott, has a lower left limb, AK amputation, 14 cm proximal of the knee joint. He was interested in improving his cycling efficiency through the use of his residual limb.

Andrew desired to return to riding a standard two-wheeled bicycle for the speed and maneuverability potential it offered over the adult tricycle he had been riding for the past several years. His main concern was his possible lack of balance at low speeds and during the starting/stopping procedure. As he would have to use toe clips on his right foot to achieve full pedal rotation, he feared not being able to lower his foot in time if required.

Scott, a cycling enthusiast, had continued cycling after his amputation by utilizing his prosthetic limb and clipless style pedals on both feet. This allowed his left limb to contribute some to the pedal action. However, he felt as if the weight and mechanical disadvantage of the prosthetic limb was causing him to lose efficiency while cycling.

OBJECTIVE

The goals for each project were set by the two clients before design began. Providing a safe and easy means to achieve low speed balance and stability while starting/stopping while riding a standard two-wheeled bicycle was the goal set by Andrew. The objective set forth by Scott was to design modifications to his bicycle to allow him to achieve greater efficiency while cycling.

APPROACH

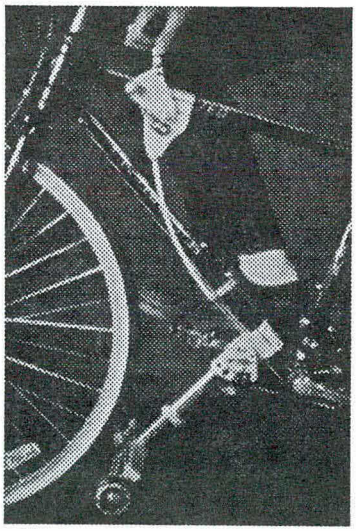
In order to achieve full pedal rotation when cycling with one leg in use, it is necessary to use a toe clip and strap assembly or a clipless style pedal. This makes a firm attachment of foot to pedal. Due to this stipulation, Andrew realized the act of balancing or unclipping would be quite difficult when slowing or stopping. It would be of equal difficulty as he started from a stop as he would have to push

off and get the momentum up to begin a pedal rotation. To solve this problem, the Bicycle Stabilizer was developed to allow the client to leave his foot in the clips during these tricky maneuvers. The product also provides the necessary stability when required.

The Bicycle Stabilizer is a retrofit product, which when mounted to a standard upright bicycle, allows the user to leave his feet or foot on the pedals while stopped, without the fear of tipping. See Figure 1.

The stabilizer consists of a retractable arm mounted to the down-tube of the bicycle, and an activation handle mounted to the top-tube. The retractable arm has a pair of inline-skate wheels spaced 12" apart mounted on the lower end of the arm. These wheels have 1" of travel dampened by two 225lb. springs to allow for shock absorption.

Figure 1.

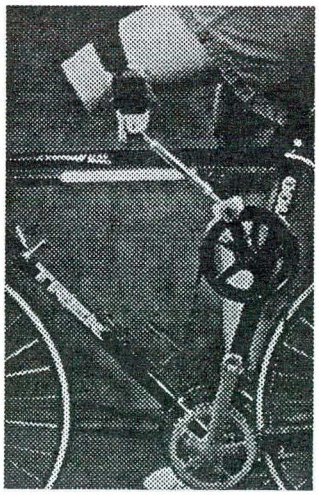


Lowering of the wheels is accomplished by pulling the handle rearward which pulls on the cable attached to the retractable arm. To raise the wheels, Andrew would push the handle forward, releasing the cable's over-center position, allowing the gas spring to push the wheels forward. The cable prevents the retractable arm from swinging into the front wheel of the bicycle.

While Andrew required the stabilizing effects for safe cycling, Scott did not have these same concerns. The goal for Scott was to achieve a more direct link from his residual limb to the pedals of the bicycle. It became evident through experimentation that Scott's left leg achieved it's peak output at a different location on the pedal rotation than did his full right leg.

The solution required altering the phase, or crank orientation, of the bicycle. A series of stock parts and a few custom parts were needed to achieve these results. A child's tandem stoker kit was affixed to the seat tube of the bike, with the corresponding timing chain ring added where the left pedal originally was located. See Figure 2. This permitted crank phase and stroke angle adjustment through chain rotation and height of the crank arm on the seat tube.

Figure 2.



BICYCLE MODIFICATIONS

Crank phase is normally 180 degrees, meaning that the left and right side cranks are 180 degrees opposed to each other. In Scott's case the left crank was set at 30 degrees ahead of normal. Doing this allowed his right leg to help pull the left pedal around. The crank for the left leg is also mounted such that the power stroke is achieved while pushing in a rearward direction instead of a downward direction as his right leg.

A strap and cup are used for attaching the leg socket to the custom pedal arm. This allows Scott to mount and dismount the bicycle with minimal adjustment.

RESULTS

Andrew has been using the Bicycle Stabilizer for over six months and has reported no difficulties in use. Even though the product added five pounds to the bicycle, his new bike remains several pounds lighter the his old tricycle. The weight advantage as well as the maneuverability and safety of this setup has provided a much more enjoyable vehicle to the client.

Scott's bicycle modifications have been in use for over seven months and the design is still being refined. The set up does provide much more efficient cycling, but there is still improvements that can be made on the socket/crank attachment. Plans are in order to have a clipless pedal assembly mounted to another 'sports' socket to provide a more secure attachment to the bicycle.

DISCUSSION

Each of these designs achieved the goals set forth at the beginning of the projects. The methods used in each are indicative of the custom nature of design for disability. While both men share similar disabilities and are pursuing similar activities, the needs of each were completely different and therefore the solutions differed greatly.

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UNIVERSAL INTERFACE HARDWARE DESIGN STANDARD FOR MOBILITY DEVICE TRANSPORT DOCKING SYSTEMS

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ABSTRACT

Docking-type securement devices for mobility devices and their occupants offer several advantages over the more commonly used belt-type technology. One large limitation of the proliferation and success of docking technology is the requirement for specific wheeled mobility device (WMD) hardware to interface with compatible vehicle-mounted hardware. Current interface hardware designs have shortcomings and require that the vehicle have specific docking hardware or it is rendered useless. This paper discusses the efforts that have been made to facilitate the development and adoption of a trans-industry universal interface design standard. The goal is to foster seamless compatibility between the WMDs, their securement devices, and the transport vehicles. Industry summits and focus groups have identified design criteria and potential hardware configurations. In addition, the optimal location for placement of the hardware on WMDs has been investigated.

BACKGROUND

WMDs, their securement devices, occupant restraints and transport vehicles all need to function as a system if individuals are to safely and independently use both public and personal vehicles while remaining seated in their WMDs. Improving accessibility and safety relies upon standardized methods being developed and adopted for interconnecting the respective technologies. The successful development of new docking-type securement devices, that eliminate several of the disadvantages of commonly used belt-type devices, depends upon standardized ways of interconnecting the WMD with vehicle-mounted securement hardware. The adoption and promulgation of a universal interface hardware design standard for docking devices can ultimately mean that a person can access and have their WMD secured in any transport vehicle, in a manner offering equivalent safety to that of any other rider seated on the vehicle. The design standard will provide the basis by which all involved industries can design and produce compatible WMD securement products. Design of the docking devices will be limited only in that the WMD hardware (i.e., the universal interface) geometry, location in space, and surrounding clearance will be defined.

METHOD

The goal of this project is to facilitate the adoption of a universal interface design standard developed by a trans-industry effort. The approach chosen to reach this goal was the following:

(1) research, develop and evaluate design specifications for universal interface hardware designs that meet constituency-defined needs;

(2) conceptualize universal interface hardware concepts that will foster compatibility between present and future technologies; and

(3) foster acceptance and inclusion of concepts and design specifications in national and international standards.

PROGRESS/RESULTS

The initial activities focused on an investigation of the array of WMD frames in an effort to categorize them and determine commonalities. A survey data form of 45 data points was developed to record relevant WMD characteristics, and a database was constructed to maintain and organize the information (1). To date, 77 WMDs have been evaluated. Of importance to this task is the location of the center of gravity and the nature of the existing frame configurations with respect to the ease of adding a common universal attachment design for the purpose of docking securement on motor vehicles.

Additional efforts included gathering information on flip-up bus seats, current

securement configurations and WMD compartment designs on vehicles. Current docking devices were also obtained for evaluation. Visitations to leading securement companies were made, providing insight into the current state of the technology. The concept of a universal interface was presented as a platform paper at the 1995 RESNA Conference (2).

The next step was to organize and host industry meetings and consumer focus groups to identify the desire and need for a universal design standard, and to identify design specifications. Two industry meetings have been held that included WMD manufacturers, securement manufacturers, vehicle manufacturers, and transporters. A focus group comprising manual and power WMD users that use public and/or private transportation was held in the time between the two industry meetings.

There was overwhelming agreement on the need for a universal interface for docking devices and that a design standard should be pursued. To that end, the two groups then generated lists of design criteria for the universal interface; a list of 19 criteria resulted from the two groups. The eight criteria listed below were included in the top 6 ranked criteria of the consumer group and/or the industry group. The first two bullets were ranked first and second priority by both groups independently, and the third and fourth appeared on both lists. The remaining four appeared on only one of the ranked lists as indicated by either an "I" (industry) or a "C" (consumer) following the criterion. These criteria and their ranking provides a target for the ensuing research effort. These results have been disseminated as information to two standards development groups.

The partial listing of the design criteria for the universal interface, as referenced above, is as follows.

- Meet all applicable safety standards (I, C)
- Promote independent securement (I, C)
- Maintain original function of WMD (e.g., folding, feel, maneuverability) (I, C)
- Accommodate all WMD types and sizes that are used as motor vehicle seats (I, C)
- Compatible with all vehicle types that transport passengers seated in WMDs (driver docking and fold-down seats accommodated) (C)
- Promote quick securement time (less than 1 minute from being positioned at the securement station to securement) (C)
- Does not preclude use of existing tie-down and occupant restraint systems (I)
- Allow retrofit to existing WMDs (I)

For several reasons, the groups proposed a two point rear docking approach for the universal securement. It was felt that two vertically oriented structures, aligned side by side on the rear of the WMD, would produce suitable locations for access by the vehicle-mounted, mating docking device. Additionally, this configuration would provide stability during normal driving and would tend to reduce WMD rotation during the rebound phase in a frontal crash. Following this decision, diagrams were produced of suggested "clear zones" that would need to be available at the rear of any wheeled mobility device designed to be in compliance with the universal design approach, thereby allowing access to the vertical interface structures by the docking devices.

Establishment and priority ranking of the criteria and definition of the clear zones is only the first step. To be adopted universally and eventually promulgated through national and international industry standards, feasibility of the approach needs to be demonstrated. That is, a series of potential interface hardware designs meeting the criteria need to be developed and tested. These designs need to address the criteria identified by the customer (i.e., WMD users and involved industries). To this end, the Quality Functional Deployment (QFD) design process has been implemented. The defined and ranked design criteria and identified clear zones have been used as inputs to the QFD design matrix often referred to as the "House of Quality". This method will assure the needs and desires of all project stakeholders have been considered and are effectively incorporated into the design of the hardware. Several hardware designs have been developed and fabricated (see Figure 1 below). Figure 1(b) shows two designs under consideration, one has been integrated into the anti-tipping component.

DISCUSSION

Industry and consumer representatives

expressed the desire to have the feasibility of the design concept(s) tested before a design standard was created. Four steps are planned in this direction: (1) the adaptation of the design prototypes to several representative production WMDs, (2) dynamic testing of the prototypes using component and sled impact testing, (3) development and fabrication of a docking concept that will successfully mate with the hardware and provide adequate response in driving and crash situations, and (4) demonstration of the docking-interface concept.

Significant progress has been made to bring industry representatives together to agree to proceed toward defining a standard design, developing the design criteria, and developing and fabricating potential hardware designs. Activity at the international level is also occurring (3). The results of the above steps to show feasibility will be disseminated to the constituents. The plan will be for these results to create further participation and support towards the adoption of a national standard.

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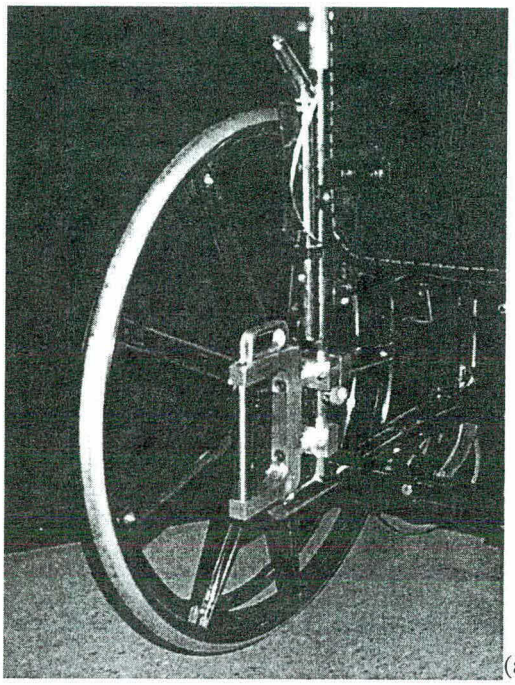
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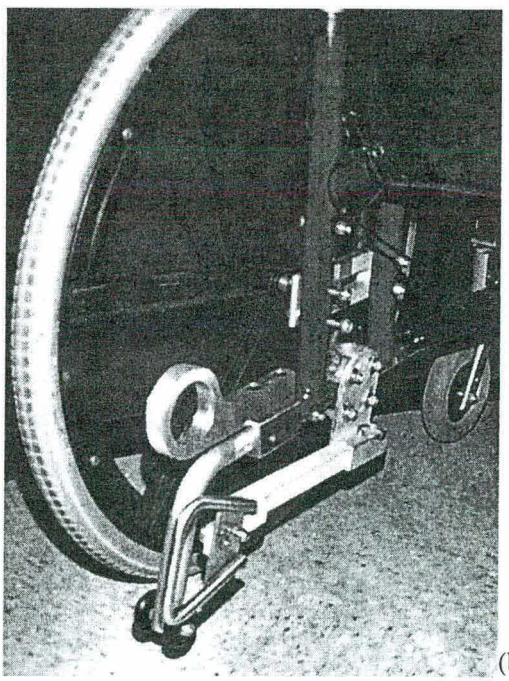
(b)

Figure 1. Prototypes under evaluation

Wheelchair Transit Safety
A conceptual case for a low 'g' securement approach

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ABSTRACT

Securement and release of wheeled mobility devices (WMDs) by their occupants on public transit vehicles is essential to realize the desires of users and the spirit of ADA. Currently used belt type technology and the lack of a universal docking approach are two major obstacles to this goal. This paper makes the case for an alternative solution that can be developed and applied in the short term for use in larger transit vehicles. Results of preliminary testing of a prototype design further support the feasibility of the proposed concept.

BACKGROUND

Increasing numbers of people with disabilities use WMDs, i.e., traditional manual and powered wheelchairs, powered bases, scooters, strollers, etc. as seats in public and private motor vehicles. There are essentially two basic approaches to the securement of WMDs that are in common use today; attendant-operated and docking devices. The attendant-operated type is reflected largely by three or four belt-type devices that are attached to the vehicle floor and hook to various parts of the WMD frame. Problems arise when there is not an appropriate location to attach the belt, for example, with scooters and some powered bases. The time required and the fact that an attendant must be available presents additional problems for both WMD users and transit authorities(1). Users of transit vehicles have expressed dissatisfaction with attendants having to grope around their legs while fastening or disengaging the securement devices. Other methods of attendant-operated securement are wheel or frame clamps, often mounted in a side-facing orientation in the vehicle, which in most cases pose significant concern for occupant safety(2).

Docking securement devices that can be operated by the WMD occupant, with the exception of few experimental devices(3), have been limited to use in private vehicles. Because there is no standard (universal) interface to mate WMDs with docking securement devices, a solution for independent docking securement in public transit vehicles remains to be developed(4).

Project Action (Accessible Community Transportation in Our Nation) conducted a survey of 112 transit systems around the USA(5). The purpose was to identify general trends and problems with services for people with disabilities. Among the many findings the following are pertinent :

- about 50% of the systems have established target dates to provide full fixed route accessibility,
- the second most frequently reported problem is securing passengers using powered WMDs or 3-wheeled scooters,
- most transit systems have not resolved the securement problem,
- the need for a safe securement system that can accommodate many types of W/Cs,
- the need for the W/C industry to establish standard securement attachment points, and
- the need for a universal securement device which can accommodate all types of WMDs.

The Americans with Disabilities Act (ADA) requires that all fixed route transit vehicles be accessible. The ADA definition of accessibility requires that mobility aids "in common use" must be able to both access the vehicle and be secured once on board(6). Since the WMD securement devices in common use today are four belt-type devices, and the universal docking interface is still at least five years away, this means that an attendant or vehicle

operator is required every time a person using a wheelchair wishes to access a public vehicle--an untenable situation.

In summary, the public transportation of WMD users in North America is in a state of chaos. The manifestations are that users are inconvenienced, transportation time and costs are unnecessarily high, legal liabilities are pervasive, and most importantly, user safety in many cases is seriously compromised. The ADA mandate of accessibility and safety, although laudatory in its intent, will not provide independent WMD securement and therefore fall short of the spirit of the law until such time that a universal docking solution can be implemented.The purpose of this article is to put forward an alternative solution for large transit vehicles that could be implemented in the short term and be responsive to the majority of the issues highlighted above.

CONCEPTUAL APPROACH

Given today's technology, and the precedence established in many other technology fields, it is a reasonable goal to allow any person using any WMD access to any transport vehicle, with the safety and independence equivalent to non-disabled riders.

Federal Motor Vehicle Safety Standards (FMVSS) and related research studies have long recognized that the collison forces transmitted to vehicle occupants are influenced by the velocity change during impact and the mass of the vehicle. Simply stated, the higher the impact velocity and lighter the vehicle, the larger the injury producing forces. Light weight is defined as vehicles with GVW below 10,000 lbs, which include passenger cars, vans and light trucks. Crash performance tests for safety devices such as occupant seat belts for use in light weight vehicles use a frontal crash pulse based on a 30mph velocity change and a test force generated by a deceleration of 20 g (30mph, 20g). In contrast, larger transit vehicles (>10,000 lbs.) travel at lower speeds and experience very few 20 g collisions. Collision accident analysis data from both the USA(FARS) and Canada(TRIAD), has shown that the injury/fatality rate on fixed route public transit vehicles to be extremely low. The average speed of collision in the FARS database was 17.5 mph. The analysis further reports 4.70 and 1.7 injuries/million passengers carried, respectively. There were no fatalities in the Canadian data and only three in the USA[7]. It follows that the statistical probability of a wheelchair rider being in an collision event while on a public vehicle is even much less probable, since on the most utilized transit authority (Seattle) WMD riders represent only 0.24% of the total ridership.

If WMD users and transit authorities can accept the above minimal risk of being in a collision on a large transit vehicle we now have a new conceptual framework for the short term solution to the WMD securement dilemma, at least for large transit vehicles. Securement of smaller paratransit vehicles (<10,000 lbs GVW) will still require the use of wheelchair tiedown and occupant restraint devices tested to 30mph, 20g.

If only the maximum forces consistent with normal driving maneuvers; i.e. rapid braking, severe swerving and maximum accelerations need to be considered, a number of exciting possibilities emerge. In-vehicle acceleration studies have measured maximum accelerations and decelerations experienced by the WMD to be only approximately 0.65g, which can occur during rapid turning[8]. Decelerations in the direction of vehicle travel generated by rapid braking are in the range of 0.4-0.5g. Given that 95% of WMDs weigh less than 250 lbs [9], and assuming a 50 %tile male occupant (170 lbs), a securement device that can withstand a load of 400-500 lbs would provide appropriate securement in all emergency driving situations, short of a major frontal collision. Heavier WMD/occupant combinations would be at higher risk. That is, their WMD may not be fully secured during severe turning maneuvers.

A similar argument has lead to another approach in at least three European countries. The approach taken is to have a rear-facing compartment without any WMD securement. The system relies on a vehicle-mounted padded bulkhead behind the WMD and the application of WMD brakes. Emergency braking causes the WMD and its occupant to slide backwards against the bulkhead. Brakes prevent rolling towards the rear of the vehicle during vehicle accelerations. A vertical

stantion running from floor to ceiling prevents rotation into the isle during turns. Four years experience in Germany is being claimed a success. Transfer of this concept to North America is unlikely as rear facing in transit vehicles is much less common. Also, reliance on the use and effectiveness of the WMD brakes for transit securement introduces a significant unknown into the safety equation. In addition, WMDs with precarious rearward stability, especially when occupied by persons without normal upper limb function, will create conditions in which violent inadvertent rearward tipping may occur leading to potential injury.

These factors lead to the case for design and development of a low 'g' containment device that will allow occupant-operated securement of WMDs in the front-facing orientation in large transit vehicles. An approach more acceptable to North America wheelchair users.

LABORATORY TESTING

A prototype design of a pneumaticly-powered containment/securement device has been pull tested in the direction of the longitudinal axis of the vehicle.The test WMD was a Quickie 200 occupied by a 175 lb subject. The test device allowed movement of the WMD about 2" when a cumulative pull force reached a value of approximately 300 lbs, the limit of the testing apparatus. Pull forces applied at 0° and 90° to the long axis of WMD had similar results, whereas forces applied at 45° caused release at a pull force of about 245 lbs.

FUTURE PLANS

Based on these findings a third generation prototype is being constructed that will constrain WMDs from 12-28'' in width with an unoccupied weight up to 250 lbs. A target design load of 500 lbs would then provide a suitable design safety factor.

SUMMARY

This paper has made an argument for the development and interim use of a low g containment device that will allow occupant-operated securement and release of WMDs in large transit vehicles. Initial prototype testing suggests feasibility. A successful commercial product would replace belt-type securement devices currently used in transit vehicles, and include an integrated occupant restraint system. Ultimately, the containment device would be integrated into the lower part of a flip-down type seat replacing similar seats now used in wheelchair stations on accessible transit vehicles.

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THE NEED TO ESTABLISH APPROPRIATE LEVELS OF CRASH PROTECTION FOR WHEELCHAIR RIDERS IN PUBLIC TRANSIT VEHICLES

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ABSTRACT

Lack of information regarding accident frequency and severity has resulted in national wheelchair safety standards that are too stringent for larger buses and trains and too lenient for public transit vans. Research is needed to provide: (1) accident injury risk and appropriate vehicle crash pulses; and (2) wheelchair tiedown and occupant restraint system (WTORS) loads. It is anticipated that the resulting findings will acknowledge the inherent safety of the large public transit bus and stimulate the development of wheelchair restraints that are less cumbersome for the operator and less intrusive for the wheelchair user.

INTRODUCTION

There is very little available information that can be used to make decisions regarding the level of crash protection appropriate for wheelchair riders. Evidence suggests that ADA wheelchair tiedown strength requirements for transit vehicles, developed without the benefit of prior risk assessment, are too demanding for larger buses and too lenient for public transit vans. Although a risk analysis study [1] has found the SAE WTORS standard to be appropriate for the latter, it is inappropriately stringent for large buses. As written, the ADA requirements [2] expose van wheelchair users to risks greater than those federally allowed for auto occupants. For others, who ride city buses for example, the requirements are overprotective and result in securement systems that are cumbersome and invasive. A complicating factor, not addressed by existing standards or considered in present WTORS designs, involves non-standard wheelchairs including strollers and extensively modified wheelchairs.

A better understanding of transportation risk would help make informed decisions regarding both a reasonable level of protection and increased access to public transportation mandated by the ADA.

Existing standards and present WTORS designs were developed based on the results of frontal 48 km/h (30 mph) crash. The direction and severity of the collision was considered to be a reasonable worse-case in terms of real-world crashes involving vans and minivans [3]. As the smallest, lightest, and fastest of vehicles that transport wheelchair riders, modified passenger vans represent a worst case in terms of accident severity. A recent review of the National Accident Sampling System (NASS) data base confirmed that injury-producing frontal crashes involving vans were the most common and that 96% occurred with a change of velocity of less than 48 km/h (30 mph), statistics similar to those recorded for passenger cars (1). With the intent of providing wheelchair riders in modified passenger vans with a level of crash protection similar to that mandated for occupants sitting on vehicle seats, the 48 km/h frontal crash test has been incorporated as a requirement in the SAE J2249 WTORS standard.

There is a very little information available that would allow estimating such a crash severity level for larger public transit vehicles that are used to transport wheelchair users. Lacking this information, it is unclear how ADA regulations were established for WTORS static strength requirements.

Current ADA requirements either under- or over-estimate the level of protection required. The ADA static strength requirement is not sufficient for small public transit vehicles such as standard passenger vans or minivans that commonly are involved in accidents similar in severity to those of passenger cars. For these small vehicles, the static strength level is approximately half of what it should be to prevent tiedown failure during a collision. In UVA tests, SAE spec

WTORS have regularly generated rear tiedown loads of 20,000 - 22,000 N (4,500-5,000 lbf), twice that of the ADA static strength requirement.

Conversely, the ADA requirement is too demanding for full size urban buses with respect to very low accident frequency and severity. The New York Public Transportation Safety Board estimates a statewide average of one injury per year [4]. A recent unpublished study for the Ontario Ministry of Transportation, using both Canadian and US accident data bases, estimated the emergency rate, the chance of a passenger with a disability being involved in an emergency situation, such as an injury-producing collision, to be one per every half billion passengers or one per 2.6 billion kilometers (1 million miles) of bus travel per year. Their estimate of the fatality rate for disabled passengers, based on a travel rate of 1 disabled passenger per 9 million passengers, is 0.000000024 fatalities per billion passengers - essentially zero. An investigation conducted with six transit bus operators who cumulatively served 18% of the total US transit bus ridership found that "The urban transit bus is an extremely safe transportation mode choice.....in 1969, only 15 of the over 5 billion passenger trips.....ended in passenger fatalities." The most common cause (56%) of passenger injuries was found to be bus deceleration that can reach 0.75g during hard braking [5].

More recent data compiled by the Federal Transit Administration (FTA) supports the Booz Allen finding that transit buses are very safe. Very few of the accidents caused during bus maneuvers or collisions result in significant injury [6]. The Ontario Ministry of Transportation study found that the fatality rate for transit buses was vanishingly small: 0.0002 fatalities per 100,000 passengers. The data in Table 1 suggest that car fatalities are 90 times more likely and transit van fatalities are at least 7 times more likely than transit bus fatalities.

The size and structure of the bus body effectively cushion the riders should an impact occur. The relative weight of a transit bus relative to a car (16,000 kg (35,000 lbs) vs. 1,700 kg (3,700 lbs)), the most frequent impacting vehicle, is another major factor that minimizes the likelihood of injurious crash levels. Most of the 21 collisions that a typical city bus will experience in its 500,000 mile average lifetime will be minor. An analysis of 26 rear-end accidents (in which the bus hits the rear of another vehicle) suggested that 80 % occurred at a speed of less than 13.3 km/h (8.25 mph) [5]. In such a collision, we estimate that passengers experience a maximum of 1.0 g, but additional research is required to verify this estimate. When impacted in the front by a 4000 lb car traveling at 56 mph, a very severe and infrequent collision, bus decelerations were less than half (<5g) that recorded in 20 mph barrier tests. A Booz Allen researcher estimated that a 10 g frontal collision is very rare and occurs only once every five years in the US.

Table 1. Fatality Rates for All Vehicle Passengers

	cars	transit vans	transit buses
Collision fatality rates per 100,000 passengers	18.82 A	1.5 B	0.0002 - 0.2 C - D
Estimated average weight	1,700 kg 3,700 lbs	3,200 kg 7,000 lbs	16,000 kg 35,000 lbs

Information sources:
A - Center for Disease Control and Prevention, 1990 data
B - Federal Transit Administration (FTA), 1991 data
C - Ontario Ministry of Transportation
D - FTA, 1991 data

Over-estimating required WTORS strength results in more elaborate and cumbersome systems. While underestimating WTORS strength requirements degrades safety in the event of a moderate-to-severe accident, overestimating strength requirements can result in cumbersome systems that may invite misuse or non-use. A 1981 workshop sponsored by the Department of Transportation concluded that *"Larger, heavier vehicles absorb more impact energy and thus require less robust and elaborate securement systems and occupant restraints. Over-design of these systems should be avoided."* [7]

While commonly available, crash tested tiedown systems that use four straps to secure the corners of the wheelchair can provide protection for virtually all anticipated transit bus accidents, they are cumbersome to use - and are routinely misused. If further investigation confirms that less demanding requirements for large transit buses more accurately reflect reasonable wheelchair passenger risk, the possibilities for alternative WTORS that are simpler and easier to use increases significantly. Moreover, European experience suggests no tiedowns may be required. A recent unpublished eight year German transit review claims no wheelchair related injuries on buses in which wheelchairs were accommodated facing rearward. The only restraints used were the wheelchair brakes and the padded bulkhead against which the back of the wheelchair rested.

Discussion and Recommendations

Our preliminary literature review and interviews with researchers, transit bus engineers, and transit operators identified severe deficiencies in two critical areas. A comprehensive data base of complete and accurate descriptions of injury-producing traffic accidents has not been developed. Moreover, the accident and injury data that does exists has not been used in a systematic manner to establish reasonable targets for crash safety.

We recommend that a series of investigations be conducted in order to: (1) establish accident injury risk and appropriate vehicle crash pulses; and (2) estimate WTORS loads. This information will help to select appropriate crash levels for which to provide protection for transit vehicles of various sizes and operational environments. Determining an appropriate crash level for which to provide protection depends on three main factors: (1) frequency of injury producing accidents; (2) severity of the resulting injuries; and (3) the definition of acceptable risk. Safety standards developers have commonly defined acceptable risk for wheelchair riders as that experienced by other vehicle riders. Other factors that must be considered in determining the selection of crash protection levels include present standards and safety technology, anticipated advances in safety technology, public interest, liability concerns, and safety costs in terms of transport inefficiencies, hardware and personnel costs, and wheelchair user independence

Once the targeted protection levels have been established, it will be possible to estimate the forces necessary to secure the wheelchair and to restrain the occupant. Expressing crash severity levels in terms of forces will help convey, in a general sense, how elaborate a WTORS need be.

The benefits of correctly estimating the required level of protection include safer WTORS for smaller vehicles and more economical and less cumbersome WTORS for larger vehicles. A better understanding of real world risk would help balance the need for improved safety with the need for easier access to transportation.

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SURVEY OF WHEELED MOBILITY DEVICE TRANSPORT ACCESS CHARACTERISTICS

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ABSTRACT

In support of the ANSI/RESNA WC/19 Standard for Wheelchairs Used as Seats in Motor Vehicles development, a survey of various types of wheeled mobility devices (WMDs) was undertaken to identify ranges of select transport access characteristics. A subset of this study, including statistical analysis of WMD weights, overall dimensions and turning radius is presented. Information related to these characteristics can be used for comparative purposes by consumers, WMD prescribers and designers of WMDs, securement systems and other WMD transportation accessories.

BACKGROUND

In addition to assuring crashworthiness of wheeled mobility devices (WMDs), the ANSI/RESNA WC/19 Standard for Wheelchairs Used as Seats in Motor Vehicles currently under development will also address the needs of WMD users related to accessing vehicles and securing their WMD once on board [1]. Issues such as accessing the vehicle via lifts and ramps, negotiating doorways, maneuvering to securement stations and assuring that tiedowns can be shortened or lengthened to accommodate the WMD in the securement station are being considered as a part of the Standard's development.

To assess the problems which may be encountered with WMD-vehicle compatibility, it was first necessary to evaluate critical characteristics of production WMDs which are commonly transported. Accordingly, surveys of various types of WMDs, including conventional manual, sport, conventional powered, powerbases and scooters, were conducted to gather information relevant to WMD transportation. This information was compiled in a database for further statistical analysis as needed by the ANSI/RESNA WC/19 committee. A subset of this information, related specifically to transportation access, is contained within this manuscript. A complete report of all survey information is available in a technical report published by the University of Pittsburgh [2]. The information gathered and analyzed through this research effort can be used in the design of vehicle layouts, securement systems, and other vehicle accessories used in the transport of WMDs. An ANSI/RESNA WC/19 companion document, intended to assist consumers in the interpretation of the Standard and provide a basis for comparing pre-sale literature, will also rely upon data obtained through these survey efforts.

METHODS

Field surveys of production WMDs were conducted using data forms to record parameters such as seating characteristics, frame and wheel dimensions, inertial properties, and locations of potential securement points. Since many of these parameters are those required by the ANSI/RESNA Wheelchair Standards to be disclosed in pre-sale literature, data gathered through surveys was supplemented by manufacturers' literature [3]. Measurements consistent with those specified in the ANSI/RESNA Wheelchair Standards were obtained following the same measurement protocols [3]. Characteristics identified for evaluation and discussed within this manuscript were those which may impact WMD vehicle access and securement for transport. Information gathered through survey efforts was recorded using commercially available database software for further statistical analysis.

A total of 77 adult WMDs were evaluated; 42 powered and 35 manual WMDs. The powered WMDs were comprised of 19 conventional powered WMDs, 12 powerbases and 11 scooters. The manual WMD sampling consisted of 21 conventional manual WMDs and 14 sport manual WMDs.

WMD TRANSPORT CHARACTERISTICS

WMD Weight

As a part of the study, WMD weights were recorded using either manufacturers' literature or by direct weighing of the surveyed WMD.

WMD Width and Length

Measurements of overall width and length for sampled WMDs were obtained either through manufacturers' literature or direct measurement following the ANSI/RESNA Wheelchair Standards protocol [3]. Measurements of overall length were obtained with footrests installed, while WMD width was obtained through measurement to the furthest points on either side of the WMD. Widths were assessed with armrests installed on each WMD.

WMD Turning Radius

An additional WMD characteristic critical to accessing vehicles and maneuvering to securement stations within vehicles is the turning radius. This measurement represents the smallest space in which the subject WMD can turn in a circle. Turning radius is typically a function of wheelbase length. For this study, turning radius was determined following the ANSI/RESNA Wheelchair Standard's protocol, and was obtained either through direct measure or manufacturers' literature.

RESULTS

WMD Weight

A weight distribution histogram of the entire WMD sample is shown in Figure 1. As shown, weights range from a minimum of 21 lb. to a maximum of 320 lb. The calculated mean weight for the sample is 116 lb.

WMD Width and Length

The histograms shown in Figures 2 and 3 provide a distribution of overall widths and lengths, respectively, of the sampled WMDs. Overall widths of the sampled WMD population ranged from 18" to 31", with a mean value of 24". Overall WMD lengths ranged from 18" to 56", with a population mean of 40".

WMD Turning Radius

A population distribution of turning radii for all types of adult WMDs is presented in a histogram in Figure 4. Of the sampled WMDs, the maximum turning radius is 56" and the minimum is 27". A turning radius mean of 38" was found for this sample.

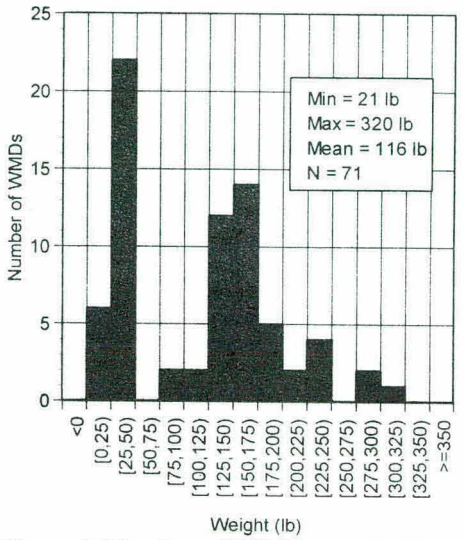

Figure 1. Number of WMDs vs. WMD Weight

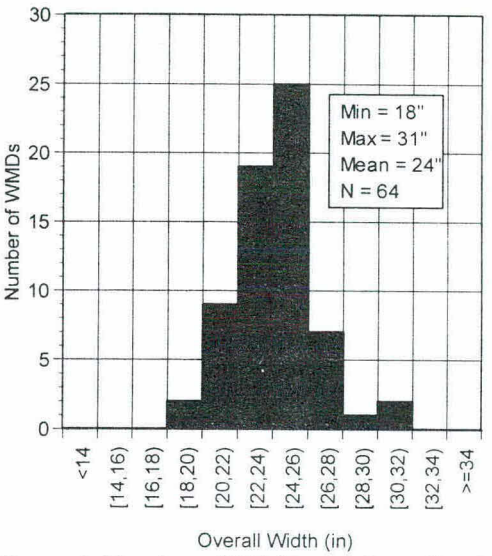

Figure 2. Number of WMDs vs. Overall Width

DISCUSSION

WMD Weight

The weight of a WMD is significant in transportation when considering lift capacities, as well as in designing the strength capabilities of securement systems. Using the weight distribution data of this study and the current capabilities of tiedown securement systems, the

WMD TRANSPORT CHARACTERISTICS

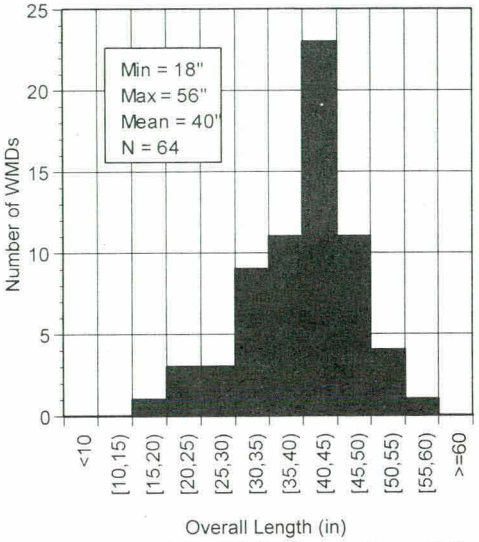

Figure 3. Number of WMDs vs. Overall Length

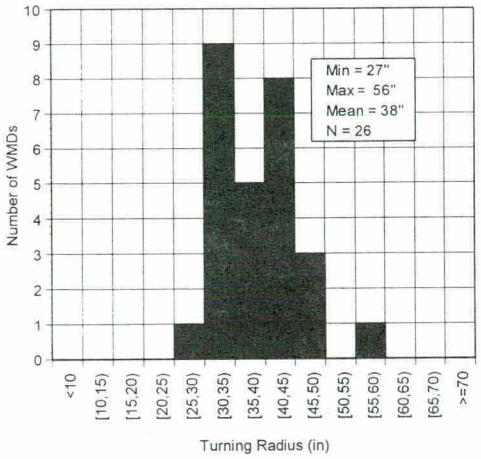

Figure 4. Number of WMDs vs. Turning Radius

ANSI/RESNA WC/19 committee has defined 275 lb. as the cutoff weight above which all WMDs must have 4 rear and 2 front securement points integrated into the WMD design. WMDs weighing less than 275 lb. will be required to have only 2 rear securement points in addition to the 2 front securement points. Following these requirements, only 3 of the 71 evaluated WMDs would need to be equipped with 4 rear securement points.

WMD Width and Length

To guide manufacturers in providing WMDs which are capable of negotiating architectural and transportation barriers, ANSI/RESNA Wheelchair Standards have defined a maximum WMD width of 27.5" and a maximum WMD length of 47.25"[3]. Three of the WMDs sampled in this study were wider than the ANSI/RESNA width limitation and six WMDs exceeded the ANSI/RESNA length limitation. ADA has defined a limit of 30" wide x 48" long as being the minimum WMD securement station. Accordingly, WMDs should also be a size which can be maneuvered through the vehicle and into such a space.

WMD Turning Radius

The turning radius of WMDs can influence the ability of the WMD user to enter the vehicle and negotiate the vehicle interior to access the securement station. Since turning radius is largely dependent on wheelbase length, it is common to find scooters having the largest turning radii. Accordingly, scooters may encounter vehicle access problems with greater frequencies than those WMDs having shorter wheelbases. Although vehicle layouts vary greatly, pre-sale literature disclosure of turning radius will be of value to consumers seeking to maximize their vehicle accessibility.

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SIG-03
Augmentative & Alternative Communication

CELLULAR TELEPHONE ACCESS FOR SEVERE DISABILITY AND ENHANCED COMMUNITY INDEPENDENCE

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ABSTRACT

Personal communications is a significant aspect of every day vocation, socialization, recreation and, to some degree,personal safety. There are several companies offering land line telephones with adapted access accommodating access issues for a number of disabilities. These telephones provide convenient communication links in the home environment. This important communication link is lost when the person with a disability leaves their immediate living environment for independent excursions into the community. The advent of cellular technology is a trendy means of communication which many people without disabilities depend on outside their homes. This paper describes a cellular telephone interface for persons with severe disabilities and the outcomes of field trials with five consumers.

INTRODUCTION

Telephones have become an integral part of our lives. Immediate personal communication is a growth industry meeting the needs of businesses and individuals. Cellular technology became popular to meet the needs of an increasingly mobile business community. It now meets the needs of a generally more mobile community. Many individual cellular telephones are acquired for that added sense of personal safety when public or home telephone access may not be readily available.

Access to land line telephones for persons with severe physical disabilities has been addressed through function specific devices or through integrated environmental control systems. Adapted access telephones are usually controlled through simple switch inputs, but remote access may also be obtained through infrared or radio frequency links. Remote links may be wheelchair based and either controlled through specific switches or the wheelchair control system environmental control ports.

When people with disabilities leave their home environment, they lose access to independent communication. Using a public telephone in the community requires the assistance of an obliging member of the public to hold and operate the telephone while removing only the required amount of funds from one's wallet. There are certain circumstances in the community where the use of a public telephone, even with assistance, would not be appropriate. Circumstances such as wheelchair failures in isolated areas or a medical necessity dictate rapid and independent access to personal communications. Access to cellular telephones for persons with severe disabilities would be a normalizing communication technology.

THE PROBLEM

The person with a severe physical disability is unable to operate the array of buttons and switches on a commercial cellular telephone and custom modifications would be required. Making modifications to the telephone would require expensive technical expertise and making it difficult to obtain timely repair/exchange of a defective telephone. Many newer models of cellular telephones use proprietary

communication protocols through proprietary connectors to control the telephone by external systems. The protocols and connectors are different for each model and each manufacturer. The challenge was to provide access to the cellular telephone without requiring modification to the telephone, while enhancing many of the features expected in adapted land line telephones.

CONSUMER EVALUATORS

A consumer focus group was established to identify important adapted telephone features and to perform the field evaluation of the proposed development. All consumers used powered wheelchairs and had normal visual acuity and hearing. Three consumers controlled their wheelchairs using proportional joysticks, one with a Peach Tree head control and one with a SIP&PUFF control. Two consumers used portable ventilators and one used a phrenic nerve pacer.

The consumers identified that important aspects in choosing a telephone were Features, Durability and Cost. The most important Features in a home dialler were continued operation in the event of a power failure, last number redial and volume adjust.

A criterion for consumer inclusion in the field evaluations required that there be no observable electromagnetic compatibility issues between the cellular telephone and any of their assistive technology. An empirical test was performed with each consumer's assistive technology to verify compatibility under the test conditions.

FIRMWARE DEVELOPMENT

Several cellular telephone models were investigated. There was no clear advantage of one telephone over another, but one decisive factor was the availability of technical information that allowed non-invasive interfacing.

An interface system was designed to be powered directly from the 24 volt wheelchair batteries and provide all the necessary voltages for operating the target cellphone and interface hardware. A separate backlit, 4x20 alphanumeric, liquid crystal display (LCD) unit was interconnected with the main interface to provide the custom mountable, scanning visual interface. A hierarchal menuing system was implemented and accessed through a one or two switch scanning methodology. All system operating parameters (scan rate, scan type, dwell, LCD contrast, etc.) were under software control and could be independently adjusted by the consumer. The consumer could independently turn the cellphone ON/OFF. This is an important feature since many hospitals where consumers might frequent have cellphone policies which prohibit operation (even in STBY mode) particularly in acute care areas.

A 180 number dialling directory, alphabetically sorted by name, was implemented and maintained in a battery backed Random Access Memory (RAM). An additional two priority number locations were provided in Electrically Erasable Programmable Read Only Memory (EEPROM). Last number redial, direct dial and sequential dialling (automated attendant) features were provided. A digital memo taker allowed selective recording/playback of up to five messages totalling 90 seconds, providing the consumer with a means of storing pertinent conversational information.

Initial mountings of the interface proved to be quite time consuming due to the customization of the visual display mounting. The positioning assessment and mounting averaged seven hours per consumer. It was determined that the most cosmetic and effective method of mounting the

cellphone, interface and some of the interconnecting wiring was to pack as much as possible into a commercially available bag.

EVALUATION OUTCOMES

All consumers had used their cellular telephone interface (CELLINK) for between two and five months before the follow up evaluation was conducted. Typically, the CELLINK was used for personal calls to stay in touch with friends and family. The second most frequent use was for somewhat essential community calls to reschedule transportation bookings. One consumer needed to dial "911" for a personal medical emergency.

All consumers felt that the CELLINK increased their independence particularly for getting help in a timely manner, personal safety and their ability to acquire transportation. Some felt that having the CELLINK gave them the security to spontaneously go places with their wheelchair where they normally would only have gone with organized transportation. They were less concerned with becoming stranded in the community, which promoted more outings.

None of the consumers observed any unusual dysfunction of their assistive technologies while using the CELLINK. Although, it was strongly advised that they should not operate the CELLINK while driving their wheelchair.

The features of the CELLINK that the consumers found most effective were the Dialling Directory, Last Number Redial and the Priority Dial. When asked what other features they would like, they responded - Connect to Home Computer, Control Land Line Telephone and Control Home Entertainment Equipment.

Three consumers felt that it was a convenience to have cellular telephone access, while two consumers felt that it was a necessity. All consumers felt that they would use a cellular telephone in conjunction with their land line home dialler.

CONCLUSION

Cellular technology is an important part of every day life for many people. This aspect makes the application of cellular technology for persons with severe disabilities even more significant for community independence and safety. Consumer 's anecdotes indicated a growing dependence on the technology, even for unique situations within their own homes. Universal access to cellular technology is currently unachievable without industry communication protocol standards. This could continue to be an issue with the implementation of Personal Communication Service (PCS) technologies without appropriate design considerations for persons with disabilities and alternate access methods.

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A COMMUNICATION AID WITH ARTIFICIAL INTELLIGENCE: COMMUNIC-EASE MEETS SEMANTIC PARSING

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ABSTRACT

We describe a joint effort between the Applied Science and Engineering Laboratories (ASEL) and the Prentke Romich Company (PRC) to develop an AAC system appropriate for children with cognitive impairments that affect their communicative ability. The effort combines the interface and low-level processing that PRC has developed for this population with high-level processing using Artificial Intelligence techniques developed at the ASEL.

BACKGROUND

Many of the speech output communication aids that PRC designs incorporate an encoding technique called semantic compaction, commercially known as Minspeak®. The purpose behind Minspeak® is to reduce the cognitive demand as well as the number of physical activations required to generate effective flexible communication. Its success stems from the use of a relatively small set of icons that are rich in meaning and associations. These icons can be combined to represent a vocabulary item such as a word, phrase, or sentence, so that only two or three activations are needed to retrieve an item. Because the icons have multiple meanings, they can be readily combined to store a large core vocabulary.

In using Minspeak® it was found that if icons on the overlay remain in fixed positions, once learned, they allow the individual using the system to find them quickly and automatically. PRC took advantage of this in developing Minspeak® Application Programs (MAPs™) which allow a large vocabulary to be pre-stored in a well-organized fashion using a logical, paradigmatic structure that greatly facilitates learning and effective communication.

One of these MAPs™, Communic-Ease™ contains basic vocabulary appropriate for a user chronologically 10 or more years of age with a language age of 5-6 years. Communic-Ease™ has proven to be an effective interface for users in this target population. It provides access to approximately 580 single words divided into 38 general categories; most of these words are coded as 2-icon sequences. The first icon in the sequence (the category icon) establishes the semantic category. For example, the <SKULL> icon indicates a body part word, the <MASKS> icon indicates a feeling word, and the <APPLE> icon indicates a food word. The second icon denotes the specific word. For example, <MASK> followed by <SUN> produces the word "happy"; <APPLE> followed by <APPLE> produces the word "eat".

In addition to the words which are accessed via the icon sequences, Communic-Ease™ contains some rudimentary morphology and allows spelling.

STATEMENT OF THE PROBLEM

Whether a child with cognitive impairments is verbal or nonverbal, some general characteristics of expressive language difficulties may include the following (2), (3): 1. short telegraphic utterances; 2. sentences consisting of concrete vocabulary (particularly nouns); 3. morphological and syntactical difficulties such as inappropriate use of verb tenses, plurals, and pronouns; 4. word additions, omissions, or substitutions; and 5. incorrect word order. While such children may have the ability to functionally communicate their needs and wants, intervention to assist them in their language production may be quite beneficial both from a social and an educational standpoint.

The question we investigate in this work is whether some higher-level processing (using Natural Language Processing techniques) might be combined with a language access method such as Communic-Ease™, to overcome these kinds of language difficulties.

APPROACH

Natural language processing (NLP) is the subfield of Artificial Intelligence devoted to capturing the regularities of natural languages (such as English), and developing computational mechanisms to process them.

The Compansion method, developed at the ASEL, uses techniques from several areas of NLP in order to take a telegraphic message and transform it into a well-formed English sentence (1). Compansion takes as input uninflected content words such as apple eat john and produces a well-formed sentence such as "The apple was eaten by John." In order to do this transformation, the system must have a large amount of knowledge associated with words (e.g., that animate objects such as John typically eat food items such as apples) and must have knowledge about validly formed sentences (e.g., in a passive sentence a form of the verb be precedes the main verb which must be in its past-participle form).

The primary goal of the Compansion prototype was to demonstrate the feasibility of an NLP-based approach to AAC techniques (i.e., is it even possible). While results so far have been encouraging, additional steps are necessary to establish its viability in an actual product for a specific user population. For example, one of the major problems we have is that Compansion requires a large amount of information associated with each word. While we have been working to provide this information automatically, it is currently nearly impossible to handle totally unrestricted vocabulary. Thus the system will work best with a population whose vocabulary needs can be well identified.

A second problem that has not been dealt with effectively within the Compansion project is the particular interface through which the user selects lexical items and chooses among multiple possible expansions.

Finally, the research effort on Compansion to date has been done on workstations in the Lisp language. Thus the system would not run well on portable microcomputers as would be appropriate for use in real-world situations.

IMPLICATIONS

In this project we attempt to combine a scaled-down version of Compansion (called the Intelligent Parser / Generator) with the interface and selection techniques from PRC to test the viability and effectiveness of an intelligent system which will overcome some of the communicative difficulties in the target population.

In our prototype system a Liberator™ Overlay / Keyboard accepts user input through a variety of methods (e.g., direct selection), and also limits user choices via Icon Prediction. With Icon Prediction only icons that are part of a valid sequence are selectable. The user selects icon sequences that are transduced into words or commands according to the Communic-Ease MAP™. In normal operation, icon labels and the transduced words are sent to the Liberator™ LCD display to give the user feedback (words may also be spoken).

In the proposed system, these components are supplemented with an Intelligent Parser / Generator (IPG) that is currently under development at ASEL. IPG is responsible for generating well-formed sentences from the user's selected words. It also provides further constraints on the Icon Prediction process. For example, if the user selected "I have red," the system might only allow icon sequences for words that can be described by a color (e.g., shoe, face).

DISCUSSION

As previously mentioned, the major role of IPG is to transform telegraphic input into well-formed sentences. Some possible transformation rules (and input / output sequences) are shown

TABLE 1. Transformation rules for IPG with example input and human translations taken from recorded transcripts of a Communic-Ease™ user

Transformation Rule	Example input	Example Output
determiner inferencing	I want cookie please mom	I want **a** cookie please mom.
verb inflection (subject verb agreement)	She work in school	She **works** in a school.
verb inflection (tense addition)	I go my old school Tuesday	I **went** to my old school on Tuesday.
multiple verbs	I go circus see clowns	I **am going to go** to the circus **to see** the clowns.
noun inflection	Cook 50 dinner	Cook 50 **dinners**.
preposition inferencing	I dance five girls	I danced **with** five girls.
verb inferencing	Mr. Keylor industrial arts teacher	Mr. Keylor **is** the industrial arts teacher.
subject inferencing	No time	**I** have no time.
conjunctions	Mom Dad be home	Mom **and** Dad are home.

in TABLE 1. These rules are being developed through prior Compansion research and analyzing data collected from Communic-Ease™ users.

Work continues on this project particularly in the area of interface development. Our methodology is to develop appropriate transformation rules and interfaces through iterative user testing including both internal and field evaluations. We have anticipated the need for flexibility and individual preferences in our interface design methodology. In addition there is a strong possibility that the prototype will be extended to handle the UNITY™ MAP™ in order to examine its feasibility with a larger population of potential users.

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AAC STRATEGIES FOR PROMPTING SPONTANEOUS REQUESTS IN YOUNG CHILDREN: CASE STUDY

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ABSTRACT

This paper describes requesting strategies implemented during AAC trial therapy with a 28-month-old nonspeaking child (SK). Assessment identified spontaneous initiation of requests as a developmentally appropriate goal that was not consistently demonstrated during communication opportunities. Trial therapy was conducted in the home during play activity with parent participation and input. Within one play activity, SK increased the frequency, promptness, and specificity of his spontaneous requesting and anticipated adult response to his communication. Follow-up activities and materials were provided to his parents and service providers for maintenance and expansion of this skill development.

BACKGROUND

Children with severe physical impairments tend to be at risk for delayed or impaired language development resulting from limited opportunity for language expression. In particular, young children learning language through augmented modes frequently lack models for successful communication using augmentative and alternative communication (AAC) modes, and experience limited adaptation of their communicative environment to their particular communicative skills or needs (e.g. Reichle, York, Sigafoos, 1991). Without enough experience at initiating communication using available AAC strategies during early years, children are at risk for increasing language delays and a passive or responsive communication style in their later years. Even skilled adult AAC users tend to initiate less frequently in conversations than nondisabled speaking partners (Light, 1988), given the mismatch in speed and ease of access for spoken and nonspoken communication modes. Early AAC intervention needs to provide support for children's behavioral initiation of communication, including during presymbolic stages.

Intentionality is one of the early benchmarks of communication skills demonstrated by very young children. Requesting "more" of a preferred object or activity is typically an early demonstration of intentional communication that occurs during interaction for children with disabilities (Wetherby, Yonclas, & Bryan, 1989). Children with physical impairments who use gestural requesting strategies must use additional cues to make their request clear, particularly if the object is not visibly present. For children who have developed symbolic communication, these cues can be provided through a variety of symbols such as pictures or signs. For children who primarily rely on nonsymbolic communication, requests are clarified through situational cues or partner-perceived behavioral signals (Wilcox, Bacon & Shannon, 1995). A key to advancing towards symbolic communication is providing children with experience in controlling these signals and recognizing the functional result to their specific communicative signals. This study explores this developing communicative awareness in one child with a variety of gestures and behavioral signals, but limited initiation of those signals within interaction.

CASE DESCRIPTION

This study describes a 28-month-old boy (SK) with cerebral palsy. During his first year, SK had a tracheostomy, and is currently only able to produce vocal sounds with a speaking valve, which he tolerates for short periods of time. SK uses supportive equipment for seating and

standing and was not independently mobile at the time of this study. He can bring his hands to midline and has a functional palmar grasp with his left hand, although both hands are missing thumbs. Vision and hearing screens are within normal limits, and he lives at home with both parents.

Formal language and developmental testing yielded the following scores for SK, with age equivalence given in months (mo.)

Battelle Developmental Inventory: (avg. 7 mo.)
Motor/Adaptive skills: range 2-6 mos.
Cognitive skills: 6 mos.
Personal Social skills: 10 mos.
Communication: overall 16 mos.
(receptive 25 mos., expressive 11 mos.)
Sequenced Inventory of Communication Development (SICD): 16 months
(for both receptive and expressive skills)
Uzgiris-Hunt Sensorimotor Assessment: skills range from 8-18 month equivalence
Communicative and Symbolic Behavior Scale (CSBS): at 1st percentile for his chronological age, considered at prelinguistic language stage

Like many children with physical impairments, formal tests do not capture the range of SK's communicative abilities, particularly when the tests are influenced by motor skills as in some of the cognitive measures. Interviews and observations with SK and his parents yielded a variety of communicative signals that he regularly used with his parents (see Table 1). He promptly demonstrated understanding of age-appropriate vocabulary (such as body parts), and played active parts in routine communication games with his parents. However, on the CSBS, which "tempts" children to use any available communicative signals to request "more" of an activity, SK tended to use less informative signals such as gaze, and did not initiate gestural signals that were within his available repertoire. His family reported that this was common, and this made his signals difficult to interpret.

OBJECTIVE

The objective of the trial therapy was to demonstrate strategies for the family to help prompt SK to use an accessible signal to initiate his own requests during a play activity.

Table 1: Communication Signal Inventory for SK

Signal	What It Means	What Do You Do/Say?
- Looks at communication partner	- Wants something	- Give him the object
	- Where is _____	- Tell him where _____ is
	- Needs help	- Help him
	- Look at this	- Look at/comment on object/activity
	- Something interesting is happening	- Look at/comment on object/activity
	- ??	- Ask another question to figure out what the look means
- Cries/Fusses	- I'm upset	- Fix problem
	- I want that	- Give him the object
	- Give me attention	- Give attention to SK
	- Frustration	- Acknowledge frustration, help
- Gaze shift (two point)	- Wants object or activity	- Give object or activity
- Reach or touch	- Wants object or activity	- Give object or activity
- Turns/shakes head, pushes away,	- I don't want it, no	- Take away object, end activity
- Loud jabbering	- I want your attention	- Give attention to SK
- Smile/Frown	- Hello/Goodbye	- Acknowledge his greeting
- Smile	- I'm happy	- Smile back, Comment
- Move shoulder/leg	- Help with dressing	- Put on clothes
- Rub face	- Sleepy	- Acknowledge that he is sleepy
- Touch talking valve, fussy look	- Take care of talking valve	- Take off talking valve
- Crinkles nose and fusses and kicks into extension	-Stomach discomfort	- Loosen stomach valve
- Fingers in mouth	- Teeth hurt	- Fix tooth pain
- Rock back and forth and laughs	- Very happy/excited	- Tell him "happy", do what's exciting
- "AAA" sound from trach, wide mouth	- Mad	- Acknowledge that he is mad
- Gives/blows a kiss	- Shows affection, I love you	- Comment, say thank you!
- Smacks lips	- Indicates "good"	- Comment, give more of item
- Touches head (esp. when asked "where's your brain?)	- I'm smart!	- Respond "yes, you're smart"

METHOD/APPROACH

The parents and consulting clinician played a preferred game with SK (ball tossing). During this activity, a suggested requesting behavior was modelled for SK within the activity: touching his chest to signal "my turn". Since SK would occasionally reach or touch objects to request them, this was considered to be within his potential repertoire. All adults were coached briefly in a hierarchical cueing strategy, where the adults first modelled and physically prompted this request from SK, then gradually decreased the prompting to verbal/gestural prompts ("is it SK's turn?"), question prompts (e.g. "whose turn is it"), and situational prompts (such as an adult requesting their own turn with the signal), with the lowest prompt being a pause cue after the previous turn was completed.

RESULTS/DISCUSSION

During 20 minutes of trial therapy, SK gradually decreased the specificity of cue needed to prompt a request. By the end of the session, he independently signalled "my turn" with little or no pause after a previous turn, and combined this request with gaze at the adult who was able to comply with his request. In previous play situations, SK had only used his gaze signal, and had persisted with this signal in repeated communication breakdowns. SK's parents also expressed comfort with this strategy, and demonstrated skills at using pausing and modelling to cue SK's independent initiation of requests.

This brief intervention demonstrates a contrast between the effects of anticipating a child's requests and prompting independent requesting. Since many children with physical impairments have limited communication strategies, parents become accustomed to anticipating a child's wishes and interpreting signals without making them explicit. This provides less opportunity for children to perceive the effects of their own behaviors, and recognize their own power in effecting change in their environments. Since the phenomenon of "learned helplessness" is an ongoing concern for children and adults with serious disabilities, it is important to recognize potentially contributing factors and to provide children with varied experience in controlling their communicative environments as early as possible. The ease with which SK learned and consistently used a communicative initiation, when he had not consistently initiated with most of his other signals, suggests the potential effectiveness of early AAC intervention in helping families structure the communicative environment to maximize their children's opportunities for initiation.

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THE AUTOMATIC CONSTRUCTION OF VOICE DATABASES FOR THE ASEL TEXT TO SPEECH SYSTEM

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ABSTRACT

This paper presents methods developed for semi-automatic generation of voice databases for the Applied Science and Engineering Laboratories' (ASEL's) text-to-speech synthesis system. This approach has substantially reduced the time and cost involved in generating new age- and/or gender appropriate voices for the synthesizer. Further, it may soon make it economically feasible to capture specific voices, for example, when someone is losing his/her voice, and deliver a synthesizer which retains a user's voice when that individual is no longer able to speak.

BACKGROUND

The ASEL TTS system is composed of two major components which run as software programs on Windows or Unix based computers. The Text-To-Phoneme component translates English text to a phonetic script which specifies a sequence of phonemes with timing and intonation information. This script is then realized as synthetic speech by the second, Phoneme-To-Sound, component. The Phoneme-To-Sound component produces a speech signal for playback by retrieving brief segments of digitized speech (in the present synthesizer, diphones) from a database, concatenating the segments together, and adjusting their durations and pitch per the input phonetic script. Because the voice quality of the synthesized speech is determined largely by the content of the database, it is possible to freely substitute new voices in the synthesizer by substituting diphone databases. Previously, ASEL speech databases were created manually and required between 4 and 8 months of trained labor for completion. Moreover, there was no method available to optimize the selection of diphones to ensure that the database finally developed represented the "best" database possible given the particular speech data available. By contrast, the semi-automatic methods presented here allow a new database to be generated in about two weeks and provide optimal selection of diphone segments in terms of relations among the acoustic properties of the diphones.

APPROACH

The process of creating a new voice database involves a sequence of steps:

- Speech is digitally recorded along with fundamental frequency (intonation) information.
- Acoustic parameters are derived from the digitized speech.
- Phonetic labels are placed in each recorded item based on the acoustic parameters.
- An optimal set of diphones are selected from the recorded items.
- The selected diphones are compiled into a database for use by the synthesizer.

Each of these steps is described more fully below.

METHOD

The first step in creating a new voice database is to select a "target speaker" with the desired voice qualities. The target speaker records about 2000 items (English words or short phrases), selected to provide redundant coverage of all desired diphone segments. In addition to a standard microphone recording of the talker, an electroglottograph (EGG) signal is recorded to provide information for tracking fundamental frequency and locating the onsets of pitch periods within voiced segments. Figure 1 shows both speech (upper waveform) and EGG signals (lower waveform) as recorded for preparation of a diphone inventory. Pitch periods are also marked with arrows along the top of the display. In this example, the diphone sequence [æb] is embedded within a longer sequence.

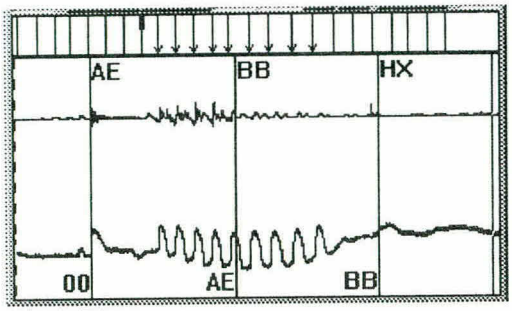

Figure 1 Recorded speech and EEG signal for possible extraction of the diphone [æb].

Figure 1 also illustrates the placement of phonetic labels within the recorded speech as shown by the regions labeled 00 AE BB and HX which are symbols the TTS system uses for silence and the phonemes /æ/, /b/, and /h/ respectively. Both pitch marks and phonetic labels are assigned to the speech automatically using software described previously (Barner, 1996; Menendez, *et al.*, 1996). Although much of this is automated and supervised by software which runs under Windows on a Pentium PC, this process requires careful human supervision to ensure the correct pronunciation of carrier words and accuracy of the pitch marks and phonetic labels and represents the most labor-intensive step in creating a new synthesizer voice.

Once all carrier words have been recorded, labeled, and verified, the automatic diphone extractor selects the set-wise most consistent inventory of diphones based on comparisons of acoustic properties among all possible diphone pairings. The acoustic properties of words are expressed as the first six Bark-Cepstrum coefficients derived from successive 10-msec analysis frames computed throughout the word. Each frame in each instance of a phoneme is compared with each frame in every other instance of that phoneme in the set of carrier words. From these comparisons the extraction program selects up to five examples of each diphone for further consideration. The selected examples are those whose parent phonemes are acoustically most central in the distribution of similar phonemes in the set. In the example of Figure 1, the diphone [æb] would be selected at this stage if both its [æ] and [b] portions were sufficiently central in their respective acoustic distributions. Further comparisons among only the items in this selected set are used to then determine the single example of each diphone to be used in the final inventory.

After the extractor identifies a single exemplar of each diphone for use , it is still necessary to select context dependent boundaries within the diphones. The boundaries are selected using the same procedure used to compare the acoustic properties of the phonemes. The Euclidean distance between the coefficients in 2 10-msec frames is computed. and then weighted by a factor dependent on the total proportions of the two phonemes being compared. (e.g. if the frame in the first phone occurs at 40% of the total duration of the phone, and it is being compared to a frame that occurs at 40% of the total duration of the second phone, the total proportions of a resulting phone made from those two phones at those locations would be .4 + (1-.4) = 1. Since the desired duration is as close to 1 as possible, the closer to 1, the lower the weight). The locations of the lowest weighted distance score are determined to be the best boundary locations for those 2 phones.

The final step in creating a new voice for the synthesizer is to load the diphone data from the automatic extractor into a database for the synthesizer. This database consists of two computer files: an index file, and a binary data file. The index contains a line which identifies the sampling rate of the digitized speech data and average fundamental frequency of the talker followed by an entry for each diphone which indexes its location within the binary database and identifies the location of the phoneme boundary within the diphone.

The binary data file contains a record for each diphone with subfields to identify the locations of pitch periods in the diphone speech data and two tables which indicate the boundary locations as a function of prior and subsequent phonetic context.

RESULTS

In a previously reported study (Yarrington, *et al.*, 1995) we compared perceptual qualities of synthetic speech generated from automatically selected diphones to speech generated from manually selected diphones. In that study, nonsense words formed from automatically selected diphones were rated as more natural sounding than the same words formed from manually selected diphones. However, we also found that words formed from automatically selected diphones were slightly less intelligible. On close examination of the data, it appeared that the overall loss of intelligibility for automatically selected diphone speech was due to a relatively small number of particularly poor tokens. Since a relatively small amount of manual labor is involved in locating and correcting the poor tokens in an automatically selected diphone inventory, we viewed this result as highly encouraging.

Since the Yarrington, *et al.* (1995) study was conducted, a number of significant improvements have been made to the software used for automatic diphone selection. In particular, the use of HMM labeler software to assign phonetic labels to the carrier words has resulted in substantially more accurate segmentation of the initial speech data. Moreover, we have introduced several refinements to the automatic diphone extraction program itself which may improve its performance and reduce the likelihood of extraction errors. Finally, an effort has been made to improve the choice of carrier words to ensure more uniformity in the characteristics of the diphones being extracted.

DISCUSSION

The approach presented in this paper has resulted in the ability to create new voice databases with minimal amounts of manual intervention. Time requirements are much more reasonable, and the resulting voices sound very much like the original speaker. This process has special meaning to people who are losing their voices to degenerative neuromuscular diseases, such as Amyotrophic Lateral Sclerosis, and has in fact been used to create a database of the voice of one person with ALS.

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BRAIN-COMPUTER INTERFACE: DEVELOPMENT OF EXPERIMENTAL SETUP

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ABSTRACT

In this paper we report on the development of experimental setup for evaluation of EEG signal as a control and communication source. In our initial experiments we recorded and analyzed surface EEG signals above sensory-motor areas while the subjects were attempting to use various mental activities to modulate their EEG signals resulting in desired movement of animated object on the feedback computer screen. To determine possible communication channels based on EEG signals, we asked our subjects to determine which mental activity produced reproducible control actions. We calculated power spectrum density (PSD) of recorded EEG signals and used sensory-motor rhythm (SMR) for feedback generating variable, i.e. object's movement direction and speed were dependent on the integrated PSD in SMR range. In our initial experiments with three subjects, during the first session all three demonstrated capability to determine which mental activity resulted in desired movements. Repeated experiment demonstrated that previously learned activity gives reproducible results. These results are very encouraging and provide a good basis for development of brain-computer interface using cognitively modulated EEG signals.

BACKGROUND

Assistive devices are essential in enhancing the quality of life for persons who have severe neuromuscular disabilities. In the absence of means to repair the damaged nervous system, three options exist for restoring function: 1) augmenting the capabilities of remaining pathways, 2) detouring around points of damage, or 3) providing the brain with new channels for communication. The only recordable physical action generated by the brain is its electrical activity (such as EEG). Using brain electrical activity for communication and control became more promising due to advances in computing, signal processing and pattern recognition technologies.

In general, the efforts to build a brain-computer interface using non-invasive EEG recordings as control signals fall into two classes: 1) those that use voluntarily modulated spontaneous EEG, and 2) those that use evoked potentials related to an external stimulus (Event Related Potentials or ERPs).

It has been demonstrated that different types of mental activity without any sensory input or motor output result in characteristic EEG patterns (Pfurtscheller et al., 1993). It has also been demonstrated that subjects can be trained to control the amplitude of specific frequency components of their EEG over the sensorimotor cortex (Wolpaw & McFarland, 1994). Based on these and other similar reports we believe that, if appropriately fast response is achieved, this technique can be used in real-time applications.

RESEARCH QUESTION

The problems that remain unsolved even with currently most successful systems are very slow training and low spatiotemporal resolution. Using combination of human and machine learning we want to increase the training speed and spatiotemporal resolution. This paper reports on the initial results achieved with our experimental setup, which is currently very similar to one described by Neat et al. (1990). Here we tried to reproduce some of the results on SMR-based one-dimensional computer cursor control, as reported by Wolpaw et al. (1991) and Pfurtscheller et al. (1996).

METHODS

Experimental task

The goal of this study was to achieve simple control actions, such as one-dimensional (up - down) object movement on the computer screen using various mental activities. During the first experiments two learning processes occurred in parallel: 1. subjects were asked to try to determine and report which thoughts produced desired actions on the moving object, and 2. researchers have tried to integrate and compare their knowledge acquired from the

literature with the information received from the subject and with their observation of the subject's performance. New knowledge was immediately implemented and tested.

Experimental Setup

Experimental setup is illustrated in Fig. 1. The subject was comfortably seated approximately one meter from the subject's screen positioned at the eye height. EEG signals were recorded using electrode cap (ECI, Inc.) with 28 gel filled electrodes distributed according to the 10-20 international electrode system, one ground electrode and the linked ears reference electrodes. For signal amplification and filtering (0.5 - 40 Hz) we have used the Brain Imager (Neuroscience). EEG signals were digitized at 200 samples/s by AT-MIO 64E-3 PC extension card (National Instruments). A special video card was used to split video output into two monitors, one for the subject and one for the operator. Experiment was supervised by the operator who also participated in the biofeedback loop. Special software was developed using LabWindows CVI software platform (National Instruments) to integrate the whole system: EEG signal acquisition and storage for off-line analysis, on-line analysis on selected channels, generation and delivery of training tasks and generation and presentation of feedback information.

Subjects

Three volunteers without previous biofeedback training participated in our experimental setup development. Their initial knowledge about this experiment was based only on reports from literature. They were told that relaxing thoughts may facilitate object's movement upwards while stressful thoughts may do opposite.

Signal processing and pattern recognition

In real-time we calculated Power Spectrum Density (PSD) using Fast Fourier Transform (FFT) and Hanning cosine window for selected EEG-signals recorded from sensorimotor areas of both hemispheres (C3, C4, P3 and P4). Remaining EEG signals were recorded and saved for off-line processing.

To test our setup and to compare our results to those from literature, we focused on SMR, which is also known as mu-rhythm. We integrated PSD components between 8 and 12 Hz over one-second time periods. We used thresholds on the SMR component of the C3 PSD to distinguish between up and down patterns and to decide on object movement control actions. To make control smoother, a moving average over last 5 second was used.

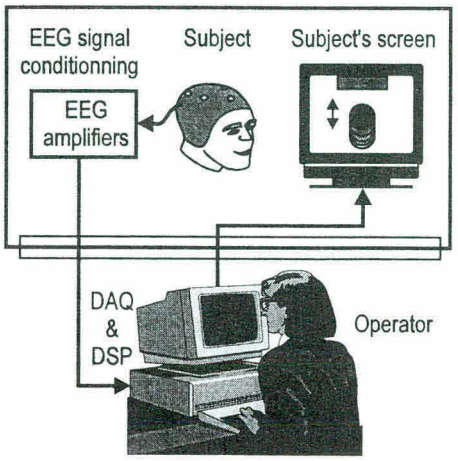

Figure 1. Experimental setup for on-line subject's training. Circle on the subject's screen represents the moving object and rectangle represents the target. The goal is to move object to the target.

RESULTS

SMR voltage distributions demonstrating the subject's control of the EEG are presented in Figure 2. Session 1 plots in Figure 2 represent data collected during the first training session, while Session 2 plots represent data collected at the beginning of the second session two days later. These results demonstrate greater concentration of high-amplitude SMR samples for the UP task (thick solid lines) than for the DOWN task (thin dashed lines). The DOWN task samples are concentrated at the lower amplitudes. It is also evident that SMR desynchronization exist in both central and parietal leads, suggesting that voluntary control in this particular case affects widespread potentials in the 8 - 12 Hz frequency range.

DISCUSSION

In this study we developed experimental setup for EEG-based communication and control experiments. To test our setup we have reproduced some of previously reported results of one-dimensional SMR-based cursor control

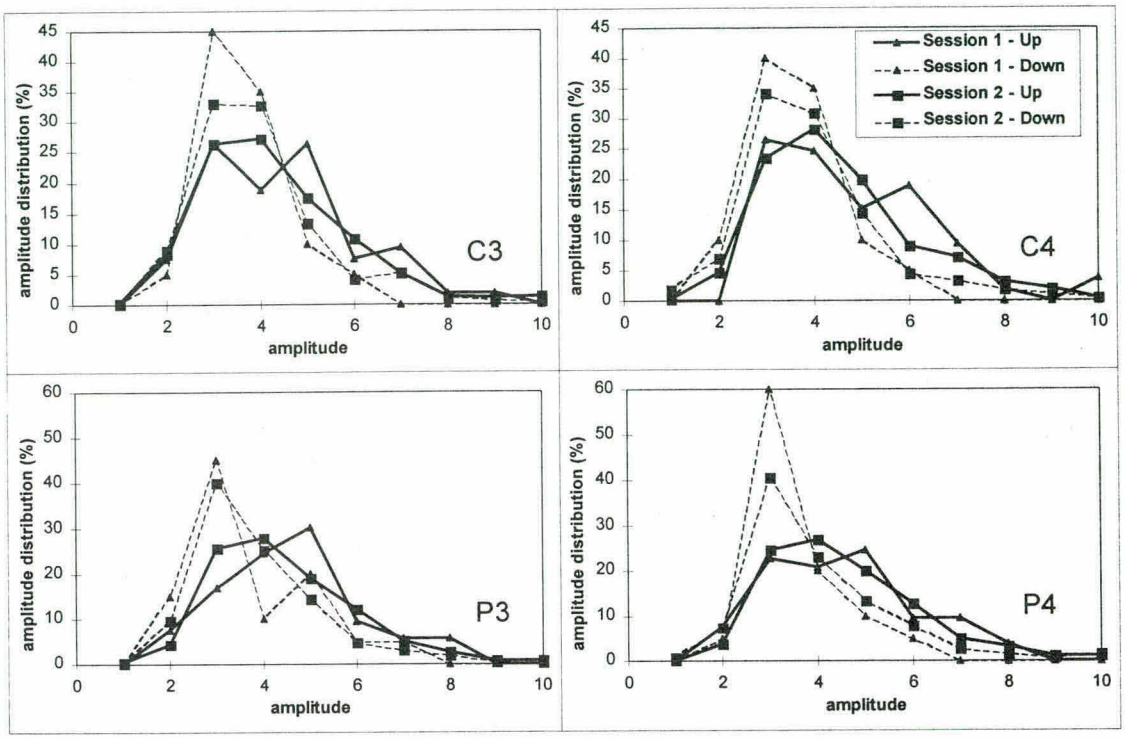

Figure 2. SMR voltage distribution for the first two training sessions.

(Wolpaw et al., 1991; Pfurtscheller et al., 1996). Our results, achieved by three subjects during the first two sessions are in accord with those mentioned above. Our subjects were able to determine appropriate mental actions which generate desired EEG patterns to move object on the computer screen up or down. In addition, we have been able to distinguish between these patterns using simple thresholds. Our study to optimize feature extraction and pattern classification parameters is under way. We will also explore implementation of machine learning techniques in automatic pattern recognition and classification of EEG signals in order to improve efficiency of human training. We will also evaluate this technique on a larger number of non-disabled and disabled subjects.

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SCHEMA-BASED ORGANIZATION OF REUSABLE TEXT IN AAC: USER-INTERFACE CONSIDERATIONS

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ABSTRACT

The effectiveness of an Augmentative and Alternative Communication system remains a focus of our work in reusable text in conversation. We noticed that to facilitate an efficient navigation of any large schema-based system, the effectiveness of an AAC system should be measured by how usable the system is from the AAC user's point of view. This implies that the entire system should be functional for the AAC user from start to finish. Therefore, the AAC user must be able to create and modify the database of schemas through the graphical interface during everyday use of the system. This paper describes a modified schema organization and the relevant usability issues associated with accessing this modified organization.

BACKGROUND

Our work continues to explore the middle ground between current reusable conversation research in short, high frequency utterances (such as greetings), and lengthy, lower frequency utterances (such as stories)[1,2]. SchemaTalk stored reusable text in a "schema" structure. The notion of a schema can be thought of as a typical sequence of events associated with a particular activity. Schemas contain scenes which contain sequences of actions which are typical in a particular domain, such as the restaurant domain. SchemaTalk associates text with the activities captured in the schema. SchemaTalk's development provided encouragement to continue studying systems which access schema-based, pre-stored text since the quality and amount of information in each conversational turn increased as the AAC user became more familiar with the system[4].

During the preliminary study of SchemaTalk, it was noticed that while a rich hierarchy of interlinked schema-based structures provided some of the flexibility and speech rate increase desired, the difficulty for our user in searching for a particular pre-stored sentence appeared to be related to the amount of reusable text stored in the system[4]. Since, a script of a particular activity seemed to be the most efficient part of the rich schema-based hierarchy, we are proposing an alternative "flat" list of these scripts for our user to select from, rather than the deeply imbedded hierarchy of scripts.

STATEMENT OF THE PROBLEM

Through close interaction with the AAC user testing SchemaTalk, we observed the difficulties he had acquiring the skills to navigate a hierarchy of schemas, especially as the number of scripts grew. We hope to address the usability of the system by simplifying the way scripts are organized and accessed.

In ensuring a completely usable application, a simple method for the AAC user to create new scripts and add them to the current database of scripts had to be included. The prototype application required the programmer to manually enter the scripts for the AAC user. Although, caution had to be taken in the new system not to overburden the AAC user with excessive commands to enter a new script.

The same considerations were taken in developing a method and interface for the AAC user to maintain and edit scripts. The original SchemaTalk did not take this mode of operation into consideration. Again, care had to be taken in the way the editing capabilities were implemented in the interface to ensure a usable system for the AAC user's special input devices.

APPROACH

In an attempt to eliminate the burden of navigating through the hierarchy of schemas to find the desired script without losing the flexibility associated with the script structure of utterances, we reverted to a simple "flat" list of scripts. As an illustration, this change allowed the user to directly access the "McDonalds" script without having to navigate through several layers of higher level scripts (such as a restaurant script, fast-food restaurant script, etc.). The interface now allows direct access through selection of the script from the listing of scripts window or text entry of the script name.

The interface was more difficult to design than it would appear at first glance. While adhering to the standards and guidelines is highly recommended, these standards and guidelines do not guarantee a usable application[3]. This is certainly true developing an interface for AAC users. However, it is still necessary to consider the seven characteristics of a good interface: user in control, directness, consistency, forgiveness, feedback, aesthetics, and simplicity[3].

We designed the interface to be visually and functionally consistent with Windows™ applications. While every command can be executed with the mouse, each can be executed with one or two key strokes from the keyboard emulator on a Liberator™ AAC device, manufactured by the Prentke Romich Company. Since the Mouse Interface and Keyboard Emulation (MIKE™) software on the Liberator has two separate themes with distinct overlays, we attempted to reduce the number of theme changes necessary to navigate the new version of the application. Movement of the cursor in the mouse theme can be challenging. Each direction of movement has three degrees of movement associated with it. Thus to get the cursor to stop on a desired button or icon can be difficult depending on its size. This had a some impact on the AAC users response times when the mouse theme was required to speak a desired utterance.

This was also a factor in deciding to create two basic modes of operation for the new version of SchemaTalk. The first and default mode is "speak mode." This allows the user to recall stored scripts and utterances similar to the previous SchemaTalk, other than the interface improvements discussed above. This mode will allow simple editing of an utterance. The user can immediately speak the desired utterance in its entirety with a single key stroke. Also, the user has the option to select and modify an utterance by using a different (single) key stroke. Once the utterance has been selected and copied to a separate window, the user can quickly edit the utterance to facilitate simple deletions, additions and modifications to ensure an accurate conveyance of the desired message.

The second mode is "maintenance mode." This is where the user can effectively create new scripts or modify old scripts. Once again, a separate window is enabled, allowing new commands which facilitate quick, efficient navigation of scripts and utterances. New scripts can only be created from an existing script or one of a limited number of generic script templates. This was necessary to ensure some continuity in the system to automatically recognize potential changes to a script. For example, changes to the McDonalds script should automatically prompt the user, offering to propagate the changes to all the scripts associated with the McDonalds script, such as other fast-food restaurant scripts.

Since the scripts are no longer stored in a hierarchical fashion, it was difficult to capture how scripts were related to each other. On the other hand, we avoided some of the classification difficulties that arise from using a strictly hierarchical organization (e.g. are pizza establishments classified as fast food or sit-down restaurants?). The system basically tracks the most prominent categories which could classify a script and then links the common categories internally. These connections are transparent to the user. Thus, when the user makes a modification to a script like McDonalds, and the Burger King script is transparently linked to the

McDonalds script, the system offers to make the changes in the linked scripts as well. We did not attempt to ensure 100% accuracy in the linking of common scripts. In fact, we decided to err on the side of caution by not matching a script rather than creating an undesired link. This should result in at most one or two additional times the change would have to be entered into the system, depending on the number of scripts stored in the system. Since the most common scripts are automatically recommended for updating to the user, a single modification should need to be entered at most a couple of times in order to propagate it to all scripts where the desire change is needed. We hope to refine this approach during system evaluation.

IMPLICATIONS

The primary focus of this version of SchemaTalk is to ensure a usable system for AAC users. Usability can not easily be defined unless the context of the situation is also considered. We incorporated the experiences of a computer-literate AAC user in the design of our current system. This AAC user has been testing the previous system and experimenting with navigating several other applications in a Windows environment with his Liberator. He was able to convey which Windows interface guidelines and standards do not necessarily provide the desired functionality or usability for AAC users, particularly ones using a dedicated AAC device as a keyboard/mouse emulator.

DISCUSSION

Given the initial success of the original prototype, we anticipate that the changes to the system and interface will greatly enhance the overall usability of the system for all AAC users. Clearly we have found that it is crucial to consider the point of view of AAC users in the design of our systems. By investing just a small amount of time and resources, we have gained a much stronger understanding of the issues an AAC user faces using the latest technologies. By educating these users on the issues researchers face during design and development, we hope to work together to find the most promising solutions to these important interface issues.

This new version of SchemaTalk will be evaluated soon and we expect to have the initial results by mid summer. We will be evaluating the system for usability, functionality, and feasibility. The overall goal is to evolve a system which can implemented on a personal computer or incorporated directly into an AAC device.

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AN ADAPTIVE SPEECH PROCESSING AID FOR HEARING IMPAIRED

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ABSTRACT

In this paper it is presented an adaptive sound compression technique for augmentative communication by people with neurosensitive acoustic deficit. The method has been developed in order to maintain the informative content of the sound according to the residual band of the single subject. Its main characteristics are the compression and the adaptive shift of the sounds' frequency components in the hearing field residual of each subject. The developed technique has been theoretically and experimentally evaluated using specifically developed software tools.

BACKGROUND

As known, each hair cell within the ear is optimized for a specific frequency and, when excited, transmits the pulses which cause the hearing sensation to the brain. The neurosensitive loss of hearing is a damage of the cochlea, so that there is an inhibition in the codification of the sound wave by the hair cells. If some hair cell is not excited, the ability of hearing the corresponding spectral component is lost, causing deafness. The extent of the frequency bands not heard is different according to the number of damaged cells and leads to a more or less serious deafness.

The deficit of hearing impaired has been studied extensively by researchers and solutions have been reached following two different approaches: the first approach consists in the deficit correction without exploiting the residual capacity of the ear, e.g. with the external hearing aids and the cochlear implants; the second approach consists in the deficit correction using frequency processing so to exploit the residual capacity of the ear, e.g. by SUVAG technique [1] and some kind of external prosthesis [2][3].

The external hearing aids use signal filtering to enhance the sound intensity and to avoid his dispersion but for serious deafness it is not a resolutive remedy.

The cochlear implants codify the sounds in electrical pulses that are then transmitted directly to the acoustic nerve. This method allows the treated person to recover the hearing capability but implies the risks of the surgical intervention.

The SUVAG[1] is a table top instrument which optimizes the frequency and intensity of the sounds in the hearing field of the patient using a series of linear analogic filters. This instrument doesn't memorize the obtained sounds so a rehabilitation strategy requires at each trial to repeat the tuning of all the filters. Moreover, the SUVAG allows only a linear analysis of the sound. For these reasons this instrument is mainly used only to assess the damage of the ear.

Recently, prosthesis based on the assumption that the majority of neurosensitive deafness inhibits the hearing of high frequency components of the sound have been developed [2][3]. These devices shift the sound higher frequency components into lower regions but, in dependence of the adopted method for sound compression, the informative content of the starting frequency spectrum can be modified. Moreover, the frequency shift, in general, is executed without taking into account the hearing residual field of single subjects.

RESEARCH QUESTIONS

The main objective of our research was to realize a sound processing technique following the second approach mentioned above. The faced problems have been: "how it could be possible to preserve the informative content of the sound" , "what kind of sounds' features should be maintained" and "how could be created an adaptive device suitable for each kind of neurosensitive loss".

Researches in this field [4][5] showed that sounds perception is mainly dependent from the ratio between the Fundamental Frequency (F0), the First Formant (F1) and the Second Formant (F2). Moreover, the intensity and duration of each sound portion have a fundamental role, especially for the perception of the consonants and for the detection of the tone and rhythm of the words.

For these reasons, we decided to create a sound processing technique with the following main features:

* the preservation of both the ratio between F0, F1 and F2, and the intensity and duration of each sound portion;
* the possibility to modify the processing technique according to the residual band of the single subject.

METHOD

Compression algorithm: the following scheme describes our method (fig.1):

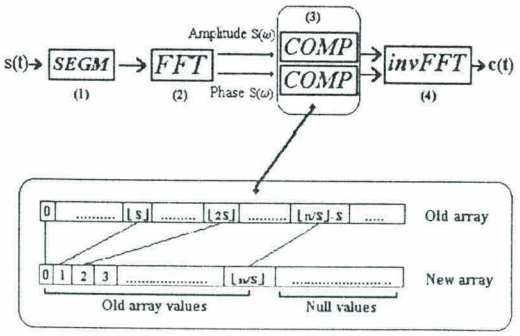

Fig. 1. Compression algorithm diagram.

the first step consists in the segmentation of the input signal s(t) into portions whose length can be chosen by the user **(1)**; each portion is Fourier Transformed **(2)** to obtain the spectral components, the resulting signal S(ω) is characterized by amplitude and phase, stored into two distinct arrays. The following step **(3)** is the compression of the arrays, using a scale factor "s" runtime fixable; an example of this step is shown in fig.2. A final Inverse Fast Fourier Transform operation **(4)** leads to the reconstructed temporal signal c(t).

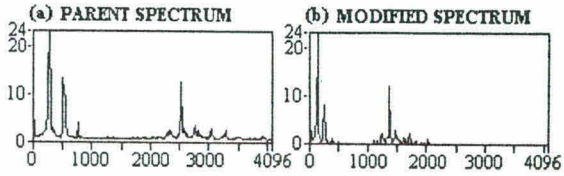

Fig. 2. (a) Spectrogram of the spoken vowel /i/,before (fig. 2a) and after (fig. 2b) compression using the scale factor s=2. The frequencies are found on the X-axis, amplitude on the Y-axis.

Module for the theoretical study: in order to analyze the effectiveness of the algorithm respect to the preservation of the distinctive sound features, we developed an automatic technique for the detection of the F0 and the first two formants. The technique uses "Cepstral Analysis" [5] for the detection of F0; the formants are detected by sampling the amplitude of the original spectrum at the F0 and harmonic frequencies, this signal is then analyzed using a specific algorithm of peak detection so to extract the formant bands. The recognition percentage is around 93.3%.

Module for the clinical study: to allow the experimental evaluation of the technique in rehabilitation centers, a first prototype of the software module, specialized on the Italian language, has been developed for the clinical study. The prototype is characterized by an user-friendly interface and a specifically developed word sounds database.

The system allows the input, blanking and visualization of data concerning the patients, but his main function is the training phase and the checking phase. In the training phase, a series of words, compressed according to the residual band of each subject, is repeatedly proposed to the patient in order to train him to listen the compressed sounds. While the patient listens the sounds, he can also see their spelling and a representative picture of the associated words. In the checking phase mode, the patient listens compressed sounds randomly chosen from the database and he must recognize the words associated to the heard sounds.

RESULTS

Theoretical evaluation: we examined 30 original and compressed vowel sounds and we noted that the features recognition increases if the compression algorithm is performed dividing the signal in very short intervals and it reaches the maximal efficiency (features preservation near 100%) for segmentation ranges near 1/16 sec.

Clinical study: we examined 6 patients of the R.E.U.L. Center (see Acknowledgements), all using hearing aids, of age spanning between 10 and 15 and with different kind of residual band. The experimentation consisted in two phases:

-listening and recognition of normal sounds;

-listening and recognition of compressed sounds.

Four subjects gave positive results, in fact the number of recognized sounds increased in the second phase. The results were not so good for the other two subjects. On the other hand, they were very well trained with the own prosthesis so, we suppose, a psychological refusal may have been.

DISCUSSION

We can say that in respect of the proposed "research problems", our method solves them. Moreover, allowing to fix the compression scale factor at runtime, the method provides the adaptive processing of the signal respect to the patient's residual band.

However, even if the first results are encouraging, more tested subjects are needed for the experimental validation of the technique. On the bases of this validation, the next step will be the study of a technique for the real time implementation of the algorithm.

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The method has been developed and experimentally evaluated cooperating with the Center for the Recovery of Hearing and Language (R.E.U.L.) of Genoa, Italy.

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A Preliminary Investigation of a Lipreading Tool Intended for a Regular Educational Classroom Setting

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ABSTRACT

This is a preliminary study that attempts to evaluate the potential of a virtual heads up display lipreading tool, LipCam, which can be used by the hearing impaired in a mainstream educational environment. Results suggest that lipreading using LipCam is possible, and that performance test scores are equivalent to normal lipreading mode performance.

BACKGROUND

"In general previous statistical comparisons of classroom settings have found that placement in regular classes with hearing students is positively related to achievement for deaf and hard of hearing students" [1].

With an increase in mainstreaming in the educational setting there is an ongoing need to assess and develop tools that would allow for inclusion. Continuous advances in technology are making more capable tools increasingly affordable.

This paper explores the potential use of LipCam, a system that was developed at the Applied Science and Engineering Laboratories (ASEL). It is intended to offer a hearing impaired student constant visual information of the lecturer's lips on a virtual heads-up display. It offers constant lip information independent of the speakers orientation, lighting conditions, and distance from the student.

LipCam is currently in a prototype stage. Although functional its current implementation is more appropriate for demonstrations rather than deployment for field testing. LipCam consists of two main parts: the teacher and the student units. The units are worn by each user on headbands. The teacher unit contains a microphone/single earphone headset. It has a miniature monochrome camera mounted next to the microphone and points to the teacher's mouth. The sound and video are transmitted to the user across a radio frequency link. The student sees and hears the teacher through a virtual heads-up TV display worn on a headband viewed in one eye. The system is completely wireless so that the movements of neither the teacher nor the student are restricted.

As with any new system, there are a number of design issues that need to be assessed. In the following experiment, the primary consideration addressed in determining the efficacy of LipCam is; the ability to lipread using a virtual medium which in its current state offers one visual mode of presentation (the image of a person's lips). There are a number of studies that have been performed to explore an individual's ability to lipread based on the amount of exposure of the speaker's face. Although results from these studies are conflicting, there has been recent evidence that suggests lipreading performances for viewing lips, and lips plus mandible, to be similar to viewing the full face[2,3].

METHODS

This study examines 3 different cases of lipreading. They are the following:

1). Lips only using a virtual heads-up display

2). Lips only on a small display

3). Full face on a regular TV monitor

The first case is designed to identify the effectiveness of lipreading while viewing a virtual image with one eye using the heads up display. The second case is to help determine whether or not viewing lips only on a small display can be achieved with less effort, and or more accuracy, (with two eyes) from a normal distance away. If results suggest this mode to be favorable then the design of the LipCam could be changed accordingly. The third is to give a baseline comparison for how effective the participant is in lipreading under more normal conditions and offer comparison to previous studies.

LipCam

Participants

Six adults with normal hearing have participated in this experiment to date. All but one had corrected vision (subject 3; 20/10 20/70). Participants had no previous experience lipreading. Their average age is approximately 31. All the participants had some familiarity with the speaker they were viewing.

Apparatus

Stimuli was recorded simultaneously with two cameras: Panasonic AG-HT5 and AG-186U-P/AG-B20-P. Stimuli was displayed in color on three different medium; Sparc Sun Station 20, Virtual Vision Sport heads-up display, and a 21" JVC TV. The display size was approximately 4" for the Sun Sparc monitor and approximately 30" for the virtual display (focusing 8 feet in front).

Stimuli

Sixty words chosen from a previous study [2] were used for test stimuli. The criteria for which they were chosen includes word visibility and frequency. In addition, four everyday CID sentence lists (A, B, C and D), and the Craig Form A speech reading test words were also chosen[4]. Ten words (Craig form A) and five sentences (CID list D) were arbitrarily chosen to be used for training. The 60 word list was divided into 3 smaller lists of relative equivalency based on visibility (primary) and frequency (secondary). Each list of 20 words contained 11 high visible and 9 low visible words. Sentence lists A, B, and C were also used to illustrate any differences in word vs. sentence discrimination.

Stimuli were recorded on video tape. There is approximately a 12 second delay between words and 30 seconds between sentences during which time the speaker was not visible.

Procedure

Subjects received written instructions for testing procedures. They were given response booklets to write down their answers and were encouraged to guess in cases where they were unsure. Subjects were rotated through a series of tests over each medium. They were given a two minute break between tests and there were 15 tests in all. The first 3 tests were training tests for each mode/medium. In order to become accustom to procedure and medium, the same training stimulus was used for each mode. Next, subjects rotated through the 3 sets of word lists until they had seen each list 3 times in a given mode/medium (tests 4-12). The last rotation, (tests 12-15), consisted of one of the CID sentence lists per mode/medium. The order in which mode/ medium was presented varied in each case. However the mode in which the medium was presented remained fixed as follows: lips on LipCam, lips on the small monitor, and full face on the TV monitor.

RESULTS

Results were scored for word correctness across modes/medium. Table 1 lists the mean for all the data collected over each mode/medium for word and sentence lists.

% Mean and Standard deviation	Lips/ LipCam	Lips/ Small Monitor	Full Face/ TV
Words Lists	23 ±7	21 ±6	22 ±8
Sentence Lists	24 ±18	35 ±21	33 ±17

Table 1: % Mean and Standard deviations over all subjects within each mode/medium.

The means for all subject data were tabulated in two other groupings to look at general trends for repeated measure effects and practice effects. Table 2 illustrates the results for the word lists only by mode/medium grouping. The second grouping examined averages across trial number, independent of mode/medium. Their means

Word List Sets	Lips/ LipCam	Lips/ Small Monitor	Full Face/ TV	Mean per round
round1	16 ±4	17 ±15	20 ±11	18 ±4
round2	24 ±19	26 ±17	22 ±12	24 ±5
round3	30 ±12	20 ±14	24 ±17	24 ±5
Total	23 ±7	21 ±6	22 ±8	

Table 2: Mean & standard deviations dependent on mode/medium.

and standard deviations are on the same order as when grouped by mode. However they do tend to show more of a steady rise.

At the end of the experiment the subjects were asked which medium and mode they preferred. Three subjects said they preferred receiving lip information, it allowed them to better focus in on the speaker; one reported to like the full face mode better; one reported to like the full face better for the sentence lists and lips only for the word lists; and another one was undecided. Presentation medium preference is as follows; three people preferred the small monitor viewing, one preferred the TV; one stated he did not like the heads-up display; and one said he felt the heads-up display was brighter.

DISCUSSION

Mean and standard deviations shown for the word lists in Table 1 suggest similar abilities for information transmission across both mode and medium. These numbers fall within the average values stated in literature for lipreading performance, 20 - 30%.

Means per round results in Table 2 show trends for word familiarity especially from round 1 to round 2. However, means for training sentence trials (tests 1-3) and (tests 9-10) grouped by trial order (independent of mode/medium) had similar increasing trends. In one case the stimulus is repeated and in the other it is not. This might indicate that there is a training effect that exists in the order of a third of a deviation.

Future studies will seek to clarify these results. More subjects will be tested to enable better statistical analysis of the data set. A variety of scoring techniques based on phoneme and viseme correctness and syllabic interpretation will be employed to further interpret the data collected. Future work may also look at other modalities such as performance under various viewing angles.

CONCLUSIONS

Preliminary results suggest that information across the three presentation modes/ medium (lips on LipCam, lips on Small monitor, and full face on the TV) are similar. The means for performance is in agreement with literature for lipreading performance. More subjects need to be tested to be able to determine which mode/ medium might be more effective. It may be the case that one mode is not superior to another and that LipCam could be designed to be used with multiple displays.

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ALTERNATIVE STIMULI FOR BRAIN ACTUATED CONTROL

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ABSTRACT

Brain actuated control, BAC, has been demonstrated to be possible utilizing an oscillating visual stimulus, acting like a carrier signal, which is modulated by thought processes and detectable in the EEG. This modulated EEG signal has been used to control a variety of physical devices. The visual stimulus required is not appropriate for use out of a well controlled space. Therefore for this study we investigated alternate stimuli to evaluate their possible use in a similar BAC operating mode. Tactile and auditory stimuli were used at the same fundamental frequency as the visual stimulus and also at higher frequencies. Specific goals were to successfully detect the stimulus carrier in the EEG signal as a steady state evoked response, and to determine best locations for electrodes. Results showed that stimulation by both auditory and tactile means generated evoked responses that were of useable amplitude for control. Fundamental frequency components as well as some second and third harmonics were observed.

BACKGROUND

As fast as computers have become, they cannot match the wide bandwidth capability of the brain-visual system pair for high speed pattern recognition and decision making. It is this superior capability of the human brain that has invited attempts to develop interfaces which would permit the direct utilization of brain function in the control of external devices. This type of control has been referred to as Brain Actuated Control or BAC. Applications for an interface of this sort exist in many areas. Among other applications, this type of "hands off " control could be eminently applicable to the assistance of people with disabilities to give them another modality of control of their environment. BAC would have a marked effect on the lives of those people with limited physical mobility.

Significant achievements in pioneering work on brain actuated control are being made at the Air Force Armstrong Laboratory (AL/CFHP) by McMillan et. al. [1,2] utilizing modulation of electroencephalographic responses to a stimulus signal. This modulation of the "carrier" (i.e. enhancement or suppression of response magnitude) is actively performed by thought processes of the subject, and the amount of modulation is used as a control signal. They have demonstrated success at controlling several tasks with their system, including rudimentary control of functional electrical stimulation (FES) of thigh muscles for knee extension.

RESEARCH QUESTION(S)

While McMillan and his group are demonstrating the capability of BAC utilizing a visual stimulus in the controlled environment of the laboratory, it is questionable whether a visual stimulus system is appropriate for use out in the real world. Interest in using this system outside of the laboratory exists both within the Air Force community and with those of us working with disabled individuals. The potential is high that a system based on

ALTERNATIVE STIMULI

BAC can be developed which would permit persons with limited function to control their environment. Stimuli other than visual, such as auditory or tactile, may be more convenient to use while moving from place to place or room to room. Therefore the purpose of this study was to investigate these alternative stimuli, and evaluate their suitability for use in a BAC system.

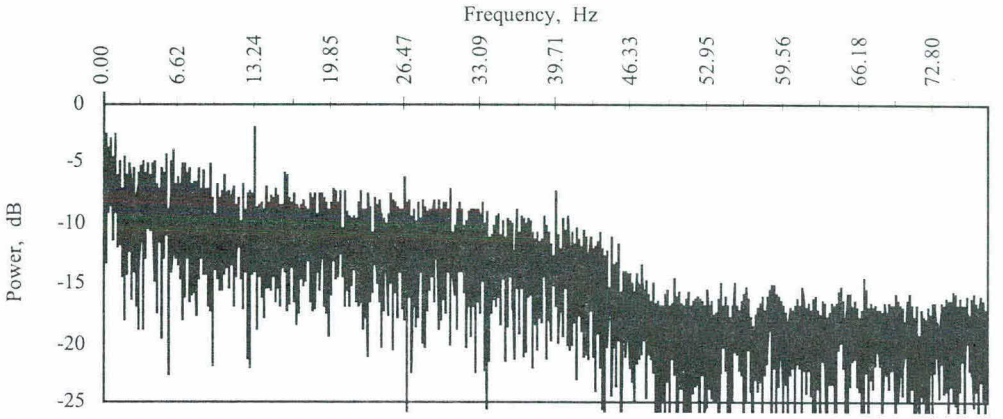

Figure 1

The BAC experimental setup at AL/CFHP utilizes visual steady state evoked potentials (SSEP) as the detected signals for the control experiments. Visual SSEPs are strong signals and relatively easy to demonstrate. It was not clear that the same result would be found looking for tactile and auditory SSEPs.

METHOD

Stimulation was accomplished in two ways. The auditory stimulus was a bilateral rectangular pulse of one millisecond duration at the repetition rate of the fundamental frequency of stimulation. Auditory level was adjusted for approximately 80 dB. For the majority of trials in this study stimulus frequencies were 13.25 Hz and 43 Hz. Tactile stimulation was accomplished with a Brüel & Kjaer mini shaker type 4810. It was driven by a train of square pulses of 10% duty cycle at the fundamental frequency. The tactile unit pulsed the nail of the middle finger of the right hand. Intensity of this pulsing was not measured but subjectively adjusted to be comfortable for the subject for an extended trial session.

Five pairs of electrode sites on the head were investigated. Data recorded from each of the five pairs of sites was analyzed for frequency component energies to determine the extent to which the stimulus was present in the EEG. During the BAC trials other data was also compiled, such as commands to enhance or suppress the SSEP and the resulting effect on the device being controlled, so that we could compare, to some degree, performance of the tactile and auditory stimuli with results acquired from visual stimulation

RESULTS

Examples of raw spectral data for the BAC trials are shown in Figures 1 through 3. Figure 1 shows the complete spectrum, from 0 through 80 Hz, for a tactile stimulation trial with a stimulus of 13.25 Hz. It is the spectrum for the complete set of data taken during the trial which showed the best learned control for this series. Data from auditory stimulus trials showed similar spectral behavior. Note the energy component at the fundamental

frequency. It indicates that we can get signals from tactile stimulation which are as much as 6 dB or more above the baseline. We found this signal level to be roughly half of the visually evoked levels, but still adequate for use in BAC trials. The Figure 1 data also shows a clear second harmonic at 26.5 Hz, a third harmonic at 39.75 Hz, and the 40 Hz filter rolloff.

DISCUSSION

If we look more closely at Figure 1 we see the first harmonic peak is significant, Figure 2, but the third harmonic peak is nearly as great, Figure 3. It is not clear why we are seeing a second and third harmonic in the EEG. Signals were checked throughout the system looking for possible harmonic distortion generated by the data collection equipment, but none was apparent. Although this behavior was not seen for all stimuli and all trials, it seems possible that the sensory system of the subject was generating these harmonics.

This study was successful at meeting its primary goals of finding evoked responses and identifying suitable EEG electrode sites for auditory or tactile BAC trials. We routinely demonstrated 5 to 6 dB of fundamental frequency signal available for use in the BAC studies. We even demonstrated as much as 9 dB, significantly approaching that level seen with visual stimulus. Observed second and third harmonics of the stimulus frequency bear further investigation. In conclusion this study made it clear that brain actuated control using tactile or auditory evoking stimuli should be possible. Further work in this area is planned.

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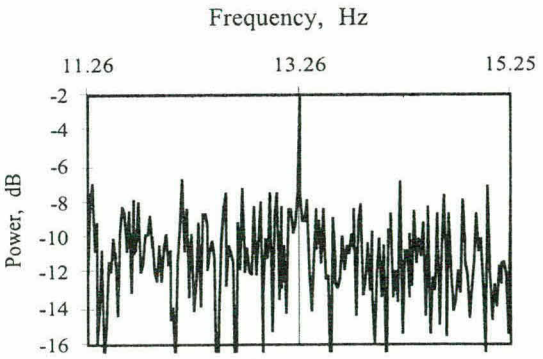

Figure 2

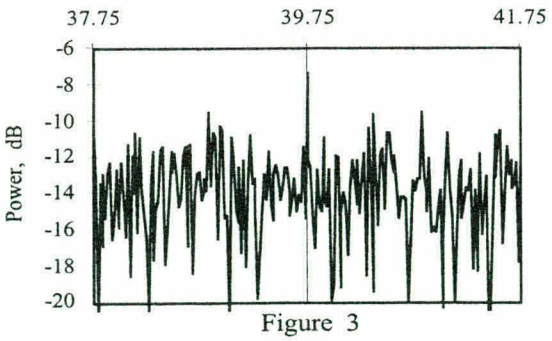

Figure 3

Full Color Image Capture in Augmentative Communication

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Abstract

Many AAC users rely on very realistic graphical representations of vocabulary sets. ZapCom is an AAC device that accommodates such users by offering both image capture and full-color image display. The image capture and display technology has been developed so that a prototype augmentative communication interface may be quickly constructed and evaluated. This technology may also be included in additional applications that would benefit from image capture.

Background

Graphcom is a DOS, PC-based augmentative communication application developed at the Applied Science and Engineering Laboratories. It incorporates photographic quality images within dynamically displayed vocabulary sets (Miller, 92). Graphcom serves a dual role as a communication device and as a language acquisition tool. The distinctive feature of Graphcom is the image capture hardware and software that allows rapid generation of custom, individualized vocabulary representations.

Graphcom demonstrated the concept of image capture at a reasonable price, using technology that was available at that time. The role and need for photographic quality images has not changed during the four years since Graphcom was introduced, nor has the need for dynamic image capture. What has changed significantly is the display quality available on laptop and notebook computers and the availability of inexpensive, off-the-shelf hardware and software products to capture images and record audio in Windows-based applications. The most notable limitation of Graphcom was its dependence upon low-resolution, gray-scale images. Additional limitations in the system included an interface that contained control information that could be difficult to understand and even inappropriate for some users. This information included page-changing controls and an on-screen menu for accessing the image capture and audio recording features. While Graphcom took advantage of dynamic picture acquisition and display, its interface was static and not modifiable.

These issues have been addressed by the development of ZapCom, a newly developed augmentative communication prototype that runs under Windows (Win32s). ZapCom allows the dynamic capture and display of full color images in a multilevel vocabulary. The interface has also been updated and written in an object-oriented style. It is more flexible than the static Graphcom interface and communication functions have been separated from setup functions. ZapCom retains the original design goals of Graphcom but makes better use of current technology.

Rationale

ZapCom was designed to support:

- The ability to capture and display full-color images on a laptop or notebook sized personal computer.
- The ability to record speech for each image.
- The construction of vocabulary sets allowing users to navigate between levels when appropriate.
- Implementation of a direct selection AAC prototype that presents images to the user, and provides speech output.

Some additional design goals reflect changes in technology and lessons learned

from the evaluation of the original Graphcom application. These include:

- Incorporation of user profiles that allow interface features to be activated or deactivated to suit a specific user's preference.
- The ability to load formatted images directly from a disk to the application.
- Encapsulation of the image capture software to facilitate the development of additional applications by developers who may wish to incorporate image capture.
- Development of a reasonably-priced, portable prototype that integrates the laptop computer, image capture and sound recording hardware and all necessary power supplies.

Design

The primary goal of the Zapcom project was to incorporate image capture into a fully functional augmentative communication prototype. In addition to those who rely on photographs for communication, other populations may utilize photographic quality images and image capture for purposes other than communication. Language acquisition and memory training are examples of applications with different interfaces that could benefit from the same image capture capabilities. For this reason, it was necessary to encapsulate much of the image processing and audio reproduction in application-independent modules. To facilitate this, ZapCom was designed using *Visual C++* and the *Microsoft Foundation Class Library* (MFC), an animation library derived from the MFC software hierarchy (Thomson, 95), the *Microsoft Video For Windows SDK (VFW), and the Media Control Interface* (MCI).

The use of the MFC hierarchy and the animation class library facilitates the display of photographic images and provides the basic image processing required to format an image for use by the application. The image processing is application-independent, supports the future use of animation, and provides efficient screen update and redrawing.

MCI provides a generic programming interface to audio devices. This allows any MCI compatible audio recording and playback component to 'plug and play' in an MCI application. Similarly, the VFW SDK provides a more specialized, lower-level programming interface to video recording and playback devices. Any VFW compatible video capture hardware may be used in the application. To further encapsulate the image capture routines, they were developed as a separate program and will be converted to a dynamically linked library.

Development

ZapCom runs on an Intel-based portable computer. The current prototype platform is a *NEC* laptop running Windows 3.1. The display supports 256 colors with a resolution of 640x480 pixels and has a built in touch screen. ZapCom incorporates full-color, 8 bit-per-pixel image capability. A *Toshiba* CCD color camera is connected to a CardCam VideoIn PCMCIA video capture and frame grabber card manufactured by *Quadrant International.* The sound device is a PCMCIA, Sound Blaster compatible sound card manufactured by *Eiger Labs*. A Radio Shack mini-amplifier speaker is the output device. A cellular phone/camcorder lead acid rechargeable battery provides auxiliary power for the speaker and the camera. Currently, ASEL is developing a vacuum formed plastic shell to house the components and a mechanical support for the camera.

The minimal ZapCom user interface displays one page (screen) of images. A page consists of two rows with four images in each row. The user selects an image by touching the screen where the image is displayed. The sound for the image is output via the speaker.

Additional system functionality is available to the communication facilitator via a pop-up menu. These menu driven functions include page changing, image import, image capture, and sound recording. Additional menu options allow the facilitator to create, modify and select a user profile.

A facilitator may tailor an interface to an individual's needs by editing that individual's user profile. Modifications to the user profile can allow the user to directly access functions via the touchscreen. A facilitator may also edit a user profile to restrict a user's access to previously permitted functions. For example, a care provider may modify the interface to include a communication buffer. When the communication buffer is added to the interface, vocabulary selections are inserted into the buffer. When the user touches the buffer, the contents are spoken sequentially. A button is also added to the interface that allows the user to clear the buffer without speech output. Also, the user profile may be modified to allow the user to access buttons to change pages or to quit the application. Providing user profiles allows multiple people to use the device or a single person may wish to have multiple configurations.

Images are captured in Zapcom in a 24 bit-per-pixel bitmap format at a resolution of 320x240 pixels. When the camera operator selects the image for incorporation within ZapCom, the images are first reduced to 160x120 pixels. After sizing the image, the image is reformatted to an 8 bit-per-pixel format for faster processing in memory and more efficient disk storage. The operator records speech to be associated with the newly acquired image. Images are added to the screen sequentially. If the screen is full the operator is prompted to select a picture for replacement with a new image.

Discussion

Work is in progress to complete a physical shell that houses all the ZapCom components so that the device may be evaluated in the rehabilitation clinic of the duPont Hospital for Children. We will evaluate the success of ZapCom's video capture technology and the impact of that technology on AAC users. The feedback will inform our continued efforts in this developmental area and influence the interest in these technologies in the commercial marketplace.

Acknowledgments

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A HEAD MOUNTED AAC DEVICE WITH EYEGAZE INPUT

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ABSTRACT

Even the fastest speech generation systems using compressed input are unable to approach the speed of natural speech because of their dependance on slow, sometimes labored, manual input. On the other hand, many individuals with physical impairments retain relatively accurate control of their eye movements[BEUK]. However, in spite of their potential for accelerated input, eye tracking has found limited acceptance as an AAC interface. This may be because of its current intolerance to natural head movement and its need for cumbersome equipment. This paper discusses the problems of uniting the two technologies to create faster and more portable AAC devices.

BACKGROUND

AAC devices with physical push-button input driving speech synthesizers are available for use by nonspeakers. However, many nonspeakers have motor impairments that limit the speed of input to these devices. While natural speakers communicate at rates of between 150 and 250 words per minute, many AAC systems allow communication rates of less than 15 words per minute[FOUL]. Reported rates are as low as 2 to 8 words per minute[BEUK]. To reduce input requirements, many systems employ techniques such as word prediction, semantic coding [BAKE] and sentence compansion [DEMA].

Recent work restricting the possible output sentences by imposing limits of context have demonstrated far greater conversational rates. By having expert users preprogram their systems for conversations within a given context, experimenters have observed communication rates of 70 words per minute[TODM].

A subject's point of gaze can be measured by feeding digitized camera images of the subject's eye to analysis sofware. The chosen method, Pupil Center - Corneal Reflection, offers a way to determine the user's point of gaze[YOUN]. An infrared LED illuminates the eye and causes a specular highlight where it reflects off the user's cornea. Image processing software is used to locate the pupil and the corneal reflection and the vector between the two is translated into a gaze direction.

STATEMENT of the PROBLEM

Studies have shown that conversations between people with a great disparity in conversational rates are often dominated by the faster communicator[ALM]. This fact leaves people dependant on slow AAC technology at a disadvantage during conversations with natural speakers.

Although eye tracking is currently available as an input method[CLEV], few AAC devices have embraced it. None of the major devices have eye tracking interfaces and systems that do are built around the eye tracker itself with little thought to reducing input requirements. The problems of implementing eye tracking

interfaces to AAC devices include:

Bulk and Immobility: By requiring users to remain at their desks during all conversations, large desktop systems do not provide users with access to the mainstream of society.

Conversational posture and gaze: The need to continuously look at the computer's monitor leaves the user unable to maintain gaze contact with the other conversants. Studies have shown that gaze is used in western society as a tool to demonstrate attentiveness. More gaze contact has been shown to create perceptions of competence, assertiveness and persuasiveness[KLEI] while gaze avoidance has been shown to convey lower credibility, attraction and persuasion[BURG].

Intolerance to natural head movement: for the software to provide a reasonably accurate estimation of the gaze, the eye's image needs to be as large as possible in terms of pixels of resolution. This requires the camera to zoom in on the eye until the field of view is only about 2-3 inches across. The user's eye can't leave this region and he must hold his head still to maintain good calibration. This is difficult, specially for a user with motor impairments.

APPROACH

The heads up interface being developed at the ASEL adds a miniature camera to the Private Eye display unit from Reflection Technology. A hot mirror, reflective to infrared light, but transparent in the visible spectrum, is mounted in front of the display. This enables the user to see the display as if through glass while allowing the camera to get a good view of the eye from its unobtrusive mount to the side of the unit.

The entire unit is worn so that the display is just below the user's line of sight. This allows the user to look past the display at conversants. When making an on-screen selection with the eye tracking interface, the user only needs to divert his gaze by a few degrees.

AAC software is planned for integration with the eye tracking interface. The software will drive a speech synthesizer, employ language coding techniques and use the head mounted display unit to show the word board and accept input. We are also exploring the possibility of modifying an industry standard speech system to operate with the unit under eyegaze control.

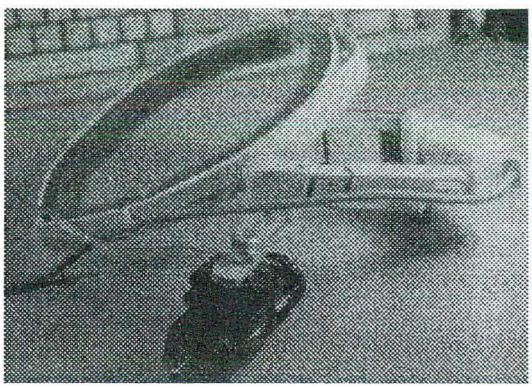

Figure 1 shows the portion of the system that is worn by the user.

DISCUSSION

The system is intended to marry two technologies. It is not the intention of the researchers to create new eye tracking algorithms. Nor is it their intention to develop new language encoding techniques. Both of these areas have sufficient bodies of reliable work to make new studies inappropriate. However, each technology must be modified to accommodate the other.

Eye tracking must be modified to work well in conjunction with a head mounted display. Speech generation systems, on the other hand, must be modified to accommodate the unique

problems of eye tracking interfaces. As an example, eye tracking systems based on how long the user looks at them. At low durations, such as 0.5 seconds, the user can select keys quickly; but will often get unwanted selections when he is just looking around. This is called the "Midas Touch" problem. Speech generation interfaces must be modified to allow users to make fast selections as well as have time to look around. A ballistic system that increases the selection time based on the interval to the last few selections may offer such an avenue.

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The Effect of a User's Search Strategy on Performance with Word Prediction

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Abstract
A previous study demonstrated that word prediction may not significantly enhance text generation rate (Koester and Levine, 1996). In that study, subjects were given explicit instructions on when to search the word prediction list. This paper presents results of a follow-up study, in which subjects were instructed to use the list whenever they felt it would be beneficial. The results concur with the original study in that word prediction only modestly enhanced text generation rate.

Background
The user's search strategy during word prediction use has received little explicit attention as a factor in user performance. Our most recent study focused on conditions under which subjects were given one of two specific strategies for when to search the prediction list (Koester and Levine, 1996). The rule for the "Always-search" strategy was to always search the list before every selection. The rule for the "Two-then-search" strategy was to ignore the list until the first two letters of the word have been selected, and then search the list before every subsequent selection. Word prediction provided no significant enhancement of text generation rate for able-bodied subjects in that study, and it provided significantly slower text generation rate (relative to letters-only typing) for the spinal cord injured subjects.

We attributed these results to the cognitive load required to use the word prediction system. Additional cognitive and perceptual processes mean that each selection takes extra time, relative to letters-only typing, and this extra time offsets the benefit of having fewer selections to make. Mathematically, it can be shown that use of word prediction will only enhance text generation rate if the benefit, measured as keystroke savings, exceeds the cost, measured as the decrease in item selection rate relative to letters-only typing (Koester and Levine, 1994).

Research Questions
One question in interpreting our previous results is whether following prescribed strategies may have hindered subjects' performance with word prediction. Allowing subjects to use a "natural" strategy (i.e., any way the subject thinks best) might yield better performance. This follow-up study addressed the following questions:

1. Are natural strategies more effective than the "Always-search" and "Two-then-search" strategies?
2. Do users who employ natural strategies also experience significant cognitive load with word prediction?

Methods
Research methods for this follow-up study were identical to those employed in a previous study of user performance with word prediction (Koester and Levine, 1996), except that subjects were not given specific rules regarding when to search the prediction list.

Subjects. The "natural strategy" group was comprised of four able-bodied subjects. All shared the following characteristics: at least some college-level education; high familiarity with the standard keyboard; and no significant prior experience with word prediction.

Systems. The "Letters-only" system involved letter-by-letter spelling on a standard computer keyboard, and the "Letters+WP" system used single letter entry augmented by a word prediction feature. A six-word prediction list with a fixed word order was used and presented vertically in the top left corner of the screen.

Experimental Design. Subject performance with and without word prediction was recorded in each of seven test sessions. Subjects used mouthstick typing.

Procedures. The study began with two training sessions, in which subjects practiced using the mouthstick with both systems. Each of the seven test sessions involved four sentences of warm-up using Letters+WP, an eight-sentence test with Letters+WP, then a two-sentence test with letters-only. Unique text blocks were developed for each session based on typing tests, revised to provide specific levels of keystroke savings. The keystroke savings in Sessions 1-4 approximated the level that might be expected with an "average" word prediction system, approximately 42% (Higginbotham, 1992). Session 5 reflects a higher level of keystroke savings (52%), with Sessions 6 and 7 providing successively poorer-than-average levels, at 32% and 22%, respectively. All items selected by subjects were timed and stored by the software in real time.

Dependent Measures. Text generation rate and item selection rate were measured in each session for both systems. Text generation rate was defined as the number of characters generated divided by the total time required to generate those characters. Item selection rate was defined as the number of items selected (including letter and word selections) divided by the total time.

Rate enhancement with word prediction was measured as the percentage improvement in text generation rate with Letters+WP relative to letters-only typing. The time cost associated with word prediction was measured as the percentage decrease in item selection rate with Letters+WP relative to letters-only. The motor benefit associated with word prediction was measured as the percentage of keystrokes saved with Letters+WP relative to letters-only.

Statistical Analyses. Differences in dependent measures for the natural strategy subjects were determined using an ANOVA, with system and session as repeated measures factors. Differences between strategies were assessed by comparing these data to that of the able-bodied subjects from the previous study, using an ANOVA with strategy as the between-subjects factor and session as a repeated measures factor. Statistical significance for each effect was judged at a familywise p-value of 0.05.

Results

Text Generation Rate. Natural strategy subjects' letters-only typing speed averaged 89 characters per minute (cpm) across sessions, while their average text generation rate with word prediction was 91 cpm. Across Sessions 1 - 4, which provided average keystroke savings, the text generation rate with word prediction averaged 5.8% faster than letters-only typing, which was not statistically significant ($p = 0.37$). When keystroke savings were higher than average, in Session 5, word prediction improved text generation rate by an average of 20.0%. Conversely, when keystroke savings were much lower than average, text generation rate with word prediction was 14.6% lower than rate with letters-only typing.

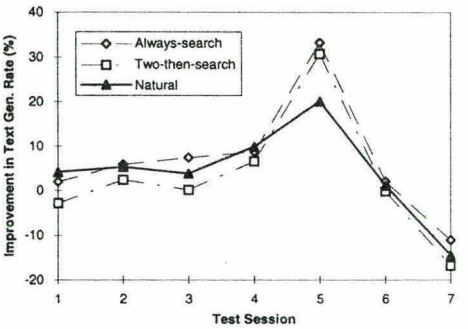

Figure 1. Percent increase in text generation rate with Letters+WP, relative to Letters-only, for each of the three strategy groups.

As shown in Figure 1, text generation performance with word prediction relative to letters-only typing was very similar for all three groups, averaging 4.4%, suggesting that none of the three strategies had a significant advantage ($p = 0.82$).

Item Selection Rate. Item selection rate for natural strategy subjects was 31% slower with word prediction as compared to letters-only typing (significant at $p = 0.002$). As shown in Figure 2, the cost in item selection rate was lowest for the "Two-then-search" strategy, followed by the "Natural" strategy, with the highest cost for the "Always-search" strategy. However, there was no statistically significant difference between the three groups ($p = 0.23$).

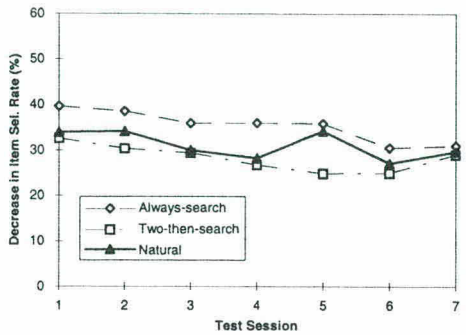

Figure 2. Percent decrease in item selection rate with Letters+WP, relative to Letters-only, for each of the three strategy groups.

Keystroke Savings. Figure 3 shows the average keystroke savings achieved by each of the three groups during use of word prediction, with a significant difference between the groups ($p = 0.001$). Subjects who used the "Always-search" strategy generally achieved close to the maximum possible keystroke savings, as would be expected. Subjects who used "Two-then-search" had a significantly lower keystroke savings, since ignoring the list for the first two letters of every word caused them to miss some early predictions. The natural strategy subjects fell in-between, suggesting that their search strategies were more effective than "Two-then-search" but not effective enough to gain the maximum keystroke savings.

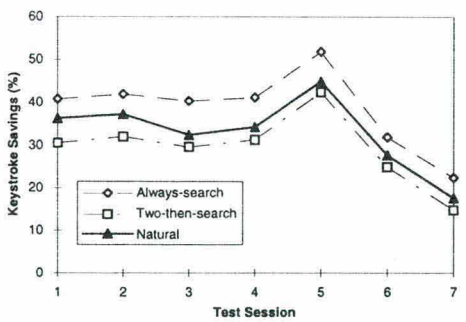

Figure 3. Percent of keystrokes saved with Letters+WP, relative to Letters-only, for each of the three strategy groups.

Discussion

The results provide another demonstration of how increased cognitive and perceptual loads can impact user performance with word prediction. Natural strategy subjects "broke even" with word prediction because the added cost of using the system, averaging 31%, was roughly equivalent to the keystroke savings these subjects achieved, averaging 33%. By following their own rules, natural strategy subjects did have a lower time cost than the "Always-search" subjects. But since the natural strategy subjects did not succeed in finding each word on its first occurrence, keystroke savings suffered.

Among the limitations of this study, the relatively short time course is one of the most significant. It's possible that natural strategies would develop an advantage over time, as the user became familiar with the system's prediction style, although we didn't see a trend in that direction in these subjects.

Conclusions

Word prediction exacts a cognitive load, whether a user follows a prescribed strategy or one of his or her own devising. None of the three strategies tested emerged as being clearly preferable, at least for the able-bodied subjects tested. The choice of the optimal search strategy continues to depend on the specific characteristics of the user.

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SIG-05
Quantitative Functional Assessment

EFFECT OF CERVICAL ORTHOSIS ON NECK MOTION DURING ACTIVITIES OF DAILY LIVING: MEASUREMENT METHOD AND COMPARISON TO VOLUNTARY RANGE OF MOTION

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BACKGROUND

Recommendations about cervical orthosis use are largely based upon the effect of orthoses on neck motion. This has been the topic of a number of studies, which have used a variety of measurement techniques, however the motion assessed has almost always been that of voluntary range of motion (VROM). We hypothesized that 1) motions during activities of daily living (MADL) are different than VROM and 2) comparisons between orthoses based on MADL would yield quite different results than those based on VROM. The specific aims of this project were 1) to develop a method for measuring MADL and 2) to compare commonly used orthoses based both on VROM and MADL.

RESEARCH DESIGN & METHODS

Three-dimensional neck motion was analyzed using the Flock of Birds device (Ascension Tech., Burlington, VT). It consists of an electromagnetic field transmitter and two independent inductive receivers. The 3D position and orientation of each receiver relative to the transmitter is tracked at 2 Hz. The receivers were mounted to each subject, one by a stiff head-band to the top of the head, and the other by a chest harness to the thorax. The transmitter was located on an adjustable tripod within 1 meter of the receivers. To avoid distortion of the electromagnetic field, orthoses containing only non-ferromagnetic material were used. The accuracy of the device has been previously demonstrated to be 0.1 degrees RMS in rotation and 0.01 inch RMS in translation.

Ten male subjects without neck pain or previous neck trauma were recruited. The receivers were mounted and three trials were performed. First, VROMs without a collar were determined by having the subjects produce maximal flexion/extension, lateral bending, and axial rotation. The last two tasks were performed only to the right side, as we assumed that right and left cervical spine motions were symmetric in normal subjects. These motions were then repeated with the subjects wearing each orthosis in random order. The orthoses were the soft collar, Philadelphia (Philadelphia Collar Co.), Miami J (Jerome Medical), & Aspen (International Healthcare Devices) orthoses. Then, MADLs were measured for each subject wearing each orthosis. The ADLs were: going from a sitting to a standing position [ADL1], coughing [ADL2], picking up an object off the floor [ADL3], twisting [ADL4], drinking [ADL5], a yes-no response [ADL6], and yawning [ADL7].

Right-handed coordinate systems at the center of the head and at the T12 level were defined by digitizing bony landmarks using a third receiver mounted to a stylus. Neck motion was calculated, with appropriate transformations, as the difference at each time point between head and thorax position and orientation. A range of motion was defined for each VROM and each MADL as the difference between the maximum and minimum angles occurring throughout the performance of the task. The data were analyzed with an analysis of variance (ANOVA) followed by post-hoc Fisher's corrected t-test.

RESULTS

The VROM results are shown for all three tasks in Table 1. Only the primary rotational component results are shown. The MADL results for all seven tasks are shown in Table 2. Only the flex/ext rotational component results are shown. Lateral bending and axial rotation component results were similar.

Table 1 **VROM**: mean (std.dev.) in degrees

	Flex/Ext	Lat.Bending	Ax.Rotation
No orthosis	113.4 (16)	57.9 (13)	83.0 (13)
Soft	91.0 (17)	50.3 (10)	77.1 (12)
Aspen	64.0 (21) #	44.7 (10)	51.2 (15) #
Miami J	56.3 (19) #	36.1 (11) #	36.0 (13) # %
Phila.	53.7 (17) #	33.7 (11) #	42.7 (14) #

Table 2 **MADL**: mean (std.dev.) in degrees

	soft	Aspen	Miami J	Phila.
ADL 1	75.6 (18)	80.5 (27)	85.3 (30)	82.7 (28)
ADL 2	15.0 (12)	18.3 (14)	13.0 (7)	17.1 (9)
ADL 3	85.3 (21)*	87.3 (24)*	88.3 (24)*	84.4 (24)*
ADL 4	22.9 (10)	25.4 (11)	25.5 (11)	23.3 (11)
ADL 5	41.7 (20)	39.3 (18)	34.2 (16)	36.5 (15)
ADL 6	33.8 (17)	26.8 (13)	21.8 (16)	24.0 (15)
ADL 7	30.6 (14)	29.4 (15)	28.0 (12)	29.3 (12)

* = not significantly different than no orthosis
\# = significantly different than Soft collar
% = sifnificantly different than Aspen
Note: significance = $p < .05$

For VROMs all orthoses produced significant motion reduction compared to no orthosis (except lateral bend and axial rotation with the soft collar) and the more rigid orthoses (Aspen, Miami J & Phila. collars) were significantly better at restricting motion than was the soft collar (except for the Aspen in lateral bend). Also, the Phila. & Miami J orthoses were significantly better in limiting lateral bending than was the Aspen orthosis and the Miami J was significantly better in limiting axial rotation than was the Aspen or Philadelphia.

MADL results were similar to VROM results in that both showed significant motion reduction by each orthosis compared to no orthosis, for each ADL except #3. However, MADL results were quite different then VROM results in terms of inter-orthosis comparisons. No significant differences were present between any of the orthoses, for any of the 7 ADLs, as assessed by MADLs.

DISCUSSION

As expected, it was proven that the orthoses provided a reduction in rotational motion for VROMs. The soft collar was the least effective at this. It was found that these rotational ranges of motion were much smaller for the MADLs compared to the VROMs, except for picking up an object off the floor. There were no significant differences in the effect of the orthoses for these reduced motions. This suggests that differences between all these cervical orthoses, in terms of motion restriction during actual day-to-day activities, may be negligible.

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CRANIAL PIN FORCE MEASUREMENT IN A HALO-VEST ORTHOSIS

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ABSTRACT

This study was designed to measure forces at the pin-cranium interface *in vivo* at various times during 3 months of halo-vest wear. A strain gaged halo was used to measure the forces on the posterior pins of a commercially available halo-vest system. The device was applied to 3 patients with cervical spine fractures. At the time of halo application, the mean compressive force in the pins was 330 (±91.5) N. Over the halo-vest wear period, the mean force significantly dropped by 81%.

BACKGROUND

Halo-vest orthosis

The halo-vest is an orthosis that is commonly used to immobilize and protect the cervical spine of patients with cervical spine trauma, with or without associated spinal cord injury.

The halo is an open or closed ring that surrounds the head, and is securely attached to it by means of 4 sharp tipped pins which are threaded through the halo to engage the outer cortex of the cranium. In order to immobilize the neck, rigid uprights attach the halo to a plastic vest that grips the torso. Thus, loads applied to the halo are shared between the neck and the halo-vest system.

Halo-vest complications

The principle problems associated with current halo-vest orthoses are cranial pin loosening, loss of vertebral alignment, infection, forehead scarring and the formation of pressure sores. It is generally thought that these problems are mechanically induced. The most serious and frequent problem encountered is cranial pin loosening[1]. Loss of fixation at the pin-cranium interface causes pain and may lead to infection or catastrophic loss of vertebral alignment. Clinical studies report incidences of pin loosening ranging between 12 to 100%[3,4]. Whitesides and others[1,5] have shown a large variation between the torque applied to the pin and the forces at the cadaveric pin-cranium interface. Presently, the pin force history remains unknown.

The objectives of this study were: 1) to develop the instrumentation required to document halo-pin forces, 2) to determine the magnitude of the pin forces at the time of application, and 3) to determine the extent of pin force reduction over the standard three month treatment period.

RESEARCH QUESTIONS

1) What forces are applied to the pin-cranium interface during halo-vest application?

2) How do the pin-cranium forces (upon which halo attachment depends) change over time?

METHOD

Instrumented Halo-vest

The halo-vest used in this study (AME, Inc. Richardson, TX) consisted of an open ring halo (horse shoe shaped, open in back) connected to a 4-pad vest via four uprights that engage lateral connectors on the halo (Figure 1). The 4-pad vest contacts the torso at the sternum, the interscapular region, and each side

of the lateral trunk along the mid-axillary line[2].

The pin engaged the outer cortex of the cranium via a sharp point. Thus, moments were not transmitted across the pin-cranium interface and only the three force components needed to be considered. Since the halo ring was open, the segments of the halo between the "rigid" lateral connectors and the posterior pin insertion sites acted as cantilever beams in response to pin loads.

Forces applied to the tips of the pins would produce either mediolateral (M-L) or superior-inferior (S-I) bending moments in the posterior cantilever halo segments. A shear force applied along the S-I axis produced an S-I bending moment. A compressive force and/or an anteroposterior (A-P) shear force produced M-L bending moments. However, the moment arm of the A-P shear force with respect to the connector site was relatively small compared to the compressive force. Also, the magnitude of the A-P shear force has been shown to be substantially less that the compressive force[5]. Thus, we assumed that the bending moment due to the A-P force component was negligible.

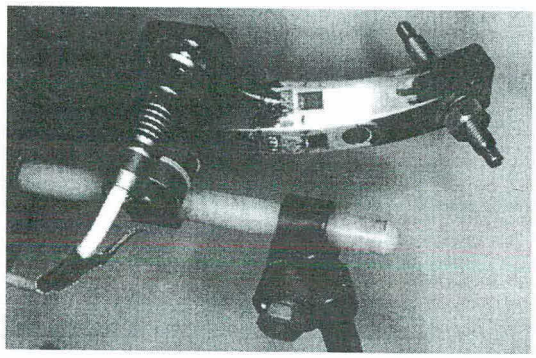
Clinical Investigation

The instrumented halos were applied to 3 patients who presented with cervical spine fractures (1 hangman's and 2 odontoid type II fractures). All patients were male with ages ranging between 18 and 48 years. The halo strains produced by the posterior pin forces were monitored during the pin tightening procedure, performed with the patient supine. Each pin was tightened to a torque of 0.68 N-m (6 in-lbs) using a torque wrench. After 24 hours, the pins were retightened to the same torque. Pin force measurements were taken during the retightening procedure with the patient in the same supine position. At each subsequent follow-up visit (1, 2, 4, 6, 8, and 12 weeks), the patient was placed in the supine position, the transducers were plugged into the data acquisition system, and the pin forces were measured in the same manner.

Statistical analysis

The pin force components at the time of retightening were compared to the forces at the time of halo removal using one-tailed paired t-test.

Figure 1: Posterior aspect of the strain gaged halo.



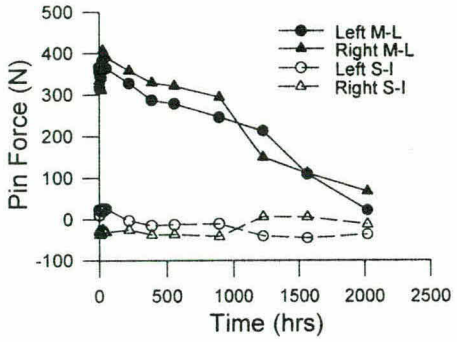
RESULTS

The mean compressive force at the pin tips immediately following the retightening procedure was 330 (±91.5) N. The compressive force was substantially greater than the mean S-I shear force value of -5.8 (±24.2) N. There was a steady decrease in the compressive force component at the pin tip with respect to time of halo-vest wear. On average the force dropped to 61 (±101) N, a significant reduction of 81% ($p = 0.002$).

Of the 3 cervical spine fractures that were treated in this study, two successfully healed within 12 weeks (Subject #1, hangman's; #3, Odontoid). The other subject (#2, Odontoid) elected surgical fixation because healing had not occurred after 11 weeks of halo-vest wear. All three subjects experienced pin loosening to some extent. Subjects #1 and #2 noted a slight clicking sensation with attempted neck motion at 11 to 12 weeks.

attempted neck motion at 11 to 12 weeks. Subject #3 had loss of fixation at 7 weeks. In all three cases, substantial pin force reductions had gradually developed before pin loosening was noted by the subject.

Figure 2: Pin force vs time for Subject #1 in a supine position.



DISCUSSION

No previous report appears to have been published concerning the forces between the pin and the cranium, *in vivo*. The mean compressive pin force of 330 N was similar to that reported by others using *in vitro* models[1,5]. The compressive forces were significantly greater than the corresponding shear forces at the time of initial halo application. The results of this study confirm the hypothesized decrease in pin compressive force over time. However, there was no change in the shear force magnitude over time. These results are consistent with previous clinical findings of pin loosening as a common complication to halo-vest wear.

The instrumentation developed for this study permitted us to measure the S-I shear forces independently of other forces. However, the A-P shear forces were coupled with the compressive forces. We assumed that the A-P shear forces were negligible. Considering the magnitude of the S-I shear forces as small, and that the A-P shear forces are most likely similar in magnitude, this assumption seems reasonable.

The cause of pin loosening remains unknown. Considering that the pin force is supported by the skull and acts through the very small cross-sectional area of the pin tip, we hypothesize that the resulting high stresses in the bone may cause bone resorption at the pin tip site. Further work is required to determine the cause of pin tip loosening and how it may be prevented.

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A DYNAMIC PERFORMANCE EVALUATION OF A 3-AXIS ELECTROGONIOMETER

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ABSTRACT

The dynamic performance of a three-axis electrogoniometer (Backtracker) was measured by comparing the Backtracker to incremental optical encoders acting as the calibration gauges for this study. Seven types of movements were recorded in three directions: flexion/extension, lateral bending, and rotation. The seven trials consisted of each individual motion (3 trials), combinations of each motion (3 trials), and all three axes moving at once. Results from this study are currently being processed.

BACKGROUND

Approximately ten years ago, the Backtracker was developed to facilitate the measurement and collection of trunk angle in three directions: flexion and extension, lateral bending, and axial rotation. At that time, the Backtracker output was validated through comparison of two other measurement methods - a hand-held clinical goniometer and planar photography. However, the dynamic performance of the Backtracker was not analyzed, only static measurements and comparisons were made (Beynnon, 1986).

Thus, the specific aim of this project was to evaluate the Backtracker's dynamic characteristics by comparing the goniometer to optical encoders acting as rotational transducer calibration gauges.

STATEMENT of the PROBLEM

The objective of this study was to evaluate the dynamic performance of a three dimensional electrogoniometer called the Backtracker. The Backtracker has been tested in static positions, but its dynamic capabilities have not been assessed. Therefore, to obtain the accuracy of the Backtracker's dynamic performance, the device was tested by comparing it to three optical encoders acting as rotational transducer calibration gauges (one for each rotational direction).

RATIONALE

Back posture and motion is widely considered to be an important factor in low back pain cause and rehabilitation. Factors such as trunk strength, position, velocity, and acceleration can also put the back at risk (Marras, 1992). Many studies have found back pain caused by awkward postures and/or movements (Hildebrandt, 1995; Lee & Chiou, 1995). Snook identified high risk jobs where low back pain was found to be prevalent in many industrial settings (Snook, 1982).

A tool which can perform an objective assessment of trunk motion would be an important contribution in facilitating the study and understanding of low back pain. In addition, the capacity of the tool to measure all three rotation components (flexion/extension, lateral bending, rotation) and to record information continuously would be crucial, since various users may be interested in studying different motions. Another consideration in the design of such goniometric tools would be the accuracy in depicting the range of motion measured in each axis of rotation. For example, trunk flexion/extension

has the most range of motion and can be roughly measured, but tasks which involve torsion and lateral bending movements contain less range of motion yet still require an accurate representation of movement.

When considering industrial settings, goniometers can be used to measure total range of motion throughout a work period or identify peak movements and/or extreme positions of the trunk. Analysis of both kinds of movement can help in targeting sources of low back pain. Subsequently, different jobs may require different types of analysis. Examples of applications requiring different methods of analysis include carpenters working in overhead postures, manual material handlers working asymmetrically, and agricultural workers performing tasks in stooped postures. Trunk motion in all of these jobs can be studied using a goniometer but the method of analysis depends on the tasks involved.

APPARATUS

The equipment used in the study consisted of a calibration jig upon which the calibration gauges and the Backtracker were mounted and a PC which received the calibration gauge and Backtracker information via a data acquisition board.

The calibration jig was built by Isotechnologies, Inc. Four metal bars were used as the support for the three rotation gimbal. This device was constructed using three axes of rotation which intersected at one point (see Figure 1). From the neutral position (as seen in Figure 1), the jig allowed for approximately 100 degrees of flexion/extension, 160 degrees of total lateral bending (80 in either direction), and 360 degrees of rotation.

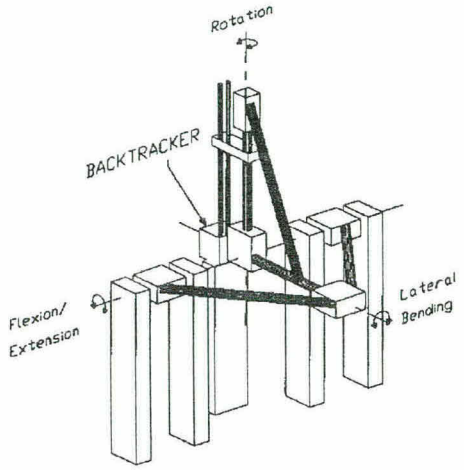

Figure 1.

The Backtracker was attached in two places. The base was fastened to a wooden board attached to the support structure and the slider was attached to the rotational axis of the jig. The attachment points were chosen to best resemble typical placement of the Backtracker on a human subject - the base at the sacrum and the slider at the mid-thoracic region of the spine. Once the Backtracker was fastened to the jig, the combined range of motion was reduced to 60 degrees of flexion/extension, 130 degrees of lateral bending, and 180 degrees of rotation (due to the physical limitations of the Backtracker construction). However, this reduction in range of motion still exceeds typical human spine motion.

Three rotational transducers (incremental optical encoders) were the instruments used as calibration gauges. The gauges were BEI L25G incremental optical encoders with 1024 cycles per turn and a supply voltage of 5 volts. The output channels were dual quadrature including an index.

EVALUATION

The protocol used in this study consisted of a simple calibration routine and then seven trials. Calibration was performed before each trial. The jig was placed in a neutral position, allowing the gauges (optical encoders) and Backtracker (potentiometers) to be recorded in a "home" state. The seven types of trials examined were flexion, lateral bending, rotation, combinations of each axis of rotation, and a final trial of all three rotations together. Trials were performed manually - the jig was moved back and forth in the desired direction/rotation for approximately 15 seconds. Each trial was repeated three times to ensure clean data collection.

DATA COLLECTION

Data were collected using an A/D board connected to a 486 personal computer. The software interface used a visual real-time display of the output signal from the Backtracker and the optical encoders. In addition, data was stored in binary files for further statistical analysis. The Backtracker output was a voltage reading (±5 volts) while the optical encoder output was a numerical reading in number of revolutions. The Backtracker reading was converted to a "true" spinal angle through a computer algorithm developed by Isotechnologies, Inc. Essentially, the program considers the spatial relationship between the Backtracker and the spine and converts the Backtracker potentiometer data to what would be the "true" spinal angles.

DISCUSSION

The results of this study are currently being analyzed. From the results, however, the similarities and/or differences between the Backtracker and the optical encoders will be discussed. In addition, the relevance of the results in "real-world" conditions will also be discussed.

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DESIGN OF A LIFTING ASSESSMENT TOOL

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ABSTRACT

This paper contains the specifics of the design of a lifting assessment tool. Lifting has long been associated with low back pain and associated disabilities. Acceleration and jerk of the lifted load are important characteristics of lifting. Many studies have made connections between these characteristics and lower back pain. With a device that can evaluate the characteristics of an individual's lifting technique, disability and lower back pain caused by lifting may be reduced or prevented.

BACKGROUND

Lifting is considered one of the major factors that contribute to low back pain disability (LBPD), and has been the focus of considerable research over the last two decades (5,6). The hypothesized cause of lifting induced LBPD is both through cumulative trauma and a single overexertion (8). It is suspected that the LBPD associated with lifting may be related to lifting technique, however a consensus on correct lifting technique has not yet been reached, either among the biomechanics researchers or the experienced professional material handlers (1,4,7).

Why some individuals perform lifting tasks for years without having a problem with LBPD while others who may have been engaged in lifting activities for only a brief time do experience LBPD, is an interesting question that motivates this research. Many models explaining the mechanisms of back injury have been proposed but by far the most widely discussed theory is that compressive loads in the lumbar spine correlate with injuries (2). Modeling compressive loads in the spine has received considerable attention over the last two decades with perhaps the most well-known model emerging from the University of Michigan: the "Two Dimensional Static Strength Prediction Model" (2). The initial models for these loads were based on static loading, but over the last few years dynamic models have also been introduced. Many researchers believe that it is dynamic loading that is the cause of the majority of the injuries resulting in LBPD (3).

When risk factors for back injuries in dynamic lifting are discussed, it is often suggested that lifting be done smoothly, and jerking be avoided (1,5). Smoothness can mean keeping acceleration changes to a minimum, and jerking in the generic sense refers to sudden accelerations. The engineering definition of "jerk" is the time derivative of the acceleration vector (da/dt).

STATEMENT of the PROBLEM

The goal of this development effort is to design, build, and test a device that can be used to evaluate an individual's lifting technique. This device could be used in a worker evaluation or training situation to reduce or prevent LBPD.

RATIONALE

A preliminary study identified the variables that can be used to differentiate between lifting

techniques based on the measurement of acceleration and jerk of the lifted material with a liftbox (9). The dependent variables include duration of the lift, initial peak jerk, initial peak acceleration, jerk-cost, mean squared jerk and other discernible characteristics of the acceleration magnitude trace.

The work presented here is a continuation of the design, development, and testing of the liftbox lifting assessment concept.

DESIGN

The apparatus of the current liftbox consists of a 1 foot (0.3 m) cube of plywood instrumented with a three-axis accelerometer. The accelerometer is connected to a PC through an A/D board. The acceleration signal is acquired on the PC through LabVIEW (National Instruments), a graphical programming software package for instrumentation.

The liftbox measures an acceleration trace in each of the principal directions at a sampling rate of 100 Hz for a duration of 5 seconds during each lift. From the acceleration trace a numerical differentiation algorithm is applied to obtain a jerk trace in each principal direction.

The apparatus has been tested to ensure that the acceleration signal is accurately representative and the jerk algorithm has also been tested and is working correctly.

From the acceleration and jerk trace of an individual's lift a number of statistics are gathered and used to describe the individual's lifting technique.

DEVELOPMENT

The current liftbox is still being tested to determine the most useful statistics to gather from the acceleration and jerk traces. The statistics being gathered are being tested to establish the dependence on an individual's lifting style, and on the task.

Once the method of analyzing the acceleration and jerk traces is verified, the next stage of development for the liftbox would be a better packaging. The accelerometer and accompanying electronics could be packaged in a smaller box that could be attached to a variety of different objects that are being lifted in the workplace. This would extend the application of this technology, to multiple realistic on-the-job lifting situations.

EVALUATION

A pilot study is currently underway to evaluate the use of the liftbox in identifying different lifting techniques based on the acceleration and jerk traces.

A group of three subjects will complete ten repetitions of each of three different lifting tasks. The lifts have been chosen to reflect lifts that are completed in the work place.

The goal of this pilot study is to test for inter and intra subject variability. A very useful outcome would be if the device showed low intra-subject variability and high inter-subject variability of the measured statistics.

DISCUSSION

The prototype liftbox is complete and the pilot study is nearing completion. With the conclusion of the pilot study the method of analyzing the acceleration and jerk traces will be solidified.

Following the completion of the pilot study a larger scale (larger sample population) experiment will be conducted to add power to the experimental results.

With a device that can distinguish the lifting technique of different individuals, various hypotheses can be tested to determine which techniques can be associated with LBPD.

Knowing what lifting techniques are associated with LBPD, worker training and workplace evaluation could be conducted to

decrease the incidence of LBPD.

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THE DEVELOPMENT OF MEASUREMENT TOOLS FOR HAND STRENGTH ASSESSMENT

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ABSTRACT

Existing devices designed to assess upper limb strength are unable to measure the extensor strength of wrists, forearms, or specific digits. The purpose of this study was to develop devices suitable for clinical use that would provide comprehensive assessment of forearm, wrist, hand and finger strength. Four devices were developed to measure strength in; 1) flexion and extension at the metacarpal-phalangeal (MCP) and proximal interphalangeal (PIP) joints, 2) precision hand grip strength, 3) wrist flexion and extension, 4) radial and ulnar deviation, and 5) forearm pronation and supination. The devices were evaluated by 28 wheelchair users and 14 able-bodied individuals in order to determine the validity and reliability of the tools.

BACKGROUND

Overuse injuries, such as Carpal Tunnel Syndrome, affect up to 65% of wheelchair users . Since hand function is essential to the independence of wheelchair users, overuse injuries are more frequent than for able-bodied individuals[1] or crutch and cane users [2]. For this population, the resulting discomfort and loss of function are a significant cause of secondary disability since the upper limbs must be used continuously to perform mobility and self-care activities. Existing devices for the assessment of upper limb strength (e.g. handgrip and pinch dynamometers) are unable to assess extensor strength, wrist and forearm strength or specific digits or joints, either alone or in combination. As a result, they provide only gross overall measures of handgrip and pinch strength. Although the hand strength assessment devices developed in this project could be used to assess the hand strength of any user group, the focus of this research was on wheelchair users.

STATEMENT of the PROBLEM

Tools currently available to measure wrist, hand, and finger strength are either not comprehensive or not practical for clinical use. There is a lack of information regarding the strength of specific muscle groups of the hand and wrist, the strength required for specific tasks such as wheelchair propulsion, and the effects of imbalance of the agonist and antagonist muscles in these areas. Without quantifiable data it is difficult to assess problems and select appropriate strength training and injury prevention programs. It is also difficult to evaluate the relationship between hand strength and the risk of cumulative trauma disorders (CTDs).

RATIONALE

Strength measuring tools assist clinicians in making treatment decisions. In a clinical setting, hand strength can be measured to document a baseline, set specific goals, and monitor progression of an exercise program. Tools measuring strength of agonist and antagonist muscles, can obtained more information regarding strength imbalances and other possible contributors to CTDs.

DESIGN and DEVELOPMENT

Pilot work completed prior to this study provided early prototypes to further develop the concepts. The prototype designs were revised based on feedback received and model prototypes were created. The model prototypes were again tested and further modifications to the design were made. The design reviews indicated that incorporating all measurement functions within one device would involve extremely complex designs and the set up and evaluation time would limit the efficient use in a clinical setting. Therefore, the two prototypes developed during the pilot phase of the project were streamlined to simplify their use. Two additional devices were designed to assess

multi-finger and wrist and forearm strength. Design criteria included: 1) secure body segments just proximal to the joint being measured without causing discomfort, 2) avoid tissue pinching between moving parts, 3) achieve adjustment ranges to include both large and small hands, and 4) firmly stabilize finger segments without causing discomfort or loss of circulation.

Four functional devices were developed: 1) Hand Strength Assessment Device (HSAD) – isolated a single joint of one digit (fingers or thumb) to measure flexion or extension at the (MCP) or (PIP) joints; 2) Pushrim Grip Assessment Device (PGAD) – measured precision hand grip strength applied to a wheelchair pushrim; 3) Wrist Strength Assessment Device (WSAD) – quantified wrist flexion, extension, radial and ulnar deviation, forearm pronation and supination strength; 4) Multi-Finger Assessment Device (MFAD) – measures the combined force of all fingers in flexion or extension at either the (MCP) or (PIP) joints.

The HSAD (Hand Strength Assessment Device) consists of a platform, an electronic force gauge, and a forearm/hand support. The forearm is secured at 45 degrees to the axis of the force gauge. The proximal segment of the digit being measured is immobilized. The segment distal to the joint being measured is secured to the force gauge. The force gauge measures tension and compression recorded as flexion and extension, respectively.

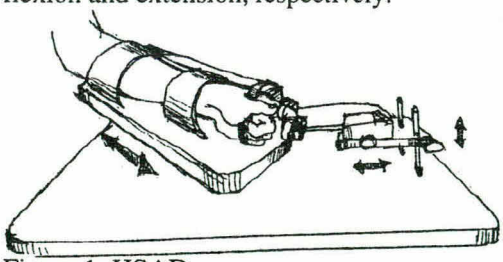

Figure 1. HSAD

The PGAD (Pushrim Grip Assessment Device) consists of a liquid filled, rubber tube which follows the arc of and is attached to a wheelchair pushrim. A pressure gauge is attached to the tube and reads the pressure as the person squeezes the tube. A rigid tube inside the rubber tube prevents the person from twisting or otherwise distorting the tube in a manner inconsistent with his or her usual pushrim grip style.



Figure 2. PGAD

The WSAD (Wrist Strength Assessment Device) consists of a torque wrench attached to a platform. A forearm support rests on the platform. Three interchangeable handles snap onto the torque wrench to allow for measurement of: a) flexion and extension of the wrist, b) ulnar and radial deviation of the wrist, and c) pronation and supination of the forearm. The forearm is secured in the forearm support except during pronation and supination of the forearm, as confinement during these movements would limit performance.

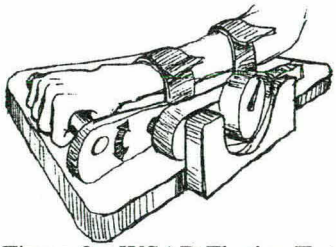

Figure 3a. WSAD Flexion/Extension

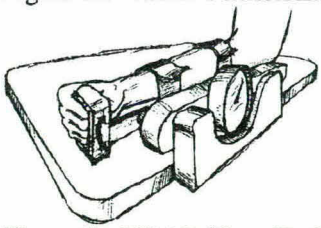

Figure 3b. WSAD Ulnar/Radial Deviation

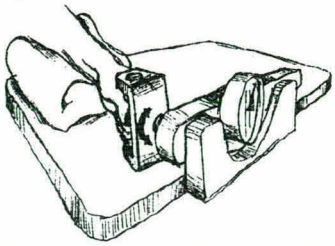

Figure 3c. WSAD Pronation/Supination

The MFAD (Multi-Finger Assessment Device) is an articulating plastic shell worn on the forearm and hand like a glove. A torque wrench attached to the side measures the combined force of all fingers in flexion or extension at either the (MCP) or (PIP) joints.

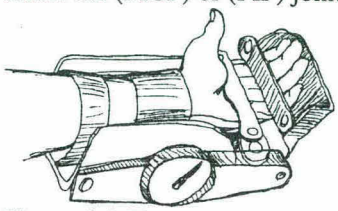

Figure 4. MFAD

EVALUATION

The devices were evaluated with 28 wheelchair users and 14 able-bodied individuals. Twenty-seven people completed evaluation of each of the four devices. Subjects were recruited to complete evaluation of two existing devices (handgrip and pinch dynamometers) and the four prototypes developed in order to establish the validity of the prototype measurements. Subjects who used manual wheelchairs were recruited initially and then gender and age (± 5 yrs) matched controls without disabilities were selectively recruited. Informed consent was obtained from each subject prior to study participation. Subjects were requested, but not required, to complete two sets of trials in order to evaluate the test-retest and intra-rater reliability of the devices. The second set of trials was completed after a rest period of at least 30 minutes or on a subsequent day to minimize the cumulative effects of muscle fatigue. The order of device testing was the same for each trial.

DISCUSSION

Four measurement devices have been developed to assess the isometric strength of the upper limb. The devices provide a comprehensive assessment of agonist and antagonist movements of the forearm, wrist, hand and fingers. Measurements obtained with the PGAD, MFAD and WSAD were found to be valid and reliable. Measurements of individual joints were also reliable but did not consistently correlate with existing measures of hand strength. Additional research is therefore required to establish the validity of strength measures of individual finger joints. The time required to complete the measurements is suitable for a clinical setting (30 minutes for the HSAD, 15 minutes or less for all other devices). This evaluation identified additional design changes to optimize user comfort and expand the range of hand/arm sizes which can be accommodated. Future work will include further subject testing to evaluate the impact of subject characteristics (e.g. wheelchair use, overuse injury symptoms) on the strength measures obtained.

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QUEBEC USER EVALUATION OF SATISFACTION WITH ASSISTIVE TECHNOLOGY (QUEST): A NEW OUTCOME MEASURE

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ABSTRACT

The need for meaningful and reliable outcome measures of assistive technology (AT) has become of foremost importance to all stake holders of the service delivery system. The purpose of this paper is to present and demonstrate an assessment tool that evaluators can use to determine user satisfaction with AT. The *Quebec User Evaluation with assistive Technology (QUEST)* is administered during a semi-structured interview and requires that the user perform two specific tasks. The assessment material is contained in a compact portfolio and has been designed so that it can be administered to persons with limited motor and/or sensory skills. In our search for a useful outcome tool, QUEST aims at reflecting a consumer-responsive and client-centered approach.

BACKGROUND

In Canada and the United States, the rapid expansion of assistive technology (AT) products and services has resulted in an increase in the number of assistive devices that are prescribed and attributed to persons with a disability. In 1990, more than 13.2 million people in the United States used assistive technologies (Scherer & Calvin, 1996). In the province of Quebec, monies spent on AT are reflective of the importance accorded to this sector of health services; with a population of approximately seven million, 240 million US dollars was spent on products and services in 1990 (Office des personnes handicapées du Québec, 1993).

Confronting the issue of cost containment is a challenge for all stake holders of the service delivery system of AT. In this context, the impact of assistive devices on home accessibility, quality of life and functional independence is currently being addressed by consumers, clinicians and researchers in the field (DeRuyter, 1995; Forest, 1996). It is only recently that insurers and payers are requesting outcomes data, that is facts and particulars on AT use, performance and efficacy in order to justify and explain the monies expended. Consequently, the need for meaningful and reliable measures of AT has become of foremost importance to all stake holders.

Among the variables that can be used as an outcome measurement is the user's satisfaction with his or her assistive device; the consumer's perspective is based on personal experience and as such provides a unique and expert viewpoint. Indeed, information on use, avoidance and abandonment of AT can best be disclosed by those persons for whom the devices were designed; these persons are the users and consumers of AT and their opinion needs to be solicited, evaluated and considered.

In the last five years, there has been a growing number of publications that focus on user satisfaction and as such it is becoming a contemporary area of study (Carr-Hill, 1992; McComas, Kesseim & Macintosh, 1995; Vuori, 1991)

STATEMENT of the PROBLEM

In order to ensure objective assessment of the effectiveness and efficiency of an AT program, it is necessary to obtain consumer-responsive outcome measures. Although various studies over the past 10 years have addressed the issue of consumer perception of

assistive devices, AT providers and researchers have not used a standardized assessment instrument to evaluate user satisfaction with AT. The purpose of the present study was to develop an assessment tool that would provide evaluators with the capacity to determine user satisfaction with AT; the instrument developed is referred to as QUEST, the Quebec User Evaluation of Satisfaction with assistive Technology.

RATIONALE

The concept of satisfaction is a complex phenomenon and as such is difficult to define. Based on a thorough review of the literature on satisfaction, the concept of satisfaction as defined in QUEST refers to a person's positive or negative evaluation of those distinct dimensions of the assistive device that are influenced by one's expectations, perceptions, attitudes and personal standards. This definition originates and is supported by two key principles derived from the analysis of the literature. The first is the multidimensional aspect of satisfaction; the characteristics of the AT device, the characteristics of the person's milieu (environment and psychosocial setting) and the characteristics of the individual define those variables most likely to influence user opinion (Scherer, 1996). The second principle is the arbitrary and subjective nature of satisfaction. Accordingly, the relative importance of each variable needs to be determined in order to correctly interpret the satisfaction data.

DESIGN

The objectives of QUEST are threefold: 1) to define the context in which user satisfaction or dissatisfaction with AT developed; 2) to determine the degree of importance the user ascribes to each of the satisfaction variables; 3) to assess the degree of satisfaction the user attributes to each of the variables and his/her global satisfaction with the device.

QUEST consists of two parts. The first part serves to record general information describing and explaining the context in which the consumer acquired and experienced his/her device. The questions address characteristics of the user (such as functional capabilities), characteristics of the environment (such as funding source for AT) and the AT device itself (such as frequency of use). The second part focuses on the assessment of the satisfaction variables. In this last version of QUEST, a set of 20 criteria represent de factors most likely to influence user satisfaction. Among these variables, 14 describe characteristics of the AT device whereas the remaining six items refer to environmental and personal influences.

The administration of QUEST requires that the user perform two specific tasks using the assessment material. Firstly, the person is asked to indicate the degree of importance he/she attributes to each of the 20 satisfaction variables. For this purpose, each variable is presented to the user on a small card (similar to a deck of playing cards) and the person is asked to sort the cards according to a five level scale of importance (with 1 *being not important at all* and 5 being *very satisfied*). Secondly, the person is asked to rate his/her satisfaction with the variables (n=14) that characterize the AT device; once again a five point scale (with 1 being *not at all satisfied* and 5 being *very satisfied*) is used to measure consumer satisfaction. Approximately 35 minutes is required to administer QUEST in its entirety.

The assessment form, instruction sheet and sorting cards are conveniently contained in the QUEST portfolio. Although it was originally developed in French, the English version of QUEST will soon be available.

DEVELOPMENT & EVALUATION

Development of QUEST is an ongoing process. Previous work concentrated on

establishing a theoretical framework, elaborating prototypes, pilot testing the first version of QUEST and subsequent revisions of the assessment tool. The psychometrics qualities of the instrument are currently being tested with various types of AT and with different user groups. Reliability studies are underway using test retest, inter-rater and internal consistency strategies Data supporting the conceptual framework of multidimensionality and subjectivity of satisfaction with AT will be used to validate QUEST. This approach of construct validity will be best served by a principal components analysis.

DISCUSSION

The present version of QUEST offers the evaluator with a compact assessment tool. The attractive portfolio containing all the testing material is easy for the interviewer to transport and administer in the natural milieu of the consumer. The evaluator can easily engage the user's participation because of the interactive and stress free nature of QUEST. Its design is such that is can be administered to persons with limited motor and/or sensory skills but not to persons with cognitive impairments.

In conclusion, assessment of outcomes of assistive technology is a challenge and a responsibility for all AT providers. In our attempt to develop a useful outcomes tool, QUEST was designed to reflect a consumer-responsive and client-centered approach. It is only through the development and use of outcome measures that AT providers will be able to met the challenge of selecting devices that the consumer uses because they fulfill a need and are satisfying.

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HOME MONITORING OF BLADDER PRESSURE IN INDIVIDUALS WITH NEUROGENIC BLADDER

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ABSTRACT

Spinal cord injured and multiple sclerosis patients are at high risk for developing kidney dysfunction due to high bladder pressures. We have developed a device for frequent monitoring of bladder pressures at home in those patients, who use clean intermittent catheterization to empty the bladder.

Vesical and abdominal pressures measured at home were significantly lower than clinical cystometric pressures. However, subtracted detrusor pressures were not significantly different. The home detrusor pressures were consistent over a large time and volume range. Therefore, the home monitoring method could be used to establish a normal range of bladder pressures at home and to rapidly identify high bladder pressures in advance of upper urinary tract deterioration.

INTRODUCTION

Due to their high bladder pressures, patients with neurogenic bladders, such as those with Spinal Cord Injury (SCI) or Multiple Sclerosis (MS), have a high incidence of urinary incontinence, hydronephrosis, and kidney failure. High bladder pressures are caused by detrusor-sphincter dyssynergia, a neurogenic pathology, which prevents these individuals from voiding. Therefore, many use clean intermittent catheterization (CIC) to empty the bladder [McGuire et al., 1991].

The standard procedure of monitoring bladder pressures is to conduct a cystometrogram (CMG), or filling pressure-volume curve of the bladder, in the urodynamic clinic. CMGs are time consuming and expensive and are therefore only performed immediately following an injury or diagnosis, when a patient presents with a urologic problem, or as a long-term follow-up procedure [McGuire et al., 1991]. CMGs are not likely to be performed as frequently as is ideal to prevent upper urinary tract deterioration.

We have developed a simple home-use pressure gauge for frequent monitoring of bladder pressures in patients with SCI or MS who are using CIC to empty their bladder [Walter et al., 1996].

METHODS

Subjects were recruited from among patients at the Hines VA Hospital who have either SCI or MS and are currently performing CIC.

Cystometries were performed on all subjects by filling the bladder with water at 30 or 60 ml/minute while bladder and rectal pressures were recorded (Life-Tech). CMG detrusor pressures are determined as bladder, or vesical, pressure minus rectal, or abdominal, pressure. An extra stopcock and length of tubing allowed simultaneous measurement of vesical pressure with the home device. Pressures measured by the home device recorded at 4-5 representative volumes during filling. CMG bladder capacity was determined as the volume at which the subject felt a strong sensation of fullness or water leaked out of the bladder.

Once a week at home, immediately prior to the first bladder emptying of the day, the subjects connected the tubing and pressure gauge to the catheter and measured bladder pressure (full bladder pressure). They then disconnected the tubing and emptied the bladder into a beaker, measuring the volume emptied. They measured bladder pressure again, immediately after emptying (empty bladder pressure). Two different pressure gauges were tested for the home device: a digital gauge (Micro Pneumatic Logic, Ft.

Lauderdale, FL) and a mechanical bellows gauge (Davis Instruments, Baltimore, MD). A reflux valve and tubing (Life-Tech, Houston, TX) connected the home pressure gauge to the catheter used for CIC. Since no rectal pressures were recorded at home, detrusor pressure was estimated as full bladder pressure minus empty bladder pressure. Capacity at home was determined as the highest volume drained in the series of measurements.

Results are presented as mean ± standard deviation. Statistical significance was determined as $p<0.05$ using Students' t-test or Mann-Whitney Rank Sum test.

RESULTS

The home device has been used without adverse effects for 2.2 ± 3.3 months by 4 subjectswith SCI and 1 with MS, all of whom are using CIC to empty the bladder. Each subject has made 26 ± 21 home pressure recordings.

Each subject underwent 1-2 CMGs to compare the home device to the clinical CMG (7 CMGs total). The difference between CMG bladder pressures and pressures measured using the digital (12.5 ± 1.81 cm H2O, n=19 over 4 CMGs) and mechanical (0.4 ± 1.3 cm H2O, n=14 over 3 CMGs) gauges were not significantly different from zero.

Home bladder capacities (583 ± 200 ml) were higher than CMG capacities (480 ± 205 ml), but not significantly so (figure 1). At each volume of overlap, CMG vesical pressures were compared to home full bladder pressures; CMG rectal pressures were compared to home empty bladder pressures; and CMG detrusor pressures were compared to home detrusor pressures. When the results from all subjects were combined, the home full (25 ± 15 cm H2O, n=117) and empty (9 ± 5 cm H2O, n=117) bladder pressures were

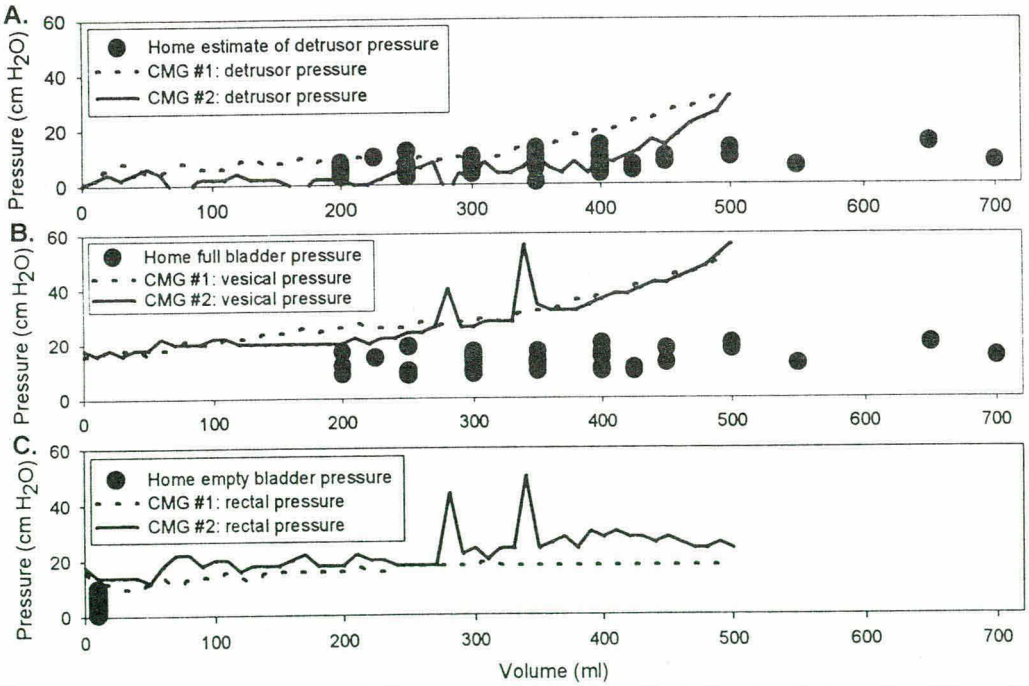

Figure 1. Cystometric (lines) and home bladder pressures (circles) in a typical subject. **A.** Cystometric and home detrusor pressures. **B.** Cystometric vesical and home full bladder pressures. **C.** Cystometric rectal and home empty bladder pressures.

significantly lower than the CMG vesical (45 ± 22 cm H2O) and rectal (23 ± 5 cm H2O) pressures, respectively. In contrast, there was no significant difference between home estimate of detrusor pressure (17 ± 12 cm H2O, n=117) and CMG detrusor pressure (22 ± 22 cm H2O, n=117).

Home estimates of detrusor pressure had a smaller range and were more consistent than CMG detrusor pressures primarily because CMG detrusor pressures increase at increasing volumes whereas home bladder pressures do not.

DISCUSSION

The home pressure gauges are simple enough for the subjects to use at home without clinical supervision. Simultaneous monitoring during a CMG demonstrated the gauges' accuracy. There were no differences between the accuracy of the two gauges used at home.

To obtain an estimate of detrusor pressure from the home data, we hypothesized that the pressure in the bladder immediately after emptying (empty bladder pressure) would reflect abdominal pressure. These home empty bladder pressures were significantly lower than CMG rectal, or abdominal, pressures. The home full bladder pressures were similarly significantly lower than CMG bladder, or vesical, pressures. The home estimates of detrusor pressures, were therefore, not significantly different from CMG detrusor pressures.

The increased vesical and rectal pressures during CMG are likely caused by the uncomfortable clinical environment and the nonphysiological filling rates [Andersson et al., 1989]. This probably also accounts for the decreased capacity during CMG, although this difference was not significant. Nonetheless, the increased pressures during CMG are negated when subtracted detrusor pressure is used.

In these urologically stable patients, the home detrusor pressure was highly consistent over a long time and a range of volumes. In contrast, the CMG detrusor pressure increased at higher volumes. This suggests that the home detrusor pressure could be used to establish normal bladder pressure values and to rapidly identify increases in bladder pressure: either an isolated incident, potentially due to a urinary tract infection, or a slower increase in bladder pressure, potentially due to increasing dyssynergia.

Home monitoring of bladder pressure can not substitute for clinical CMG measurement. However, we suggest that, in patients performing CIC to empty the bladder, frequent home monitoring of bladder pressure could supplement CMG recordings and would enable early identification of high bladder pressures.

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EARLY PHYSICIAN NOTIFICATION OF PATIENT DISABILITY RISK AND CLINICAL GUIDELINES FOLLOWING OCCUPATIONAL LOW BACK INJURY: A RANDOMIZED CONTROLLED TRIAL

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ABSTRACT

For a one year period, all workers with low back pain injuries, who filed a report to the Vermont Department of Labor and Industry within 12 days of their injury, were contacted by telephone for administration of a short disability risk questionnaire. Back-injured workers with relatively high scores on the disability prediction questionnaire participated in a balanced randomized controlled trial. The intervention combined physician notification for the patient's disability risk with care recommendations including AHCPR algorithms. The control group received no intervention, although both groups were followed up at 3 months post injury to confirm work status. The intervention had no significant impact on disability, pain, or satisfaction with health care.

BACKGROUND

Low back pain continues to exact enormous societal and personal costs in industrialized countries worldwide. Several studies have shown that the vast majority of these costs are due to the minority of back pain injured who are disabled from work for more than a few months.

The idea of intervening quickly after occupational low back injury is compelling, particularly if this can be done before adverse biological and psychosocial consequences compound the pain. The potential of quickly identifying the minority of back-injured workers who will become chronically disabled has inspired the development of several predictive models and questionnaires. In addition to their potential clinical applications, these predictive tools might be useful in research through stratification of back-injured workers according to their risk for disability.

If in fact injured workers at high risk for disability can be identified quickly, how can we best intervene? Following publication of the Quebec Task Force's exhaustive review of the relevant literature and observation of its limited impact, Spitzer has concluded that the prolonged disability from low back injury is aided and abetted by the health care provision system in general and by doctors and physiotherapists in particular. The physician's role in controlling return to work after occupational injury can be critical , so physician education might provide an opportunity to reduce disability. Lack of physician consensus regarding optimal care and adequate scientific support for many common therapies is currently reflected in highly variable clinical approaches to low back pain. Clinical guidelines have been widely promoted as tools for improving quality of care by reducing practice variation. In 1994 AHCPR published the best known guidelines for acute low back pain.

RESEARCH QUESTIONS

1. How accurately does the previously

reported Vermont Disability Prediction Questionnaire (VDPQ) (Hazard, 1996) identify people who will be out of work due to back pain three months after their injuries?

2. For people with high disability risk scores on the VDPQ are subsequent self-assessments of pain, satisfaction with health care, or work return rates improved by physician notification of risk combined with AHCPR algorithms and a letter outlining care recommendations?

3. How do physicians rate the influence this intervention has on their care of the injured worker?

METHOD

Between February, 1995, and March, 1996, all First Reports of Injury completed by workers who were 18-60 years old, and received within 12 days of low back injury, triggered a telephone contact of the injured worker by a staff member at the Vermont Department of Labor and Industry. All individuals with VDPQ scores suggesting a high risk of prolonged work disability were to be called within 15 days of injury to explain the physician intervention portion of the study. For the first 6 months of the enrollment, every participant with a VDPQ score of at least 0.37 (scale= 0.0-1.0) was considered at high risk. For the last 6 months, the cutoff score was lowered to 0.23 to increase enrollment without introducing bias. No intervention was recommended or performed by the research staff for the low risk participants, though they were contacted through mail or phone questionnaire to review work status 3 months after initial injury.

All VDPQ-designated high risk participants who could be contacted within 15 days of injury and who gave consent were then randomly assigned to the intervention or control group. All participants in the intervention group designated a primary treating physician. Each designated physician was sent a letter identifying the patient and their risk for work absence 3 months after injury. The letter made recommendations for limiting work loss. The reverse side of the letter displayed the AHCPR initial assessment and treatment algorithms. Nearly identical risk and guidelines letters were sent to the same physicians one month after injury. Three months following injury, all high risk participants who could be contacted were interviewed by phone regarding self-assessed pain, satisfaction with health care, and impact of health care on return to work (0-10 scales), days of work loss, current work status, and health care utilization.

RESULTS

Sixty-two percent (1281/2066) of the participants did not meet the initial inclusion criterion of reporting their injuries within 12 days, and 15% (15/99) of the VDPQ high scores could not be contacted within 15 days of injury. The nonconsent rate for responding to the telephone VDPQ was 43%. There were 304 people, including 187 (62%) men and 117 (38%) women, eligible for and consenting to participation in the VDPQ portion of the study. There were no important differences between consenters and nonconsenters on basic demographics.

Of the 304 eligible consenters, 268 (88%) were contacted three months after injury. Of those contacted, 32 (12%) were not working because of back pain, and the rest were either working or out of work for reasons unrelated to back pain. Overall the predictive performance as measured by kappa was lower, and the ROC area of 0.78 was lower than the 0.92 obtained in the earlier study. Some reduction in prediction accuracy is to be expected when a predictive tool developed in one sample is applied to a new sample, and demonstrates why validation requires multiple trials

Physician Intervention:

Fifty-nine participants consented and were enrolled in the intervention study. Comparison of consenters and nonconsenters revealed no

significant ($p<0.05$) differences for our measured demographics. Participants assigned to the intervention had lower hourly wages ($8 vs $10, $p=0.029$) than those in the control group, but the other factors and VDPQ scores were not significantly different at the $p<0.05$ level.

Self-assessments of pain, satisfaction with health care, impact of health care on return to work, day of work loss, and days until first return to work did not differ between intervention and control groups at the $p<0.05$ significance level.

Once the follow-up was complete, the 30 designated physicians were sent questionnaires asking about the utility of the risk notification and guideline letters in caring for their patients in the study. Of the 18 (60%) physicians who responded, 14 (78%) said they had received the letters, and 4 (22%) were not sure. Thirteen (72%) reported they had read the letters, while 5 (28%) were not sure. One physician stated that the information had influenced the care of the patient. Four (22%) physicians were not sure if the information had any impact. Of the 13 (72%) physicians who reported no impact by the letters, 4 stated the patient had gone to another physician, 3 were already familiar with or practiced consistently with the guidelines, 3 used or recommended manipulation, 2 said the patient recovered quickly without needing guideline input, and 1 gave no explanation.

DISCUSSION

Prevention of chronic disability after occupational low back pain is complicated by an apparent paradox. Action must be taken quickly, yet the majority of back-injured workers will return to work without particular medical intervention. This study aimed to test the combined preventive strategies of focusing intervention on the minority at highest risk for disability and then presenting the treating physicians with notification of that risk along with guidelines for care.

Over half of the originally eligible sample were not contacted because of late report filing. These participants may not have behaved like their peers who enrolled in time for early intervention (within two weeks of injury) and who completed the study, and generalizations from our results to other research or clinical settings should account for this possible bias. Caution is also suggested by the potential selection bias in the large number of participants who did not consent to participate in the study, even though the variables compared between these groups did not differ significantly. On the positive side, the VDPQ did serve to reduce the number of subjects entering the intervention portion of the study, thereby reducing research costs and resource utilization. Hopefully similar savings can be realized by this risk-stratification strategy in future studies. This approach may also elucidate outcome differences in future therapeutic trials by eliminating participants for whom intervention is unnecessary and perhaps costly or risky.

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A MULTIMEDIA SYSTEM FOR GENERATING GAIT ANALYSIS REPORTS

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ABSTRACT

In this paper we discuss the need for better reporting of gait analysis results and describe a system that implements our concepts of how the report generation process can be improved. Gait analysis is a process that entails the use of much quantitative data. The system we have developed, Dr. Gait III, provides a means to view and electronically annotate all the information commonly present for gait analysis: medical history, physical examination, time/distance data, joint angle graphs, moments, powers, force plates, EMGs, video, and stick figures. It provides annotation functions for each type of data and also contains decision support tools to automatically annotate some types of data. During report generation, individual pieces of data are tagged for inclusion in a report. The report is then composed in a word processor according to a standard template for where data items should be placed resulting in a rough draft that can then be completed by the analyst.

BACKGROUND

Gait analysis is the process of determining the cause of abnormalities in a patient's walking pattern so as to treat those abnormalities and improve the patient's functionality (1). A gait analysis session consists of several steps. First, the patient's physical characteristics such as leg length and weight are measured. Next, several range of motion parameters are measured such as the flexion/extension of the hip, knee, and ankle. Reflective markers are then affixed to the patient in various locations and a camera system records the trajectory of these markers in 3-D space while the patient walks. Surface or wire electrodes are also used to determine the muscle activity of the muscles of interest. This information is generally collected by computer and resides in electronic forms. In addition, most labs also record video of the patient walking.

STATEMENT of the PROBLEM

A gait study generates a considerable amount of data. This data must be analyzed in order to make a diagnosis and recommendation which is a time-consuming process. Furthermore, once a diagnosis and recommendation have been made, these must be communicated in a reasonable manner to the referring physician. At this time, most labs collect and summarize the gait analysis data and then print out the data on a series of forms for the analyst to look at. The analyst writes up the diagnosis and recommendations and sends these to the referring physician along with the printouts of the data. This style report separates the discussion of the data from the data itself and results in a considerable amount of page flipping to understand the data that is being reported on. A poor understanding of the report can lead to poor treatment of the patient. To summarize, there are two main problems with the current way that gait analysis reports are generated: 1) it is time-consuming, and 2) the reports are often difficult to understand.

APPROACH

To address the time-consuming nature of

producing a gait study, we suggest that using a computer program to organize, display, and annotate the data allows for more efficient analysis of the data. A computer can easily handle the multiple types of data typically present for a gait study (numerical data, textual data, graphical data, and video) and it is possible to easily view each different type in one location rather than going to a VCR to view video, flipping through papers for graphs, etc. Efficiency can also be improved by the use of decision support tools that automatically perform some of the routine tasks that normally comprise gait analysis.

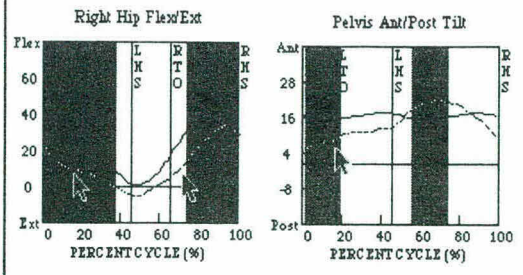
We believe that a report's understandability can be improved by combining the data and its discussion. For example, when discussing a problem at the hip, the hip joint angle graphs should be near the text as well as moments and the EMGs of relevant muscles. Furthermore, the data should be annotated in such a way as to draw attention to the important portions of the data. Organizing a report in this way allows the referring physician to read the report without flipping pages excessively and the annotations clearly identify the problems that were found. However, generating a report with these properties would appear to be more time-consuming than the current method of appending the data to a discussion. This is where a computer implementation is again useful. A computer system that organizes and displays the data can also be used to annotate the data during the analysis process. Additionally, the computer system can speed report generation by automatically generating a rough draft of a report based on the data items that were indicated to be important by the analyst.

We have developed a computer system, Dr. Gait III, that strives to provide the functionality described above. Dr. Gait III uses data directly from the gait analysis laboratory that has been either collected digitally to begin with or captured from analog data. The data that can be viewed on-line includes: medical history, physical exam, time and distance data, joint angle graphs, moment graphs, power graphs, force plate graphs, EMGs, Quicktime video, and animated stick figures. The physical exam and time and distance data are originally entered into a database and then exported as tab-delimited text for Dr. Gait III. The graphs are all generated from numerical data that has been processed from the original motion data with a program designed for determining kinetic and kinematic data. Video of the patient walking is taken with a S-VHS camera and then captured digitally to Quicktime video. The stick figures are generated from marker data by the program.

Each piece of data may be annotated in a manner appropriate to the type of data. For example, text screens provide the capability to change the style (bold, italics, etc.) and color of the text. Screens with graphs provide two means of annotation — a colored highlight of a region and colored arrows that may be placed anywhere on the screen. Video screens also provide two means of annotation for any frame of information — colored arrows and colored vectors that can be drawn on the video.

The routine tasks that have been automated in Dr. Gait III are based QUAWDS (2) which is an expert system that broke the entire task of gait analysis into several steps: finding determination, muscle fault generation, muscle fault rating, and generation of explanatory coverage of muscle faults (2). The first of these, finding determination, has been implemented for the joint angle graphs, physical exam and EMGs. For these data items, the system can automatically annotate the items that are abnormal.

In the case of the joint angle graphs, there are two methods available for determining abnormality — by standard deviation or by prediction region (3). Each of these methods highlights the abnormal regions of the graphs.



Sagittal Plane Hip and Pelvic Motion: The flexion of the right hip is decreased from 25% of swing until 75% of single limb stance. The anterior tilt of the pelvis is decreased during weight acceptance. The anterior tilt of the pelvis is increased from 50% of weight release until 25% of swing.

Figure 1: Annotations and automatic text.

For the physical examination, Dr. Gait III uses a graduated system to determine whether the item is severely out of range or mildly out of range. Severe problems are marked in red and mild are marked in orange.

For the EMGs, if the activity in a phase is all below the threshold and there is a normal indicating that there should be activity, then that region of the graph is highlighted to indicate disphasic activity. Similarly, if there is activity in a phase outside the threshold and the normal indicates that there should not be activity, then the region is also highlighted to show disphasic activity.

Any item of data may be selected for inclusion in the report and the annotations that were made to that data item are also included. This provides a simple method for including annotated data that is not very time-consuming because many of the annotations can be made automatically. Additionally, text can be generated to accompany some of the findings such as that shown in Figure 1. Once the data has been noted for inclusion in the report, a procedure is run to build the report in an organized manner based on common templates in a word processor. Further editing of the report is still necessary, but the data is already in place thus making it easy to view the data while writing the discussion.

DISCUSSION

The tools described here are currently being used in our lab for doing gait analysis. Although a time-savings has not yet been realized, we believe that the quality of the reports is quite high and worth the time it currently takes (a little longer than was previously spent generating reports). Our current research is to automate more of the process so that a real time savings can be achieved without sacrificing any of the quality of the reports. Furthermore, we will investigate the actual use of electronic reports rather than paper.

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TESTING THE EFFECT OF VERTICAL MOTION ON CHILDREN WITH CEREBRAL PALSY

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ABSTRACT
Thirty children with spastic diplegic cerebral palsy participated in a study to investigate the effect of vertical oscillatory motion on respiratory function, muscle tone and balance reactions. The subjects were volunteers taken from the hospital's cerebral palsy clinic. Each subject was given a battery of tests twice before and twice after riding on a device that vertically oscillated them for ten minutes. Trends toward increased lung capacity, increased sway motion in static standing and decreased muscle tone were seen following the vertical oscillatory intervention.

BACKGROUND
Different forms of whole body passive movement are used by occupational and physical therapists to modify muscle tone, make changes in posture or improve sensorimotor function. Proponents of the sensory integrative approach to therapy support the use of rotary, linear or vertical bouncing motions in order to affect the vestibular system. The vestibular system is an important part of the sensorimotor system. Theoretically, use of vestibular stimulation in children with cerebral palsy can help to organize their entire system, thereby improving sensorimoter performance[1][2]. In addition, therapeutic horseback riding has been used successfully with many children with cerebral palsy [3]. Could it be that the bouncing motion provides some vestibular input that helps to normalize the sensorimotor system?
This ongoing research intends to determine if motion (particularly vertical oscillations) does have an effect on children with cerebral palsy.

RESEARCH QUESTION
Does whole body vertical oscillatory motion have an effect on muscle tone, respiratory function or static standing balance in children with spastic diplegic cerebral palsy?

METHOD
Sample
Thirty subjects with spastic diplegic cerebral palsy were chosen on a volunteer basis from the cerebral palsy clinic of the hospital. The age range was from 6 to 22 years. The mean age was 12.5 years. There were 12 females and 18 males. All of the subjects were able to ambulate independently. Some used assistive devices to ambulate.

Procedures
Each subject was tested twice before and twice after riding on a platform that vertically oscillated them 3 inches for 10 minutes at 1.5 Hz. A description of each test given follows:
Modified popliteal angle test:
The subject was seated with legs hanging, hips as far back in the seat as possible with a seat belt used to hold them in place. The lower leg was lifted using a hand held dynamometer with a cuff placed at the heel. The leg was

lifted until a point of moderate resistance without the upper leg lifting off the seat. Here the force was measured with the dynamometer and the angle was measured using a magnetic sensing instrument, the POLHEMUS (3SPACE, Isotrak, by Polhemus Navigational Sciences Division of McDonnell Douglas Electronics Compay). Each subsequent measurement was taken at the same force. Changes in angle were then noted. The seated position was used in order to minimize the need to change positions between tests since that could affect muscle tone.

Leg drop pendulum test:

This test was chosen in order to attempt to objectively measure spasticity [4]. The subject was seated with legs hanging. The lower leg was extended to a point of resistance but without the upper leg lifting off the seat. When the subject was relaxed, the leg was dropped and allowed to swing to its resting position. The leg was brought to the same starting angle each time. The dynamic knee angle was measured using a magnetic sensing device, the POLHEMUS, which was placed just above the lateral maleolus of the more involved leg. This test was performed six times for each of the four testing periods.

Vital lung capacity:

Each subject was tested using a hand held spirometer. The largest of three measurements was taken.

Sway measurement:

Body sway measurements were taken during static standing. The sway motion was measured using a magnetic sensing device, the POLHEMUS, which was placed on the upper back at about the first thoracic vertebral level.

RESULTS

Modified popliteal angle test:

Five subjects showed an increase in popliteal angle following the intervention and five subjects showed a decrease following the intervention.

Leg drop pendulum test:

Position data for knee flexion/extension was analyzed and eleven attributes of motion were defined. Recall that there were two tests performed before and two tests performed after intervention. An analysis of variance was performed on each attribute. It was assumed to be a significant finding if:

1) there **was not** a significant difference (.95 confidence level) between the two tests given before intervention **and**

2) there **was** a significant difference (atleast .95 confidence level) between the second test given before the intervention and the first test given after the intervention.

This scenario would indicate that the cause of change was most likely related to the intervention. Seven of the thirty followed this scenario with an increase in motion for maximum range of knee motion during the pendulum drop. Five of the thirty showed this scenario for an increase in the average velocity of motion.

During the pendulum test, position data was also collected in the frontal plane. This can be thought of as "side to side" motion of the lower leg which indicates rotational motion of the hip. A significant finding as described above was found for a symmetry measurement of this side to side motion. This was calculated by finding the difference between the average of the first 100 points and the average of the final 100 points for a particular leg drop trial. An ANOVA was performed on the entire group for this measurement to determine if there was a change in symmetry following intervention. A significant difference (.95 confidence level) was found The trend noted was in the direction of increased internal rotation.

Vital lung capacity:
Sixteen of the thirty subjects showed an increase in their vital lung capacity following intervention.
Sway measurements:
Overall, sway measurements tended to increase. Mean sway measurements were calculated. Twelve showed an increase in their mean sway motion and seven showed a decrease following intervention. Sway area was calculated. This was calculated by summing the area of subsequent triangles made from the mean position, the previous position and the present position. Thirteen subjects showed an increase in sway area and five showed a decrease.

DISCUSSION

It was hypothesized that whole body vertical oscillations would cause an increase in popliteal angle, a decrease in muscle tone, an increase in lung capacity and an improved ability to balance.
No changes were noted in the popliteal angle measurement following intervention as had been expected. This may be due to the subjects' variability in voluntary muscle activity when they were expected to be completely relaxed.
Major changes were not seen in the pendulum test for spasticity in the standard sagital plane measurement as had been expected. In a previous pilot study [5], a change was noted in this test.The difference may be because we started each leg drop at the same angle in this study whereas in the pilot study we lifted the leg to a position of moderate resistance. However, unexpected changes were seen in the frontal plane. This could be due to some subtle tone changes of hip rotators.
A trend towards an increase in lung capacity following intervention was seen. The vertical oscillations may cause a decrease in tone of the diaphragm, thereby allowing a deeper breath to be taken. A trend towards an increase in sway motion was seen. This may be due to a decrease in muscle tone which could initially increase sway during static standing.
The next step in this research is to determine the effect of vertical motion on gait. The ten of these thirty subjects who were most affected by the motion will be tested again using the hospital's gait laboratory.

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AN INVESTIGATION INTO THE EQUIPMENT NEEDS OF PEOPLE WITH RESTRICTED GROWTH IN THE UNITED KINGDOM

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ABSTRACT

This article describes a recent study into the unmet equipment needs of people with restricted growth. The study utilised a combination of questionnaires and semi structured interviews. Information gathered from the questionnaires and interviews was collated to form a list of equipment needs and general problem areas experienced by the volunteers. This list was circulated to people with restricted growth enclosing a request to assign a priority rating to each item. The results identified six items of high priority which are now being designed at the Institute over a three year programme.

BACKGROUND

For many years the design team at the Institute has recognised that the best people to identify the need for new assistive devices are those with a disability. The team has been investigating methods of formalising links with disability organisations to widen the source of new projects and improve their selection.

It was decided to work with a support organisation and undertake a survey of the unmet equipment needs of the members. The Restricted Growth Association of the UK (RGA) agreed to work with the Institute to investigate the particular needs of their members. The most common type of restricted growth is achondroplasia. Over 80% of cases are born to parents of average stature, approximately 1 in 25000 births (Apley & Solomon, 1993). The RGA felt that their members were a neglected group, within the UK, in terms of assistive devices.

RESEARCH QUESTIONS

The study aimed to ascertain the specific equipment needs and problems experienced by people with restricted growth, which would benefit from engineering design.

Work was planned in four main phases, as listed below:

1. a postal survey of 100 members of the RGA using a specially designed questionnaire,
2. a series of in-depth interviews with a small group of respondents,
3. feedback to as many members of the RGA as possible,
4. a programme of up to 3 years design work to explore solutions to the problems which may evolve.

METHODOLOGY

Questionnaire

A questionnaire was designed to encourage the individual to think through their daily life in a systematic way in order to identify where problem areas occur. The questionnaire aimed to be non directive but to provide a reminder of all aspects of daily life, i.e. mobility, personal care, paid and unpaid occupation, and leisure. Respondents were asked

to include their name and contact address only if they were willing to participate in the in-depth interviews, or if they wished to be kept informed of the work. The RGA agreed to mail the questionnaires to members in order to protect anonymity and following a pilot study the final questionnaire was circulated to ninety of their members. The recipients were either adults with restricted growth or parents of a child with restricted growth.

Interviews

The interviews were semi structured using the information from the questionnaires as a springboard for discussion. Each one lasted an average of two hours. The interviews allowed for expansion of the written information received and enabled detailed assessment of particular problems. It was also possible to tentatively explore possible engineering solutions to some of the difficulties highlighted.

Feedback

The information received from the questionnaires and interviews was combined to produce a list of equipment needs and problem areas. The list was sent to all questionnaire respondents who had supplied their addresses and was made available to delegates at the Restricted Growth Association Convention in October 1995. Attached to the list was a postage paid reply form asking individuals to indicate whether they would use each item regularly, occasionally or never, and to grade each problem area on a scale of 1 to 5 (1 = no problem, 5 = serious problem). The replies would indicate an estimation of priority for each item, although not a finite assessment of need.

RESULTS

Questionnaire

Thirty one questionnaires were received, a response rate of 34.4%, and twenty one respondents indicated a willingness to participate further in the study.

The respondents provided a representative selection of the RGA membership - 54% males and 41.9% females (one unspecified), ages from 3 to 60+ years, and a variety of causes of restricted growth with the largest group being achondroplasia (67%).

A common theme arising from the questionnaire was that many difficulties occur for people outside their home or usual place of work i.e. where they are trying to cope with an environment designed for much taller people. Problems could be grouped into three discrete clusters - lack of reach due to height and restricted arm length, poor availability of appropriately sized children's toys and equipment, and mobility equipment.

Interviews

Eight interviews were arranged. Volunteers included three children and five adults. Two of the adults were a married couple, two lived alone and one with an elderly parent. Three of the adults were in full time employment.

The interviews proved to be a useful setting for discussing in greater depth the difficulties described. The interviewees considered their own and other peoples ideas for new equipment. Everyone was willing to demonstrate problems

that they encountered and spoke objectively on ways around their difficulties. A list of 19 possible devices was compiled.

Feedback

The list of equipment needs and problem areas was circulated for prioritisation, and from the replies a "wish" list of six equipment needs was compiled:

1. lightweight step which will fold very small for carrying,
2. an extending "prodder" to keep in a handbag or pocket,
3. very adjustable tricycles and bicycles for young children,
4. child's toilet seat with handrests to assist young children to sit on the toilet when their arms are too short to use for balance,
5. folding bottom wiper which can be easily held by children with small hands,
6. gadget to lift a loaded coat hanger on to a wardrobe rail.

A number of general problem areas were also highlighted. The three most common general problem areas were:

1. appropriately sized sports equipment,
2. opening doors on public transport and in public buildings,
3. general lifting and carrying.

DISCUSSION

This survey has been an experimental one. In this particular study of people with restricted growth most of the equipment needs are relatively simple items in engineering terms but they present the important challenge of ensuring designs are discrete and functional and make a significant contribution to the lives of busy people coping with an ill designed environment. A programme of design work began in October 1996 to address the "wish" list. The engineer and therapist involved with the project are working closely with the southwest regional group of the RGA at every stage of the design process. It is hoped that by the end of the three year design period the resulting devices will satisfy the needs of people with restricted growth.

The overall conclusion is that this approach is useful and should form an integral part of the Institute's future projects programme. It is hoped that experience gained from this project can be used in the future to explore the equipment needs of other disability groups. The detailed information gained from the survey, and the "feel" for the difficulties experienced by people with restricted growth should assist effective design work.

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SIG-06
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THE DESIGN AND DELIVERY OF A LEARNING & COMMUNICATION SYSTEM

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ABSTRACT

On December 12, 1996, an early communication device was delivered for the students at Perkins School for the Blind, Lower School Program, Watertown, Ma. These students are visually impaired or blind, with multiple handicaps between the ages of five and sixteen years old. The "Learning and Communication System II" (LCS II) is a portable, battery operated, rechargeable device that assists in the training of pre-linguistic skills. The user interfaces with a single switch. These skills include auditory scanning, turn taking, cause and effect, and matching skills.

BACKGROUND

On file with the University of Massachusetts/Lowells' Assistive Technology Program was a request for a communication device for an eleven year old female with hearing and vision impairments, atheoid cerebral palsy and cognitive delays. Meetings with the requesters helped form the concept to build and deliver a learning and communication system (LCS) as part of Project Lab B for the Spring 1996 semester. This was successfully delivered in April 1996 and is the foundation and predecessor for the LCS II. For the Fall 1996 Project Lab C, I contacted Perkins School to see if there was an interest for the same type of device with auditory scanning capabilities. A response was received within 2 days.

STATEMENT of the PROBLEM

To provide a learning and communication system that met the following criteria:

- To scan 3 positions at selectable variable scan rates while illuminating amber incandescent lamps
- The use of an assistive single switch (i.e.,Ablenet Big Red switch)
- The capability to select randomly, stop the scan, and indicate a choice by illuminating a green lamp at the selected position
- The capability to preselect a scanned position for a predetermined choice or response
- Auditory scanning capabilities -- ability to easily record up to 3 seconds of words, voices, or sounds at each scanned position; this includes responses for random choices and correct or incorrect selections
- To be portable, battery operated and rechargeable

RATIONALE

Currently in the field of assistive devices there are few designed for the non-verbal vision impaired child at a pre-linguistic level. Incorporated into an Individual Evaluation Plan (IEP), this device offers the versatility for training on a daily basis with minimum set up time for operation.

DESIGN AND DEVELOPMENT

There was a time constraint of 14 weeks to propose, design, order parts, build, test and deliver the device. For efficiency the design and development stage was performed simultaneously.
The electronic design consisted of the following 4 subassemblies:
1) The scan/select circuit
2) The record/playback circuit
3) The cabinet and controls interfacing
4) The battery charger circuit

Scan/Select Circuit

The design of the scan/select circuit uses 11 low-powered Schottky integrated circuits (IC's) chosen for their efficiency and durability. The design of a CMOS timer circuit allows for the selection of scan rates of 3, 5, or 7 seconds

from an external rotary switch. A random choice stops the scanning and indicates a selection. Pushing the restart button resumes scanning. The matching capabilities utilize the logic circuitry to allow the selection of any random or any one scan position. The circuit continues to scan if one makes an incorrect choice and will continue until one chooses correctly. Incandescent lamps with more intensity than conventional light emitting diodes (LED's) were to aid in working with the vision impaired.

ISD Record/Playback Circuit

This circuit uses an Information Storage Device (ISD) 2560 IC design that allows the therapist to record words or sounds not exceeding 3 seconds each. The ISD IC mounts to a double sided printed wiring board (PWB) that I made in the university lab. The advantages of a PWB versus a wire wrapped board is that the large ground plane prevents annoying hums and noise while using this IC. The frequency response of this IC exceeds that of a telephone but would not be considered HI-FI. These messages are recorded through a self contained microphone, the positioning of external switches, and pushing a button. A total of seven messages are recorded. One message for each scan position, a universal message for a random or correct match selection, and a recording is made for each incorrect match selection tried. The audio output is direct from the board to a 2" speaker (Fig. 1).

The Cabinet and Control Interface

The LCS II was designed to fit in a 10"x12"x4" (LxWxH) finished aluminum cabinet as shown in figure 1. The scanning and select lamps are

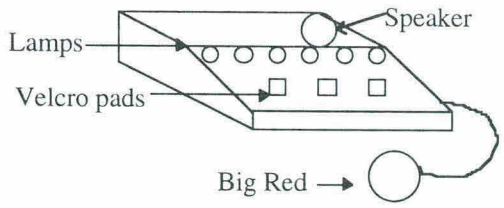

FIGURE 1

positioned over the area where the pictures or objects are attached. Velcro pads that can be used to attach 3 1/2" x 5" card/photo holders (supplied with the unit) or objects that the therapist will be working with. All controls on the right side (i.e., power, scan time, select, and play/record) and the left side (i.e., message select, lamp test and record push button) are positioned as not to be a distraction to the student. The Big Red Switch attaches via a standard 1/8" jack on the right side.

Battery Charger Circuit

The unit uses 4 "D" cell high capacity (4 amp hours) rechargeable NI-CAD batteries that require a constant current charge of 400 milliamperes (ma) for 14 hours. Using a 9 volt 800 ma wall transformer, the charger input is regulated for constant current using a standard type voltage regulator (LM317) and 3 ohm resistor. For safety purposes this unit is battery operated. The device will operate for a minimum of 15 hours.

EVALUATION

The LCS II, operation manual, and spare lamps were delivered within the designated time frame. When presented and demonstrated to the Lower School, the LCS II worked as promised. The speech and language therapist was immediately able to record and use the device with one of the children in her class.

DISCUSSION

There is a wide gap in the area of scanning/teaching assistive devices. Between the simple scanning talk devices to computers with multiple programming capabilities, there exists a need for an intermediate device. Durable, easy to operate, with auditory scanning and cognitive skill development capabilities, the LCS II meets this need.

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TOY REPAIR AND MODIFICATION WORKSHOPS TO ENHANCE EDUCATION AND PROVIDE LOW-COST ADAPTIVE DEVICES

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ABSTRACT

Switch-operated toys are important tools in pediatric therapy and education, but it is often difficult to obtain funding to purchase and maintain these devices. Over the past three years, workshops have been organized in which adapted toys have been repaired and in which battery-operated toys and switches have been modified by the Case Engineering Service Group. The toy repair workshops have restored over 130 adapted toys and switches to working condition for local pediatric rehabilitation agencies at minimal cost. The toy modification workshops, in which junior and senior high school students adapt battery-operated toys and build adaptive switches, have exposed them to aspects of engineering, and increased their awareness of children with disabilities, while providing over 180 newly adapted toys and switches for children with disabilities.

BACKGROUND

The Case Engineering Service Group (CESG), a community service organization of the Case Western Reserve University (CWRU) School of Engineering, was founded in 1990 to provide an opportunity for students to apply their engineering knowledge to design custom assistive devices for individuals with disabilities. Since that time, the membership in the CESG has grown to include graduate students, alumni, faculty and staff of CWRU, and now encompasses three main programs; custom assistive devices, the computer lender program, and the toy modification program. This last program, which is the focus of this paper, involves the organization of workshops in which either previously adapted toys are repaired, or new toys are modified and adaptive switches made to benefit local rehabilitation hospitals and agencies.

Exposure to technology in pediatric therapy is crucial to the cognitive and physical development of many children with disabilities. The introduction of switch-operated toys allows the children to begin to understand the relationship between cause and effect. Due to the limited market for these devices, they tend to be expensive and have a limited selection. The challenge that medical professionals and families of children with disabilities face is to find both the funds and a motivating toy for the child. In many instances, the time, knowledge and funds are spent attending to the basic medical needs of the child and little is left for devices that nurture developmental skills. Several organizations have developed manuals which describe how to modify battery-operated toys and build adaptive switches [1, 2]. This information was useful in preparing for the workshops.

OBJECTIVE

The workshops had several objectives. One goal was to educate both undergraduate and high school students in product development. A second goal was to provide children with disabilities increased access to toys that assist their development. The workshops were also intended to encourage community service among the students, and to provide them with an increased awareness of the disability community.

METHOD/APPROACH

Two different types of toy workshops were organized. One type consisted of repairing inoperative adaptive toys, switches, and other assistive devices. The other workshops involved engineering students guiding junior and senior high school students in the modification of battery-operated toys to allow

switch access, and the building of switches for children with disabilities.

Toy Repair Workshops

As part of the interactions with rehabilitation professionals, individual members of the CESG were occasionally asked to examine adapted toys and other assistive devices which were no longer functional. Many of these devices were easily repaired, allowing the rehabilitation organization to save the money that would be required to replace the item. It was decided that it would be more efficient to organize workshops in which groups of volunteers repaired the devices.

Nonfunctional toys and other assistive devices were solicited from local rehabilitation hospitals and agencies. Monthly or bi-monthly workshops (depending on the volume of devices) were organized, and students and staff were recruited to participate in the workshops. A university electronics laboratory was made available in the evenings for these workshops, which provided most of the necessary repair tools. These tools consisted of basic electronics tools: soldering irons and solder, screwdrivers, needle-nose pliers, wire cutters, a hot-glue gun, heat-shrink tubing, and a heat gun. Other needed supplies were purchased, such as wire, 1/8" phone plugs and jacks, and fresh batteries. Guidelines were distributed on how to evaluate the malfunctioning item, so that the most common problems were investigated first. The workshops were limited to three hours. Occasionally, toys were adapted and new switches were made.

Toy Modification Workshops

Junior and senior high school science teachers contacted the CESG to express interest in exposing their students to "hands on" engineering. The CESG then organized half-day workshops on the university campus. Prior to each workshop, a group of battery-operated toys were obtained (purchased or donated), and switch boxes were machined with appropriate holes to allow the switch parts to be assembled by the students. Several desirable switch types had been identified by clinicians, such as lever switches, pull switches, tilt switches, foot switches, and squeeze switches. At the start of each workshop, a representative of the CESG presented a general introduction to the motor or cognitive limitations of some children with disabilities. A basic battery/switch/toy electrical circuit was also described, and the concept of adding a second, easier-to-operate switch in parallel was explained. The students were instructed to determine the best way to connect the wires for the second switch, including how to best route the wires out of the toy so they could be attached to a connector. They were also provided with the prepared switch boxes, switches, jacks, plugs, wire, foam, sections of plastic, nuts, bolts, washers, paint, and decals and were encouraged to be creative in assembling the switches. The students were typically divided into groups of two or three, and a CESG volunteer was assigned to one or more groups, to provide guidance and to perform any necessary soldering. The older the students, the less guidance was required. At the end of the workshop, each group presented their modified toy to the rest of the groups.

RESULTS

Toy repair workshops

In the past two-and-a-half years, ten toy repair workshops have been held, spaced approximately three months apart. Seventeen volunteers participated in the workshops. In these sessions, 61 toys and 72 switches were fixed. Twenty-one toys or switches were determined to be unfixable. In addition, 18 toys were adapted and 3 switches were made.

Toy modification workshops

In the past two-and-a-half years, five toy modification workshops were held. Approximately 20 volunteers helped guide an average of 50 students per workshop, or helped prepare the materials. Each workshop produced about 20 adapted toys and 20 new switches. A total of 96 toys and 91 switches were donated to local pediatric rehabilitation facilities.

As an offshoot of these workshops, Rainbow Babies & Childrens Hospital (Cleveland, OH) produced an in-house video to educate patients, family and staff on the benefits of adapted toys and the ease of the modifications required to convert mainstream battery-operated toys.

DISCUSSION

The toy repair and modification workshops have been highly successful. Over 130 toys and switches have been repaired, saving pediatric rehabilitation facilities thousands of dollars in replacement costs. More than 180 newly-adapted toys and switches were made and donated to local rehabilitation agencies. The junior and senior high school students received a positive exposure to engineering and increased their awareness of the obstacles that exist for children with disabilities. The student and staff volunteers were able to apply their engineering knowledge in an enjoyable way and provided a community service. The university has received good publicity and has potentially attracted more students to engineering.

Other groups are encouraged to duplicate these workshops, and are welcome to contact the authors for further assistance. The following pointers should be helpful to those who are interested:

Toy Repair Guidelines:
1) Have the clinician describe the problem as detailed as possible.
2) Before taking the toy apart, try putting in fresh batteries.
3) If the toy was not operating at all, look for broken or disconnected wires.
4) Remember that some of the toys will be unfixable, so try to limit the amount of time spent per toy.
5) Discourage volunteers from working on the toys at home - it's harder to maintain control over when the repairs are completed.

Toy Modification Guidelines:
1) Arrange to have a minimum of one volunteer for every four students.
2) Have the volunteer do any soldering.
3) Have several sets of basic tools available, such as scissors, wire strippers/cutters, soldering irons.
4) Have the students place batteries in the unmodified toy and turn it on, so that they know its functions before they do any modifications.
5) Do a safety and quality check on all the completed toys and switches before donating them.

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Enabling SUCCESS

Enabling Students to Undertake the Challenge of Careers in Engineering and Science in School

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Project Summary

The National Science Foundation, under the Program for Persons with Disabilities, has funded the Enabling SUCCESS project at Louisiana Tech University, beginning 1996. This three-year project seeks to stimulate student interest in science, engineering, and mathematics (SEM), to heighten the awareness among middle school students, their families, and their science teachers of the opportunities for persons with disabilities in these fields, and to provide them with an understanding of the importance of career exploration and taking appropriate college preparatory courses in high school. The project staff is working with middle school students (grades six through nine). This paper summarizes the major activities of the project.

Assistive Technology and Careers in SEM Workshops

The staff will conduct workshops to increase awareness of the opportunities and capabilities of persons with disabilities to succeed in science and engineering careers. The workshops will emphasize preparation for careers in SEM, careers of disabled scientists and engineers, demonstrations of assistive technology, and legal aspects of including students with disabilities in classroom activities. The attendees will be students, parents, and teachers. The first workshop was held at Louisiana Tech University on January 11, 1997. Fifteen students and their parents along with fifteen of their school science teachers attended. Children interacted with a disabled computer scientist and enjoyed both structured and free time the Louisiana Tech's children's discovery museum, the IDEA Place.

Classroom and Student (Adapted) Science Kits

Adapted science kits will be prepared for students with disabilities to explore science concepts in the classroom and at home. Adapted science equipment will be distributed to at least four north Louisiana school systems. Teachers who have attended an Enabling SUCCESS workshop will be eligible to apply for a mini-grant and technical assistance from the project. Home science kits will be distributed to students with physical disabilities beginning in year one and to students with sensory impairments beginning in year two. The kits will contain a variety of age-appropriate science projects and experiments, including necessary supplies and adapted equipment. Middle school students who participate in this and other project activities will be known as Science Explorers.

Teacher Awareness Seminars

The project staff will share information with current and future teachers regarding the ability of students with disabilities to pursue and become successful in science, engineering

and mathematics careers. Presentations will be made in teacher education classes (including workshops and summer institutes) and at a state-wide teacher association meeting.

Study and Career Guidance (Mentoring) Program

The project staff will provide encouragement to middle school students to develop and pursue interests in science subjects leading to SEM careers. Middle school students will be matched with college students who are majoring in science, engineering, mathematics, or science education. The college students serving as mentors are three engineering majors, one mathematics major, and one chemistry and science education double major. The college student mentors will interact with the Explorers on a regular basis, and offer encouragement in courses and career planing. They will also distribute the home science kits and maintain contact with the students on a bi-weekly basis (by phone, personal visit, or e-mail). A newsletter will be prepared and distributed to provide information to students, parents, and teachers in the state. A career counseling guide will be prepared, summarizing careers in SEM and describing the preparation necessary during middle school and high school. Project participants (staff, students, parents) will be invited to at least one annual field trip to a science exploration activity or museum.

Super Summer of Science Showcases

A series of four four-hour Science Showcases will be conducted on the Louisiana Tech University campus on selected Saturdays during the summers of 1997 and 1998. Students will hear from science and engineering instructors and participate with their parents in interactive science project demonstrations and experiments. Two different areas of science, mathematics, or engineering will be highlighted at each showcase.

Project Staff

The staff is co-directed by two engineering professors with many years of experience in engineering education and in rehabilitation engineering. Other key staff members include a sixth grade science and mathematics teacher, a rehabilitation specialist, and a rehabilitation engineer.

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A MODEL SCIENCE, ENGINEERING, AND MATHEMATICS PROGRAM FOR HIGH SCHOOL STUDENTS WITH DISABILITIES

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ABSTRACT

The Science, Engineering, and Math (SEM) Project is a model program developed by the University of Delaware designed to increase the number of students with disabilities in SEM academic programs and professions. The model entails working with high school students with disabilities on on-line and field based activities. On-line activities include telementoring and Internet based SEM projects. In-person activities include extracurricular workshops and summer programs. These programs are designed to build technical skills, increase student SEM exposure, and prepare students for post secondary education. This paper describes these activities as well as planned future program components.

BACKGROUND

The University of Delaware conducts ongoing research and development focusing on disability issues and on increasing the opportunities available to people with disabilities. The Science, Engineering, and Mathematics (SEM) Project is one effort in this area. This Project conducts research on disability related information access issues and develops models for increasing the participation of individuals with disabilities in SEM academic programs and professions. In particular, one component of the program is designed to encourage high school students with disabilities to engage in SEM areas of study and careers.

It is well known that people with disabilities are underrepresented in SEM fields(Malcom, 1991). There is no inherent reason why this should be so; there are many people with disabilities who have been successful in these fields (Stern, 1995). Yet students face barriers which include lack of sensitivity to their needs and lack of encouragement from teachers, parents, and society at large. In order to increase the number of individuals with disabilities in SEM academic programs and careers, students must be provided with positive SEM experiences and professional role models.

OBJECTIVE

The SEM Program seeks to increase the number of individuals with disabilities in SEM academic programs and professions. This goal is to be achieved through:

- increasing students' technical skills,
- mentoring of students by positive role models,
- involvement of students in challenging SEM activities and projects,
- building of educational opportunity and career awareness,
- building of a sense of community among participants.

METHOD & APPROACH

The model incorporates positive experiences and professional role model mentoring for students through participation in extracurricular activities. These activities are designed to utilize technology and the Internet. This focus on the Internet, and e-mail and the World Wide Web (WWW) in particular, allows for the formation of a "virtual classroom and community." These concepts are used to supplement in-person instruction and activities. Additionally, the use of the Internet allows individuals to participate in the program from a wide array of geographical locations and sites, e.g., home or school. Students currently participating in the program are regionally located, residing in Delaware, Pennsylvania, and New Jersey.

The use of technology and the Internet is supported by a loan bank of equipment. Students in need can borrow modems,

computers and software. Additionally, participants are provided with Internet accounts through the project or local Internet Service Providers.

In-person instruction and activities supplement the on-line activities. This mode is chosen when difficult concepts are being presented that require frequent interaction or to help build a sense of community. Thus, the methods used in the program can generally be divided into four types: (1) on-line individual, (2) on-line group, (3) in person, and (4) student/mentor:

On-line individual methods include instructional material and SEM based student assignments or challenges. Instructional material cover topics including computer, software and Internet use as well as disability and SEM related information. The student challenges cover various topics and principals in SEM and are named *Science Serendipity, Science Trivia, Math Mania, Math Trivia, and The Internet Pizza Challenge*. The assignments vary in their difficulty and are presented on a regular basis. The Pizza Challenge, for instance, is a monthly set of challenging questions that can are to be answered using research on the Web, and a certificate for a pizza (provided by a local franchise) is awarded to the student with the best solution. The other programs are single question contests in mathematics or science. A sample Science Serendipity Question follows:

Introduction - This Serendipity topic is, because it is winter, static electricity. My brother and I, when we both lived at home, used to try to shock each other by shuffling our feet across the nylon rug and then reaching out and touching each other with our fingers. We were great at shocking doorknobs--sparks would jump as much as half an inch! We were fairly unsuccessful at shocking each other, though we could easily shock people who weren't rug shufflers. This brings up several questions:

1. My first question is--what is serendipity? Where did the word come from?
2. What is static electricity, anyway?
3. Why does rubbing across a rug apparently generate it?
4. Why is winter best for observing static electricity?
5. Why was it much easier for my brother and me to shock doorknobs or innocent bystanders than each other in the above situation? [WWW suggestions followed in the original]

Note, additional on-line SEM curriculum examples can be obtained from the project home page **http://www.asel.udel.edu/sem/**.

On-line group methods include participating in related newsgroups and listservers as well as SEM group projects. The major group project was CyberFair 96, an international competition for students involving research and WWW page construction to present student findings.

In-person programs include afternoon workshops and a week long summer program. The workshops are designed for individuals or groups. Past workshops have covered topics related to WWW page construction, in which students designed and constructed personal web pages, and finding the right college, in which students used the Internet and a local database to help select an appropriate college. The summer program, called the Summer Science Fest, is a week-long day program held on the University of Delaware campus. During the summer of 1996 students worked in small groups to do team building, conduct Internet based research, and design WWW pages based on their research findings. The summer program also featured nature studies, conducted on-site at the Ashland Nature Center, and aerospace studies, conducted in conjunction with the Delaware AeroSpace Academy. The aerospace studies featured rocket principles and launches in addition to robotics based experimentation. College information was also featured including admissions and ADA information and Engineering Department tours. The week ended with demonstrations of the disability based research being conducted at the Applied Science and Engineering Laboratories, and had a pot-luck dinner with families and mentors where students presented their research results.

Student/mentor methods involve pairing each student with an adult mentor who provides a strong role model. Mentoring not only involves students but also families and community members (mentors, and future employers). The pairing of student and mentor is made on the basis of interest and, if possible, disability.

Interactions between students and mentors include email messages, phone calls, and in-person student-mentor visits, such as bring a child to work day.

RESULTS

There are presently 24 students in the SEM program. Their disabilities include brain trauma, spinal cord injury, cerebral palsy, learning disabilities, deafness, and visual impairment. There are approximately an equal number of adult mentors. Mentors are professionals in SEM fields who have been selected for their willingness to share information about their professional specialty, their willingness to communicate and relate to a high school student, and their ability and interest in using computer technology (email and Internet) to communicate with a student. Approximately one quarter of the mentors have disabilities.

Students have increased their facility with the Internet and with email and Web browsing tools as measured by the type and quality of their responses to the various questions and projects. Comments from cooperating institutions have been very positive in their reaction to their experience in including students with disabilities in ongoing programs, and changes in attitude by staff of these programs is evident. Parents have expressed positive feedback and gratitude for their students' inclusion in the program.

The Summer Science Fest was a resounding success. Students were queried about the Summer Science Fest experience. The students were asked to give their opinion using the scale: 1=terrible, 2=poor, 3=average, 4=good, 5=excellent. Results are reported in the accompanying Table.

Questions - Please rate:	Mean
The week overall	4.62
Team building exercise	4.33
Aerospace rocketry	4.46
Campus tour	4.15
ASEL tour	4.6
Staff's sensitivity to your needs	4.77
Staff's accommodation to your disability	4.77
Interested in add. workshops? (5=definitely yes, 3=maybe, 1= no)	4.23
Interaction with other students	4.46
Interaction with staff	4.58

CONCLUSION AND FUTURE DIRECTIONS

Through the development of this model we have found, not suprisingly, that students respond positively to various aspects of the program. For instance, some are voluminous writers to their mentors; others like in-person functions. Without exception, all enjoyed and were challenged by the summer experience. It was found that relying exclusively on on-line experiences was not as effective as a mixed on-line and in-person approach.

Future plans include: continued student mentoring, a second CyberFair entry, increased post-secondary school information and counseling, a second Summer Science Fest, and monthly learning themes of technology and career awareness.

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FROM SNAKE LIGHTS TO POWER DRILLS: USING ADAPTIVE DEVICES TO SUPPORT STUDENTS WITH DISABILITIES IN SCHOOLS

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ABSTRACT

Matching appropriate supports to students' unique needs is an essential component of providing academic and social opportunities to students with disabilities who are included in general education classrooms. Supports may require modifying the environment, adapting curriculum, accessing appropriate related services, and/or adapting equipment. The following case studies provide examples of how customized adaptive devices enable students to become productive and valued members of their school communities. In addition, the use of transdisciplinary teams to identify and meet assistive technology needs will be highlighted.

BACKGROUND

As schools attempt to meet the needs of an increasingly diverse population, teachers and other professionals must become familiar with a range of instructional supports and services. For many students with disabilities, supports may include physical/occupational therapy, augmentative/alternative communication equipment, curriculum adaptations, and assistive technology. Matching appropriate technology to a student's needs and interests is a process likely to be successful if it involves using a team approach (York & Rainforth, 1991). Ideally, this team should represent various disciplines and expertise and may include the student, family members, teachers, other related service providers, peers, rehabilitation engineers, and individuals who can offer specific technical expertise as needed. When transdisciplinary teams brainstorm solutions for modifying or customizing devices, creative adaptations and higher expectations are often the result. A university course that offers inservice and preservice opportunities for teams to create adaptations provided the resources to design the devices.

OBJECTIVE

Designing assistive technology devices for students with disabilities meets a two-fold purpose. First, students are able to more fully participate in classroom and extracurricular activities with their peers. Second, participating on Tech Teams provides hands-on experience for both professionals who must consider assistive technology in the range of supports, and for university students who are considering working in education or rehabilitation-related fields.

METHOD

The following projects were designed as part of a rehabilitation engineering course offered across education, rehabilitation, and engineering departments. Five students, ranging from ages four to 16, were targeted to receive assistive technology devices. A transdisciplinary "Tech Team" was coordinated for each student, including the student, special education teachers, occupational therapists, mechanical and electrical engineering students, and family members. The teams discussed ideas and defined a specific activity, researched commercial devices, designed a prototype, and after field-testing and additional modification,

constructed a customized adaptation to meet the needs of the student.

APPROACH

Each Tech Team met with their student in order to assess specific needs and brainstorm possible solutions. Each of the five teams designed their plan of action according to school and work schedules, family involvement, and geographical location. Most of the teams used videocameras to record initial interviews and assessments to expedite the process. Tapes were brought to class so that all teams could brainstorm additional ideas and offer unique perspectives.

RESULTS

A brief description of each of the five devices will provide an illustration of how commercially available products can be modified to meet specific educational and/or social needs of students with disabilities.

Modified bicycle: Cecilia, four years old, has a type of dwarfism which presents mobility difficulties and general physical restrictions. She attends a pre-school with children with and without disabilities, and is beginning to gain strength and confidence to walk independently. Cecilia does not want to be pushed in a stroller, but is not able to walk more than short distances. The team proposed modifying a bicycle for her to use at school and at home for increased mobility. After a great deal of research and shopping, the team found a small bicycle with training wheels which was redesigned to accommodate Cecelia's range of motion. The original frame was cut and re-welded, a new seatpost was added, supporting pieces were re-positioned, and the gear ratio was modified to provide maximum control. In addition, blocks were added to the foot pedals. Cecilia not only picked out the colors and design of the frame, but figured out that if she turned the handlebars around, she could drive the bicycle more easily.

Teacher Attention Getter: Nathan, seven years old, has spastic quadriplegic cerebral palsy. Like most second graders, he enjoys computer games, but he operates his computer by activating a single switch with his left cheek. He has no verbal speech but communicates through the computer, head gestures, facial expressions, and eye gaze. The students in Nathan's classroom quietly raise their hands to obtain the teacher's attention or to ask questions. Nathan needed an alternative way to accomplish this task. His team modified a Snake Light™ by rewiring the switch, mounting the light to PVC pipe that was painted to match Nathan's wheelchair, and mounting a small switch to a swing-away metal bar covered with pipe insulation that was positioned next to his face. The second graders suggested that the light be covered with different colored tissue paper to cut the glare.

Automatic jump rope turner: Megan, a fifth grader with cerebral palsy, uses a wheelchair. Despite her limited arm strength, Megan loves to hold the end of a jump rope (which is strapped around her hand and wrist) while a partner turns it from the other end. Megan's friends wanted to see her become more actively involved in this activity. The team modified a battery-operated drill which could be operated by a joystick. An extended arm rest with a joystick was designed which can be attached to the existing arm rest. A wheel was mounted to the drill, with an area for the jump rope to be attached. The drill was secured to the side of the wheelchair with support rods and connecting hinges. Megan operates the speed of the rope through the joystick. She has quickly learned how to manipulate the joystick, making her an eventual candidate for using a power wheelchair. Although Megan

has limited verbal skills, her pleasure in using the adaptation is clear from her expressions and laughter the first time she saw that she had control of the jump rope.

Off-road walker and carrier: Jonathan acquired cerebral palsy as a result of nearly drowning. As an 11-year old, he uses both a walker and a wheelchair, has limited fine motor dexterity, and has difficulty in eye-hand activities. Jonathan is eager to be as independent as possible and requested that his walker be modified for use at the beach and in the snow, and that his wheelchair be equipped with an attachment to carry his walker. The team designed two configurations for attaching dolly wheels to Jonathan's walker. Two wheels are attached for beach use, while all four wheels can be attached for walking through the snow. In addition, a mounting system was designed for Jonathan to carry his walker on his wheelchair. The carrier consists of two extra Quickie™ armrests, mounted to the chair, in addition to using the existing arm rests that are turned around to extend behind the wheelchair. No extra straps are needed and Jonathan can get out of his wheelchair, crawl around to the back of the chair, and retrieve his walker independently.

Walker accessory: Shelton, 16, attends a large high school where he travels from class to class using either a walker or a wheelchair. He has spastic cerebral palsy, uses pictures and sign language for communication, and attends general education classes all day. He has difficulty maneuvering through the lunch line whether he uses his wheelchair or his walker, so the team redesigned his walker for easier access and they also modified a sports bag that could be carried on a swing-away bar attached to the front of his walker. The team combined parts of two walkers, one too wide, one too short, into one walker that fit both Shelton's stature and the aisle in the cafeteria. The walker has the opening in the front. A rod was attached horizontally across the front of the walker with a clamp on one side of the front leg of the walker, and closed with a grip clip on the other leg of the walker. A nylon bicycle bag was reinforced with a plastic sheet in the bottom frame and was attached to the swing rod to make it easy for Shelton to access. He can now pick up his own lunch, carry materials independently, and is now eligible to work as an attendance monitor in the office.

DISCUSSION

In each case, the targeted student was involved in the entire design process. The use of the adaptations increased specific skills and overall independence for the students with disabilities, improved their self-esteem, and raised the expectations that peers, teachers and family members had for each student. In addition, the professionals and engineering students on the Tech Teams gained a new understanding of how assistive technology devices can expand academic and social opportunities for students with disabilities.

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SIG-07
Technology Transfer

THE TECHNOLOGY TRANSFER PROCESS: TOWARDS A CONSENSUS ON TERMS AND ELEMENTS

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ABSTRACT
The RERC on Technology Evaluation and Transfer developed and operates a program to bring new or improved products to the marketplace. The terms and elements involved in this process are not agreed upon within the field nor broadly understood outside the field. This paper defines terms used, and describes the elements within the process of evaluation, transfer and commercialization for the RERC-TET as a start toward a consensus.

STATEMENT OF THE PROBLEM
The literature describes numerous models for technology evaluation, transfer and commercialization. Even within the field of rehabilitation engineering, multiple programs recently presented their approaches (2, 3, 8).

Articles typically assume the reader is familiar with the terms used. This is a precarious assumption in a multi-disciplinary field of activity. To ensure understanding in communication, it is important to establish a basic vocabulary.

Further, the process of moving from an invention to a commercial product is commonly misunderstood. Truism like, "build a better mousetrap and the world will beat a path to your door," are not valid. In reality, the invention is merely the first step in a complex process involving evaluation, development, transfer and commercialization. It is important for inventors, innovators and entrepreneurs alike to better understand that process.

The term "technology transfer" is widely used but not in a consistent way manner. It has become a catch-all phrase to encompass various stages of technology development, evaluation and commercialization. Because the terms and the process are not well understood, expectations for technology transfer vary from overly simplistic to wildly optimistic. Technology transfer practitioners in the field of assistive technology will benefit from establishing a consensus on terms and elements.

APPROACH
The RERC-TET developed and implemented a program to intake, evaluate, develop, transfer and commercialize new or improved assistive technology products. To do so, the RERC-TET studied existing literature to identify and define terms, and reviewed operating programs to develop a viable process.

The RERC-TET has the experience of contact with several thousand inventors, the evaluation of several hundred prototype devices, and is meeting its goal of commercializing about five devices per year. The RERC-TET's activity for those three years is reported elsewhere in these proceedings (4).

In developing a process to move inventions to the marketplace, the RERC-TET selected from among the terms and steps described in the literature and in practice. They are offered here as a starting point for discussion and eventual consensus.

Technology Transfer Terms

Technology - the application of scientific knowledge in a device. The device may vary in degree of function (e.g., item, piece of equipment or product system), development (e.g., alpha vs. pre-production prototype), tangibility (e.g., hardware vs. software), and in level of complexity (low tech vs. hi-tech) (5).

Technology Evaluation - assessing the potential value of a technology as embodied in a device. A thorough evaluation assesses the device's value from technical, market and consumer perspectives, and reconciles the results within a valid methodology (10)

Technical Evaluation - the feasibility of the device functioning as expected (e.g., components that are lighter and stronger may be feasible, while anti-gravity devices may not be feasible).

Market Evaluation - the business parameters influencing the manufacture, distribution, sale and profit margin of the device as a commercial product. The closer the device matches a company's existing parameters (e.g., product line, price point, distribution channels), the more interested the company will be. (12)

Consumer Evaluation - the buyer's criteria that determine selection, purchase, use and satisfaction with the device as a commercial product. The RERC-TET's work with hundreds of focus groups has narrowed these criteria to eleven (11).

Technology Transfer - the process of taking scientific knowledge applied to one device, and applying it to another device. Such transfers can occur between and among scientific disciplines, professions, industries, economic sectors, geographic regions, or societies/countries (7).

Technology Commercialization - the process of transforming a device into a product for manufacture, distribution, sale and use in the marketplace (1).

Supply Push Transfer - a transfer activity precipitated by a technology in search of an appropriate application opportunity. For example, composite materials developed for aircraft transferred to hang gliders and then to wheelchairs.

Demand Pull Transfer - a transfer activity precipitated by an application opportunity in search of an appropriate technology. For example, orthotists called for a strong, lightweight material for external braces, and a defense contractor replied by applying composite materials used in ballistic missiles (9).

Intellectual Property Law - field of law encompassing products of the human mind or intellect (e.g., inventions, patents).

Invention - anything made that is a new, useful and unobvious, process, machine, manufacture, or composition of matter, or any new or useful improvement thereof.

Patent - a grant by the Federal government to an inventor of the right to exclude others from using, selling, or making an invention during the lifetime of the patent.

License - a written document granted by the owner of the patent, giving permission to another to make, use or sell articles embodying the invention.

Assignment - transfer of title or ownership of patent rights in a written document. (6)

Technology Transfer Process

The technology transfer process encompasses many elements, from identification and evaluation, through development and intellectual property protection, to negotiation, manufacture and sale. The following definitions provide an overview of the elements involved.

The order and role of each element is determined by the actual technology under transfer. The order and role of each element is determined by whether the transfer is driven by supply push or demand pull forces, and by the needs of the participants in the transfer process.

Identification - participants must identify a technology and a technology application, and the likely buyers and sellers needed to complete the remaining elements of the technology transfer. The relative order of technology and application determines if it is a supply-push or demand-pull transfer. The results may be indistinguishable.

Research and Development - the identified technology is applied by generating a prototype device, which is designed to demonstrate how the product will function in reality. The R&D process may involve one or more participants, depending on the resources and expertise available. The results are assessed to determine if the prototype is an invention and if that invention has value as intellectual property. If so, the owners pursue patent or other protection.

Evaluation - the prototype's potential value as a product requires assessment of its technical, market and consumer attributes. A thorough evaluation considers existing alternatives to determine if anyone really needs the product under evaluation. During evaluation, the prototype may go through multiple design iterations to meet technical, user and market requirements, including cost and production constraints.

Transfer - the prototype device and supporting evaluation documentation are offered by the seller to the buyer, along with the terms for changing ownership (e.g., license or assignment). The transfer negotiations may require additional participants to provide needed expertise, funding or marketplace support to the partners. The negotiation's success depends on the match between the buyer and seller's perception of the product's value in the market.

Commercialization - the buyer must then incorporate the product into their organization's capacity for manufacture, distribution, sale and support. Once the product is introduced, customers make the purchase decision, acquire and use the product. The outcomes from product use (e.g., utility, satisfaction) drive future sales. The company seeks customer feedback to refine the product as needed over time.

IMPLICATIONS

All the elements described above are needed to ensure a technology is successfully developed, transferred and commercialized. While every element in the technology transfer process is necessary, no one element is sufficient to guarantee the product's success in the marketplace. For example, the evaluation work may prompt a company to license the technology, but it may then delay introducing the product, or develop the product in response to internal constraints rather than in response to consumer requirements.

Further, the transfer elements are necessary for commercialization, but they are not sufficient to ensure that the customer will have a successful outcome using the product. If the product is not designed for easy use with clear instructions or training, the customer may misuse the product and thereby not gain the expected benefit.

Success stories in technology transfer are often written in retrospect. They may involve a coincidental development of need and solution, or it may be a case of the right person in the right place at the right time. The role of serendipity in the process is frequently lost in the story, but may have been critical to the transfer's success.

Technology transfer programs try to control variables that typically converge by chance -- to harness serendipity. The downside of this effort is that many attempts will fail because of the myriad variables involved. The upside is that we gain the ability to focus technology transfer on specific application areas such as on assistive devices.

Technology transfer programs have to support all the elements of the process to make it work. It is important for people involved or interested in the process to understand the terms and elements. The RERC-TET will work with other RESNA SIG-07 members to establish a consensus for this purpose.

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THE PRODUCT TEAM IN TECHNOLOGY TRANSFER

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ABSTRACT

Many factors impact the success of a technology transfer process. Good management, sufficient expertise, use of cross-functional teams and an appropriate planning strategy such as QFD provide a good start. The process continues to be refined based upon our experience with new products and commercialization partners. Three examples of such refinements are presented.

BACKGROUND

The Rehabilitation Engineering Research Center for Technology Evaluation and Transfer (RERC-TET) is a partnership supported by the National Institute on Disability and Rehabilitation Research (NIDRR). The three partners are the Independent Living Center of Western New York (ILC), the Western New York-Technology Development Center (TDC) and the Center for Assistive Technology (CAT) at the University at Buffalo. AZtech Inc. is established as the RERC-TET's business entity.

The RERC-TET's mission is to establish consumer driven processes for introducing new products into the marketplace and to improve existing products. The RERC-TET uses multiple strategies to meet this mission including: technology transfer, a process by which to transform inventions into market products; fee for service activities, which improve products already on the market; and national focus groups, which identify consumer needs not adequately met by products on the market [4].

This paper focuses on the refinements of the *product team* role in the *technology transfer process*. The product team concept was introduced early in 1996 to provide efficient, quality support of commercialization efforts while retaining the focus on the assistive technology needs of consumers.

Submitted inventions (devices) pass through a sequence of three screens: the *intake screen*; an *internal expert* review; and the *standing committee*. At each step, devices are either weeded out or the device passes on with value added. For devices having passed these screens, an *agent agreement* is negotiated between AZtech Inc. and the inventor. Product team work then starts [5].

The product team employs a *cross-functional* approach with market, technical, consumer, ad hoc and commercialization expertise assigned on a per device basis. Cross-functional teams have been shown to: pool knowledge; improve communication; help to standardize documentation and problem statement; and improve work quality [6].

Quality Functional Deployment (QFD), is employed as a planning tool for translating customer needs and expectations into company requirements. QFD has been shown to: identify features critical to the consumer; focus design efforts on critical features; support work concurrence; eliminate design cycles; reduce development time and cost; and increase profits [1,3]. QFD has prior application in rehabilitation engineering [8].

Product team support for commercialization varies on a per device basis but may include: prioritized consumer needs; competing products; market demographics; reimbursement; concept drawings, QFD product planning matrix, drawings, specifications and prototypes.

In simplest terms, a device is successfully commercialized when a company *licenses the rights to a device* and then proceeds to produce and market it.

OBJECTIVE

Product team activity has proved to add value to devices during evaluation and transfer [2]. The tools involved require continued refinement to adequately accommodate the diverse interests of inventors, manufacturers and consumers. Three refinements of product team activity and their potential impact on commercialization efforts are presented below: a) the development of a production capabilities

profile; b) production cost estimates; and c) further refinement of consumer focus groups. Case studies, based on work done at the RERC-TET, illustrate these refinements.

APPROACH

a) The Production Capabilities Profile

Product design must be coherent with a company's production capabilities and preferences. Obtaining appropriate information and applying it in a timely manner is crucial.

A license agreement is negotiated with Company B for an ADL device. During negotiations, the product team provides support including: market, competing product and reimbursement information, detailed design concepts, specifications, drawings and sub-assembly prototypes. The product team is however, slow to recognize Company B's actual production capabilities with the result that some design concepts, specifications and prototypes need to be reworked.

In response, the product team developed a company *production capability profile* to obtain information which includes: staffing; expertise; product lines; size of production runs; floor space allocation; fabrication, assembly and manufacturing infrastructure; and outsource history. This information used to: constrain design concepts, specifications and prototypes to those coherent with company capabilities and preferences; screen potential commercialization partners; and shorten license negotiation time.

b) Production Cost Estimates

A production cost estimate must reflect consumer, market and technical constraints and a company's production capability. The company often has good estimates of marketing, packaging, franking and other costs from its current product lines. Materials and assembly costs are more difficult to estimate because of their dependency upon production techniques, design optimization, use of sub-contractors and other factors. Production techniques are further dependent upon market size. As an example, milling might be appropriate at low production volume and injection molding at high volume.

An ADL device is not yet licensed. Consumers indicate that they were very dissatisfied with all related products on the market. About 90% of these consumers say they would probably or certainly buy a product having ideal characteristics at about 3 times the selling price of current products. Potential market size is roughly 80,000 unit sales per year.

Encouraged by the apparent market potential, the product team provides support including: development of market and reimbursement information, detailed design concepts, specifications, concept drawings and a concept prototype. Consumer evaluation of this prototype indicates that it is near ideal.

Company C shows interest but declines to license the product because of poor sales of *their own product* and a *belief* that the device can not be manufactured so as to hit the consumer selling price. A subsequent analysis, which includes conservative estimates of production, marketing and distribution costs indicates that this belief is probably incorrect.

In response, once a company shows interest in licensing a device for production, the product team develops a cost estimate for materials and assembly coherent with company capabilities using production practices consistent with market size. Taking this step, eliminates a company's need to estimate production costs and provides persuasive support for product profitability -- a companies basic motivation.

c) Focus Group Refinements

Focus groups are a primary source of consumer product information. Ideal focus groups are *complete* in the sense that participants are probed for expected (normally unspoken, "too obvious"); revealed (normally spoken, "seems important"); and exciting (normally unspoken, "too far fetched") product characteristics. Exciting characteristics are often obtained from technical information not available to consumers. The weight and rank

of identified product characteristics are used to focus design efforts and rationalize design trade offs resulting from cost or production constraints [7].

A license agreement is negotiated with Company A for an electronics device that has clinical applications. Prior to negotiation, the product team catalogs recommended product features. Consumer identified device characteristics are not complete, ranked and prioritized at this time.

An R&D agreement is negotiated between AZtech and Company A. At the company's request, some device characteristics are modified. Product team actions following the license agreement include: the design and testing of electronics hardware and software, documentation and CAD schematics and arrangement for a follow up consumer evaluation. Company A produces the circuit board, hardware, housing and subsequently resolves all other production issues. Consumer follow up evaluation of the prototype indicates that target device characteristics should not have been modified and a partial redesign is required.

In response, the product team worked with the ILC to strengthen the protocols by which completeness, weight and rank of product characteristics are obtained. Completeness is approached by reference to generic questions developed through a *systematic study* of information obtained and lacking in prior focus groups. *Weight and rank* of product characteristics are determined through follow up surveys of focus group participants. This information supports the QFD process and is now available at the earliest stages of commercialization for consideration by potential licensees.

DISCUSSION

Technology transfer is comprised of a sequence of steps, any of which if done poorly, lead to bad results: slow or failed commercialization or commercialization of a poor product. This paper illustrates how employing cross-functional teams within a structured analytic framework can effectively capture these steps while encouraging continued refinements to the methods employed.

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CUSTOMER ORIENTATION: A BLUEPRINT FOR ACTION

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ABSTRACT

We describe the various services offered by RERC-TET to incorporate customer input in the design and marketing of assistive technology. Our methodology enables the industry to obtain direct customer input before entering into the market and thereby minimize the risks associated with the launch of a product.

INTRODUCTION

Each year thousands of new assistive technology devices are introduced. Yet few adequately meet customer requirements [1, 2]. Most are abandoned and rarely, if ever, achieve a strong customer following. It frustrates manufacturers who claim to have invested a substantial amount of their scarce resources in the design, manufacturing, and eventual marketing of these devices. Inability to earn a reasonable economic return discourages new entrants in the market place and this negatively impacts the quality of life of persons with functional limitations.

We at the RERC-TET have urged the industry industry to adopt a customer orientation to ensure delivery of useful assistive devices and thereby gain economic success [3]. To facilitate in transition to this approach to commercialization of assistive technology, we offer a set of inter-related services at a fee to anyone interested. In the following we describe the key services.

NEED IDENTIFICATION

Although it may be possible to find creative insights in a vacuum, it may be more productive to combine creativity with information from consumers. Most consumer goods manufacturers employ consumers to identify their unfulfilled needs. These are used as a starting point when making decisions about resource allocation for developing products which offer benefits to satisfy the customer needs.

We at RERC-TET recommend employing focus groups for idea generation. The group is usually composed of 8 to 10 "end users" (persons with a disability), "secondary users" (family members or care providers), and "prescribers" (if professional selection is required). The group is brought to a central location and the members are compensated for 2 to 3 hours of their time.

Usually the discussion would begin with each participant describing how they accomplish specific tasks and when they last obtained the device. Participants would enumerate what they like and dislike about their current device and identify what requirements remain unmet. The discussion leader would engage participants in identifying how and what technology needs to be developed to improve participant quality of life. These discussions would provide a valuable insight into the customers' opinions, usage pattern, attitudes and buying processes of assistive devices. The discussions are video and audio taped and the sponsors are provided with a written report. It would help managers pinpoint gaps in the market place and identify opportunities for products to solve them.

CONCEPT DEFINITION

Customers buy products which deliver the benefits they seek. Assistive technology market is littered with products which have failed not because they were not needed but because they did not deliver what the customers expected of them. At RERC-TET we engage consumers in defining core product benefits. In focus groups customers describe the broad product concept -- e.g., an all-season cane for the visually impaired. The group identifies the key product features, e.g., comfortable grip, skid resistance, light weight, ease of assembly, etc. The moderator engages the participants in revealing their preferences -- what product features are more important, the trade-offs which they are willing to make when choosing among the alternatives in the market place. In the case of our cane, the consumers may state that comfortable grip is more important than low weight. The group also describes how they would judge whether their specific requirements have been met by the candidate device. Thus, for example, the comfortable grip may be judged by the smoothness of the shape of the handle, presence of leather mount on the handle, etc. The identification of key product features and preferences helps the manufacturer decide which benefits to include in the core product benefits and what can be done to deliver them.

CONCEPT SCREENING

The R&D team of the assistive technology manufacturers frequently develop different combinations of technology to deliver key customer benefits. These are mostly in the form of verbal descriptions and/or drawings as to how the finished product might look. Our protocols call for the use of focus groups to screen the competing concepts and identify the most attractive concept(s) to devote managerial resources. Consumers are presented with the concepts, one at a time, and asked to evaluate them in terms of their believability, likely performance, uniqueness when compared to the existing alternatives, differences from the competition, ability to meet customers' specific needs, and purchase intention. Qualitative and quantitative responses are summarized for the management to select among the alternatives for development of prototype towards eventual commercialization.

PROTOTYPE EVALUATION

A well designed product delivers the core benefits sought by the customer. Frequently, laboratory tests are used to determine the adequacy of product performance. However, such tests assume they are representative of the actual in-home usage of assistive devices. Furthermore, the usage situation may vary. For example, an all-weather cane would have a different performance in a hilly terrain versus that in a plain. A major drawback of the laboratory tests is the focus of the design team on the physical measures which are easily quantifiable rather than the softer measures such as "comfort", "handling", "feel", etc., which are difficult to quantify but may be extremely important for the consumers.

In the RERC-TET protocol, we supplement the engineering measures with the consumer evaluations under actual in-usage conditions. A representative group of consumers is recruited to provide feedback on the assistive device. Participants are provided with diaries in which they record daily evaluations of the device on core benefits and in-use characteristics (e.g., mobility of the device, operation in different locations, control, ease of operation, etc.). To pinpoint the likely advantages of the prototype in the market place, the subjects are asked to compare it with other devices which perform a similar function and provide the relative importance of the various evaluative criteria

in the purchase decision. In addition, they indicate the likelihood of buying the device should it become available in the market, and the price they would be willing to pay for it. These diaries are mailed back at the end of each day to prevent the participants from physically comparing evaluations recorded on different days. They are encouraged to identify deficiencies in the prototype and suggest how its total value could be enhanced.

Instead of in-home testing, for some technically less complex devices we employ 3-5 focus groups to evaluate the prototype. Designers who work closely with the research team employ the information gathered to make design changes and create a beta version. Using a subset of the original participants, additional focus groups are conducted to obtain consumer reaction to the relative success in interpreting consumer specifications and incorporating them in the re-design efforts. This process continues with third or even fourth generation of the prototype to ensure a satisfactory device.

OUR EXPERIENCE

Over the past three years, we have applied these and other similar protocols to dozens of assistive devices. These devices were part of our normal submissions while others have been strictly "fee-for-service" arrangements. Over 2,000 primary or end users; secondary users, e.g., family members, and professionals have participated nationwide. These individuals now comprise a data base of consumers who can be contacted for future product evaluations.

Consumers who have participated in RERC-TET's process have unanimously endorsed it. In follow-up surveys they strongly support the inclusion of consumer input in the product development and market launch processes. Additionally, participating inventors, assistive device manufacturers, and other professionals in the industry have found our process to be helpful. Their comments range from "the initial product evaluation produced valuable production information" to "(your) focus groups provided valuable consumers as well as professional input, which helped us considerably in testing price, sensitivity, perceived value, and product evaluations, in addition to consumer reaction to the basic product function."

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A PRELIMINARY CLINICAL OUTCOMES STUDY OF THE BladderMANAGER™ PCI 5000

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ABSTRACT

The Department of Veterans Affairs Rehabilitation Research and Development Service's Technology Transfer Section has initiated a clinical evaluation outcome study on the BladderMANAGER™ PCI 5000. The PCI is a portable, non-invasive, battery operated, ultrasound device that measures bladder volume. It is manufactured by the Diagnostic Ultrasound Corporation, Redmond WA and was developed to provide persons who follow a time-directed intermittent catheterization program an alternative that would allow them to measure their bladder volume and thus determine when a catheterization is actually needed. This paper discusses the preliminary aspects that were involved in bringing this technology into the VA's technology transfer process.

BACKGROUND

One of Department of Veterans Affairs (VA) Rehabilitation Research and Development's (Rehab R&D) priority area's is spinal cord injury (SCI). The VA funds R&D that can result in products or techniques with potential to: promote greater functional independence in activities of daily living, and improve the treatment and rehab of veterans with SCI. Successful outcomes are not confined to the VA but are also transferred into the national health care system where benefits can be derived by persons with similar disabilities.

Optimal bladder management is a challenge for SCI patients. Goals include maintaining renal function, continence, and avoiding infections (1). As part of a study to identify lifestyle issues that are a concern for individuals with SCI, bowel and bladder management were identified as significant concerns for people with SCI as a result primarily of the potential for social embarrassment in the event of an accident, but also because of morbidity associated with bowel and bladder dysfunction (2).

Patients are often placed on a program of intermittent catheterization (IC) as soon as possible. The IC program is time-directed with a person catheterizing every 3 to 4 hours unless they drink more than their recommended levels which would require more catheterizations. The person must limit fluid intake to guard against overdistention of the bladder.

Despite adequate technique, with expected sufficient bladder emptying, many of these patients nevertheless experience repeated UTIs. Different causes for such infections have been proposed. Possible reasons are that IC does not empty the bladder sufficiently (3) and can lead to a high percentage of unnecessary early as well as some late catheterizations (4).

At present there is no practical, portable (wearable) product that can, in a non-invasive manner, measure bladder volume.

Product Description

The BladderMANAGER™ PCI 5000 is a portable, battery operated, B-mode ultrasonic device intended for the non-invasive measurement of urinary bladder volume. A mechanical sector-scanning transducer collects cross-sectional images of the bladder from twelve scan planes. From that

information, the instrument automatically calculates the estimated bladder volume. The PCI 5000 is comprised of: 1) scanner - which consists of a control unit and scanhead connected by a cord; 2) coupling gels pads; 3) rechargeable batteries; 4) battery charger; 5) programming keypad. The scanhead transmits and receives ultrasound signals and sends those signals to the control unit for processing. The control unit processes the signals, calculates the current bladder volume, tracks time between catheterizations, displays % of bladder fullness to the nearest eighth and bladder volume to the nearest milliliter.

Patients and/or caregivers are alerted visually and/or audibly when the bladder volume exceeds a pre-programmed threshold.

The PCI can be operated in manual, reminder, auto, and lighted auto modes. The unit is supplied with coupling gel pads which are placed on the scanhead in order to transmit the ultrasound emitted by the sensor to the body of the user. Two rechargeable battery packs are also supplied with a battery charger. There are various attachment accessories available which position and hold the scanhead in position when auto mode is in use.

Programming the unit is accomplished by placing the control unit on the keypad and then entering the following data: full bladder volume, reminder interval, maximum void interval, and gender. The PCI 5000 stores the values and retains the data even when the battery pack is completely discharged or changed.

OBJECTIVE

This multi-center evaluation is being conducted to obtain clinical data to evaluate the potential for the measurement of bladder volumes by the BladderMANAGER™ PCI 5000 to affect the overall patient treatment, bladder management, and rehabilitation such that serious, or potentially serious, health outcomes are reduced, in frequency, among veterans with neurogenic bladders who follow a time-directed IC bladder management program. In addition, the study will also: 1) define prescription guidelines to include indications and contraindications for use; 2) assess ease of operation, safety, training and maintenance requirements, reliability, clarity of instructional materials; 3) obtain comparative responses from staff and subjects to prior bladder management programs; 4) identify any modifications that may be needed to improve the precommercial model for optimal use and to enhance marketability.

METHOD

The Request For Evaluation (RFE) is a screening process used by the TTS to identify developments that have reached a stage of accomplishment appropriate for acceptance as a technology transfer project. A RFE review of the BladderMANAGER™ PCI 5000, with collaboration from the Directors SCI and Physical Medicine & Rehab Services, resulted in a recommendation to proceed with a clinical evaluation.

The TTS has procured (30) evaluation units for the study. As part of the procurement contract, the manufacturer commits to marketing the product or technique; crediting the VA Rehab R&D Service in all commercial literature; and preferential pricing for VA/federal government purchases.

The TTS, with collaboration from the National Director SCI Special Programs, screened for potential VA SCI centers. Five centers were selected and agreed to participate in the study. Clinical trials have commenced and are expected not to exceed a 12 month period.

TTS, with collaboration from the National Director, SCI Programs; Director, Rehab Education Program; and manufacturer, also conducted an instructional workshop for the designated staff from each of the participating sites prior to commencement of the trials. The workshop focused on product orientation / training, evaluation protocol, roles and responsibilities, objectives and related issues. One important outcome of the

workshop was defining a UTI for the purposes of the evaluation. General consensus of the participating staff was to define a symptomatic UTI as significant bacteriuria ($\geq 10^5$ colony forming units (cfu) / ml) which may include one or more of the following signs and/or symptoms:

- Clumping of leukocytes in the urine ;
- leukocyte estrase;
- Fever (> 38C or 2° above subject's baseline);
- ⊕ nitrite;
- Cloudy urine ;
- > 10 WBCs / hpf (pyuria);
- Malaise, lethargy, or sense of unease;
- Elevated white count;
- Epididymitis;
- Increased odor or foul- smelling urine.

Asymptomatic bacteriuria, without significant pyuria, or any other systemic manifestations, represents colonization of the urinary tract and is not considered a symptomatic UTI.The VA Cooperative Studies Program, VAMC Perry Point MD, is providing data management and analysis for the study. Both user and control group subjects will be randomly selected from a pool of approximately 100 SCI patients, identified via chart review, who follow an IC program. Subjects will be accepted into the study based upon meeting specific inclusion/exclusion criteria. Measurements will be taken for both groups in a uniform fashion for statistical analysis.

Participation in the evaluation is completely voluntary. The field PI will review the informed consent with each identified subject and provide information on the purpose and significance of their participation in this evaluation. In order to ensure the collection of sufficient data, all subjects must commit to at least a six month evaluation period.

DISCUSSION

Results of the clinical evaluation will serve to validate the following primary outcomes: incidence of UTI; catheterization frequency; episodes of incontinence; and level of patient satisfaction with their bladder management program while using the instrument. It will also identify any modifications required to improve clinical application and marketability. This is an example where a federal agency (VA) and a private company, by working together, can bring about positive changes for citizens (disabled veterans and non-veterans) with a concomitant economic boost.

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ENVIRONMENTAL CONTROL UNIT

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ABSTRACT

An environmental control unit (ECU) that can be placed on a wheelchair tray was designed and built for an eleven year old boy with moderate cerebral palsy. His movement is so restricted that he needs assistance performing daily tasks such as controlling the lights in his home. The ECU remotely controls the television, VCR, and five lights in the subject's home. The ECU allows the subject to have greater control over his surroundings, which leads to increased independence.

BACKGROUND

The subject is an eleven year old boy with moderate cerebral palsy. He stands 3'6" tall and weighs approximately 48 lbs. Due to the cerebral palsy, the subject is unable to walk. Therefore, he remains in his wheelchair or lays on the floor the majority of the time. He is left side dominant and sits towards the left side of the wheelchair due to severe hip trouble attributed to irregular bone growth and poor muscle tone. Speech is functional, although difficult to comprehend at times. Range and control of motion are limited. However, the subject has good use of the 2nd digit of the left hand. Brain damage is apparent, with the subject at a level of first grade intelligence compared to the fifth grade level corresponding to his age.

STATEMENT OF THE PROBLEM

An environmental control unit was designed and built for an eleven year old boy with moderate cerebral palsy. The ECU remotely controls the television, VCR, and five lights in the subject's home. The five lights include the lights in the hallway, kitchen, family room, bathroom, and his bedroom.

RATIONALE

Due to the limited amount of independence attributed to the impaired movement caused by cerebral palsy, the subject is incapable of performing daily tasks such as operating the television, VCR, and lights in his home without assistance. Therefore, it was desired to design and build an ECU for the subject to allow him to have greater control over his surroundings and thus increase his level of independence.

DESIGN

The main components of the ECU are a keyboard, X-10 device, Emerson TV/VCR remote controller, Leapfrog, optoisolators, Basic Stamp II microprocessor, decoders, and power supply.

A keyboard was chosen to act as the interface between the subject and the ECU due to the subject's good use of the 2nd digit of the left hand. There are a total of 16 functions that can be controlled by the ECU so there are 16 keys on the keyboard. These keys are arranged in a top row of one key and three other rows containing 5 keys each. Two indicator LEDs are located in the top right corner of the keyboard. The green Led indicates that the power to the ECU is ON. The red LED provides user feedback, as it flashes after a key is pressed.

In order to control the lights, an X-10 transmitter and five X-10 receivers, one for

each light, were used. The X-10 transmitter emits a radio frequency (RF) signal which is broadcast in all directions. This eliminates a line of sight requirement and allows for a maximum range of operation of 100-150 feet. The X-10 receiver which is plugged into the same electrical outlet as the light, accepts the RF signal and correspondingly controls the light. There are two codes which must be set on the X-10 devices: a house code and a unit code. All of the X-10 devices must be set to the same house code, in this case 'O'. Each receiver is set to a unique unit code (1-8).

The television and VCR to be operated are an Emerson television/VCR combination unit. Therefore, the Emerson television/VCR remote controller was incorporated into the ECU's design. The remote controller operates with infrared (IR) signals, which requires the television and VCR to be in the line of sight of the remote controller. In order to eliminate this line of sight requirement, the Leapfrog device was included in the design. There are two components to the Leapfrog: an IR receiver/RF transmitter and an RF receiver/IR transmitter. The IR receiver/RF transmitter is attached directly to the remote control and converts the IR signal of the remote controller to a RF signal. This signal is then broadcast in all directions, thus eliminating the line-of-sight requirement. The RF receiver/IR transmitter, which is a separate unit placed in front of the television/VCR, converts the RF signal back to IR and correspondingly operates the television and VCR.

A microprocessor, the Basic Stamp II by Parallax, acts as the control mechanism of the ECU. Input from the keyboard is sent to the microprocessor which determines which key was pressed. It then sends a signal to the appropriate switch on the appropriate device (X-10 or remote controller). The microprocessor allows flexibility in the assignment of functions to keys on the keyboard. Also, it is useful in constructing a time delay in the program so that there is a refractory period after each key is pressed. The Basic Stamp II contains 16 I/O pins and an EEPROM device. The program is written in BASIC. A resistor network is used in order to determine which key is pressed. The microprocessor constantly monitors the resistor-capacitor (RC) time constant value of this network. Each of the 16 keys has its own RC value. Therefore, the microprocessor continually reads the RC value to determine which key, if any, has been pressed. In this way, the microprocessor assumes control of the ECU.

As stated above, the Basic Stamp II contains only 16 I/O pins and there are 16 inputs needed. Therefore, two decoders are used in conjunction with the microprocessor to obtain a greater number of I/O pins. The decoders are placed between the microprocessor and the X-10 transmitter and remote controller. The decoders convert a hexadecimal number output from the microprocessor back to original input and send the signal to either the X-10 transmitter or the remote controller.

Motorola H11A1 optoisolators were used to replace the mechanical switches on the X-10 transmitter and remote controller. Optoisolators are electrical integrated circuits that use LEDs and transistors to enable current to pass through, and thus close the switch.. When the LED on the input side of the optoisolator is activated, a photosensitive component allows the current to pass through the transistor which closes the switch.

The final component of the ECU is the power supply. A 12V 2.3Ah rechargeable camcorder battery by Telepower (type TP2312) supplies power to all of the ECU's components. These components consist of the microprocessor which requires an input of 7 - 15V, the X-10 transmitter which requires two input power sources consisting of 3V and 6V, the Emerson remote controller which operates

at 3V, the Leapfrog which uses 12V, and the two decoders which operate on 6V. The power to the microprocessor and Leapfrog are run directly from the camcorder battery. The X-10 transmitter, decoders, and remote controller are supplied with power through the use of a three terminal voltage regulator. The voltage regulator, the Motorola 7806, converts the 12V from the power supply to 6V. The 6V is then run to the decoders and X-10 transmitter. Capacitors are used with the voltage regulator in order to ensure a constant voltage output from the voltage regulator. The 3V necessary for both the X-10 transmitter and the remote controller is obtained through the use of a 3V zener diode configuration. This configuration steps the 6V from the voltage regulator down to 3V. This power supply methods allows for all the components to operate off a single power supply. Thus the task of recharging or replacing the power supply is optimized.

The X-10 transmitter, Emerson remote controller, microprocessor, power supply, and printed circuit board are all located inside the keyboard.

DEVELOPMENT

A custom keyboard was designed in order to allow a optimized interface for the subject. Therefore the keyboard measures 17.0" x 10.5". Square keys are used and the distance between keys is 2.4".

A clear plastic keyguard prevents the subject from pulling a key out of the keyboard or from unintentionally pressing a key, as might occur if the hand is drug across the keyboard. The keyguard has round holes, and the height of the keyguard is the same as the height of the keys on the keyboard.

It is also important to note that all of the components chosen for the ECU allow for complete wireless remote control of the television, VCR, and lights. Therefore, the subject is able to control these devices from any location in his home without any line of sight requirements. This allows for the greatest independence of the subject.

EVALUATION

The ECU has been successfully designed and implemented in the subject's home. The ECU functions as desired, and the subject is able to operate the ECU easily and with great pleasure.

DISCUSSION

The ECU provides the subject with increased independence, allowing him to control things that he never was able to previously. This increased independence will aid in the development of a greater sense of freedom and will be a positive influence on his intellectual and emotional development since he is now capable of performing more actions without assistance.

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TECHNOLOGY TRANSFER VIA INVENTION REVIEW: YEAR 3 PROGRESS REPORT

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ABSTRACT

In September 1993 the RERC on Technology Evaluation and Transfer (RERC-TET) became operational. In the subsequent 36 months, the RERC has received over 2400 telephone, mail or electronic inquiries from inventors. Those inquiries resulted in 750 submission packages being sent out, 260 device submissions, 102 product evaluations, and 43 devices deemed appropriate for commercialization. This paper reviews the progress of the program, and evaluates the results a supply push model of technology transfer (4) has in the field of assistive technology.

BACKGROUND

The RERC-TET is funded by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education and is charged with soliciting inventions of assistive devices, refining promising prototypes, and assisting them to become commercial products. The RERC-TET is comprised of four organizations, each representing a different perspective on the marketplace (1). The Center for Assistive Technology or CAT at the University at Buffalo performs administrative functions of the grant, technical evaluations of submitted devices, determines projected refinements for the submitted device and in some cases performs the research and development to complete a pre-production prototype of a device.

The Western New York Technology Development Center or TDC examines a submission's market potential, develops commercialization and marketing packages for devices, and assists with the licensing of devices.

The third and most important partner is the Western New York Independent Living Center or ILC, a consumer advocacy group. This group brings the consumer focus to submitted devices. Our Consumer Team (ILC) has consumers with disabilities evaluate the submitted device, and determine the degree of need for and how well the submitted device performs the function it is intended. They bring the consumer perspective to bear as to what features and qualities the submitted device may be lacking to make it a useful device that truly fulfills the needs of the consumers. The results of our Consumer Team's evaluation of a device's potential to address a currently unmet or poorly met need in the marketplace determines whether or not the RERC assists the inventor in commercializing the device.

A fourth entity is Aztech, Inc. a not for profit, community based enterprise run by, and for, persons with disabilities. Aztech was created by the RERC and is the commercialization arm of the RERC. Our teams solicit inventions and perform extensive evaluations of the submitted devices prior to our entering into an agreement with an inventor to seek a commercialization partner for their device.

APPROACH

The RERC-TET first implemented a program for device prospecting -- a public information effort to promote the RERC's existence and mission (2). This effort proved fruitful in providing submissions from professionals in the assistive technology field. However, the RERC was still not tapping the vast sea of inventors of assistive devices.

Most independent inventors were unaware of our existence or fearful to submit their device due to other highly publicized invention commercialization scam programs. The RERC needed to bring credibility to the process of companies and/or groups assisting inventors in the commercialization of inventions.

To enhance the RERC-TET's credibility, the RERC-TET undertook a two fold method of approaching inventors. First, the RERC-TET elected to become active in invention competitions by sponsoring or co-sponsoring inventor competitions. Our project director became a judge of the American Society on Aging device competition. Upon completion of the competition, the RERC contacted and solicited submissions from inventors of quality assistive devices. The ASA approved having AZtech Inc. co-sponsor the event in 1997.

In addition, the RERC-TET was present and distributed literature at the 1996 United States Patent and Trademark Office's Annual Conference and Exposition held at Walt Disney's Epcot Center in Orlando, Florida. We are negotiating to co-sponsor future USPTO Conferences and Expositions to increase our visibility and credibility.

The RERC-TET is also participating with Maddak, Inc. in the 1997 Design Awards Competition held normally at the AOTA conference. We will provide our commercialization review to all winners and to selected other entries. This presence along with a three-part article in the magazine "Inventor's Digest" generated a strong response from inventors. In this series of articles the RERC counseled and educated inventors on various national organizations available to assist inventors. The RERC-TET was also described in detail in these articles and this generated significant credibility for the RERC among inventors and manufacturers alike(3).

As described previously (4), the RERC-TET has a very exhaustive evaluation stage for submitted devices. After passing this stage, our Director of Commercialization enters into negotiations with the inventor and secures an agreement that allows Aztech to become the inventor's agent and seek a commercialization partner for the device. Upon completion of this agreement, the RERC-TET forms a product team comprised of members from our technical, marketing, and consumer groups. These team members lay out a scope of work and timeline for commercialization of the submitted device.

Action steps include:
Identifying relevant product manufacturers; More in depth literature search on competing products; Literature search for technical references, standards and regulations; Consumer input through focus groups held on the device determining possible product enhancements and priority ranking of characteristics; Technical analysis detailing device characteristics, technical feasibility, and product enhancements; Market analysis with a competing product matrix benchmarking competing products versus the submitted device's characteristics; Identification of the target market, distribution channels; Supporting documentation in the way of CAD drawings, pictures, or graphics; Virtual product matrix.

All this leads to a Commercialization package that is sent to prospective, previously identified companies, doing business in that device's specific market sector. These specific action steps and the RERC-TET product team process are reported in greater detail elsewhere (5).

RESULTS

Information dissemination and education of inventors, we found requires time. As more independent articles are written regarding the RERC-TET's existence, and additional news outlets pick up our story, the RERC-TET's credibility increases. Increased awareness and credibility have three positive impacts: First comes a higher quality of submitted devices. Second comes contacts from manufacturers now willing to review our devices and consider us a viable business partner in the commercialization process. Third comes requests from manufacturers seeking to tap into our knowledge regarding consumer preferences, markets, and competing products.

In the three years of the RERC-TET's existence, over 25,000 brochures regarding the program have been distributed. Those 25,000 brochures have generated 2400 inquiries regarding the program or for general information regarding assistive technology. From those 2400 inquiries we have ascertained that approximately 800 callers possessed prototype assistive devices and we have sent out 750 of our submission packages. To date 260 packages have been returned by inventors as submissions. Again as stated previously [1], the majority of these device submissions are rejected in our initial screening process. Rejection reasons vary from existence of a competing product unbeknownst to the inventor, to technical unfeasibility, to existence of other technology that performs the same function, to not being an assistive device, to the almost non-existence of a market for a potential product. Forty-three of the 260 (17%) device submissions have passed our evaluations.

As we evaluated more devices, our screening process became tighter. Rejections increase as we become more adept in our competing product searches, and our consumer, marketing and technical screening processes.

Of the forty-three devices that passed our evaluations, some represent new and unique solutions to meet unmet functional needs. An

example is the Universal Lift, a mechanical transport device for raising and lowering an impaired person between the ground and a higher level for boarding and deplaning from a helicopter and commuter airplane. (patent # 5,489,181)

Other devices address functional needs that are currently met -- but not adequately met -- by devices available in the marketplace. An example is the Flasher Timer, a timing device that functions to alert the user, who may have a hearing impairment, dual sensory loss (vision and hearing), or developmental delays, by simultaneously ringing a bell and flashing a strobe light.

Inventors of devices that have passed our screening processes and fulfill an unmet or poorly met need are offered agent agreements by the RERC-TET. Under the terms of those agreements, the RERC acts as the inventor's licensing agent attempting to secure a license of the device from a manufacturer. Thirty-one of the 43 inventors who were offered agent agreements accepted. Seven products are manufactured, licensed or marketed via agreements with Aztech, Inc.

Four products are manufactured or marketed without agreements with Aztech, Inc. but with significant assistance from Aztech. As an explanation we provide the results of our evaluations to inventors along with a listing of target commercialization partners for the inventor's device. In some cases the inventor has rejected our offer of becoming their licensing agent and has used our reports and referrals to secure a license agreement from a manufacturer on their own.

Twelve more devices are in the process of being manufactured, licensed or marketed with assistance from Aztech. The balance of the agent agreements have been terminated as a result of technical problems, companies offering license terms that did not meet the high expectations of inventors, or through lack of interest being shown on the part of manufacturers. We continue to review devices to refresh the pool of agent agreements we have in our portfolio.

DISCUSSION

The underlying basis for a supply-push model is that there are useful devices languishing as prototypes and with the appropriate assistance they can be pushed into the marketplace. From our results of 43 viable devices from 2400 contacts, we can attest that a supply-push model (4) requires a great deal of effort to sustain a flow of devices.

We have found that an invention evaluation program needs time to become known as a viable, trustworthy business organization. Credibility builds over time as the program becomes well known and its success stories are documented. Along with this increased credibility comes an increase in the quality of invention submissions. Manufacturers are beginning to see the RERC-TET as a resource, providing both viable consumer approved new products for their business and consumer, marketing, or technical input to their existing products.

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An Elbow Orthosis that Assists with Flexion of the Arm

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ABSTRACT

We designed an elbow orthosis to supply functional flexion of the elbow for an individual with a brachial plexus injury. The orthosis consisted of two orthoplast pieces with velcro attachments for the forearm and upper arm; two .25 inch elastic cords and two velcro neoprene pads. The first author wore it for work and on vacation and reported increased functional use and was able to wear it for up to 10 hours without complications. The design of the orthosis was light-weight and easy to don/doff by the first author. Future models of this type of orthosis could use light-weight spring steel attached to the side of or posterior to the elbow.

INTRODUCTION

Commercially available elbow orthoses are primarily designed and constructed for rehabilitation purposes and/or to maintain joint alignment and range of motion [1]. These orthoses can be large, uncomfortable and difficult to put on and limited function is gained by their use so that the end result is that they are not used regularly. The purpose of this research was to design and introduce an elbow orthosis that helped the first author with his brachial plexus injury which was light-weight, comfortable, easy to don/doff and functional in daily activities.

Individuals that sustain a brachial plexus injury have a wide range of function and/or limits with the arm and hand. Most traumatic brachial plexus injuries involve, to some degree, loss of function to the shoulder joint. Most of the elbow orthoses do not address this issue in the construction and design of the orthosis. This might result in adding function to the elbow, but could also increase discomfort and/or pain to the surrounding areas of the body. Some orthoses are designed with protrusions on the medial side of the orthosis that can cause pain, discomfort, and/or further injury to the side of the chest because the individual cannot do shoulder abduction thus the arm and the protrusion rest against the chest wall [2]. This pain can also lead to the individual not using the device. So they might have had to pay a lot of money for a device that provides no additional function because it is not used.

This paper will concentrate on the design and testing of an elbow orthosis to assist the first author with flexion of his right arm. A lot of the devices available to individuals with brachial plexus injuries are not always comfortable and/or easy to don/doff. Also, the devices are not always functional for everyday activities and are very limited in function for outside activities. When an individual sustains a brachial plexus injury, the level involved at the spinal column is C4 through C8. Flexion of the arm is innervated by nerves at the C5 level and the shoulder abduction is innervated by nerves at the C7 level [3].

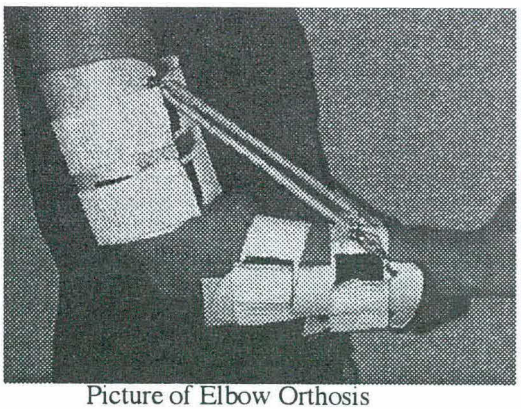
METHODS

The first author was involved in near fatal car accident and sustained a subluxation of C1 and C2. The two vertebraes were fused and it was subsequently found that the first author experienced nerve-root avulsion at level C5 through C7 on the right side. The first author has limited bicep use (latissimus dorsi transfer to bicep tendon), no deltoid or shoulder function, but EMG studies showed that the tricep function was 80% and the right hand function was 95% of normal. The subject had tried an elbow orthosis that did assist with flexion of the arm, but there was a projection off the side of the device that irritated the individual's side especially when the arm was being flexed. The device's set-up was very uncomfortable and the subject would not wear it for any length of time so that it was not effective.

Lengths of the arm were measured: acromion process to the horizontal level of the axillary region, 3.25 inches; axillary region to the olecrannon, 10 inches; and olecrannon to the ulnar styloid, 10.5 inches. A model of the

forearm and upper arm pieces were made to fit the first author's right arm and the length of the two pieces were determined to be 7.75 inches for the forearm piece and 7.25 inches for the upper arm piece. The models were then used as blueprints to cut the orthoplast pieces. The pieces were formed to craddle the under side of the forearm and the posterior side of the upper arm. The forearm piece extended from 2 inches below the olecrannon to 1 inch above the ulnar styloid. The upper arm piece extended from just below the axilla level to 2 inches above the olecrannon. A velcro neoprene pad was placed under the orthoplast, and the pieces were secured to the arm by padded velcro at both ends of the pieces.

Water was heated to 160° in order to make the othoplast pliable to form it to the arm. The orthoplast pieces were secured to the arm by ace wraps until the orthoplast pieces were harden. The pieces were then trimmed to round the edges and make them more comfortable to the first author. Padded velcro straps were attached to both ends of the pieces. Holes were put in the forearm piece near the radial and ulnar styloid for the elastic cord to be attached to the piece. An eye-bolt was attached to the upper arm piece 4 inches above the olecrannon and both elastic cords from the radial and ulnar styloid were attached there. The elastic cord was cut to a length so that the arm was held in a flexed position, but the cord was not stretched at this time.



Picture of Elbow Orthosis

RESULTS

Measurement of the forearm, from the olecrannon to the ulnar styloid, was 10.5 inches and the upper arm, acromion process to the olecrannon, was 13.25 inches. Measurement from the acromion process to the axillary region was made in order for clearance of the upper arm piece. The length of the forearm piece was made to be 7.25 inches and the upper arm piece was 7.75 inches so the pieces did not inhibit the flexion of the arm. Two .25 inch elastic cords were secured to the forearm piece by the ulnar styloid and the radial styloid and both were connected to the lateral side of the upper arm piece, 4 inches above the olecrannon. The elastic cord was cut so that the elbow was flexed near 90° and the cord was tight but not stretched. This allowed the first author to extend the arm using his tricep (stretch the cords) and then the cords would recoil and flex the arm. The elbow orthosis provided the first author with a range of motion (ROM) from 90° to 175° with these elastic cords.

DISCUSSION

The elbow joint was used as the axis of rotation with this elbow orthosis, which helps minimize the possibility of further injury to the joint. With a brachial plexus injury there will be, in some degree, loss of function to the shoulder musculature because the arm flexors and the shoulder muscles are innervated by the same spinal cord levels (C5-C7). The design of this elbow orthosis compensates for the shoulder musculartur function limitations.

The elbow orthosis is light-weight, comfortable, easy to apply to the body and can be worn under clothing. It provides flexion of the arm for the first author and helps in daily activities. Without flexion of the arm, the first author's arm would just hang at the side or rest on top of the desk or table with limited function. With flexion of the arm, the first author's arm is in a more functional position, and allows the first author to use his right hand without having to lift the right arm and hand with the left arm. Acceptance of an orthosis and the usage of it can be determined by the comesis, weight and function gained [4].

The first author wore the orthosis at work and while on vacation from 2 to 10 hours a day. The first author found that he started

using the right arm without thinking about it. The upper arm piece slid down at times, but it could be pulled back into place. The first author had no problems doning/doffing the orthosis and felt that it significantly increased the function of his right arm. The ROM was from 90° to 175° with these elastic cords. A tighter elastic cord could be used to flex the arm more, and bring the arm into what previous research has stated is the functinal ROM for the elbow, 30° to 130° [5 & 6].

This type of elbow orthosis can be made for other individuals with a brachial plexus injury by forming the forearm and upper arm orthoplast pieces and connecting the elastic cords. The lengths of the arm can be accomodated for when making the othoplast pieces and the elastic cords can be cut to different lengths or a bigger diameter of elastic cord could be used, if needed, to compensate for a larger arm. Future models of this type of elbow orthosis might be able to use spring steel molded to a 90° angle and fitted to the individual's elbow on the side or posteriorly. The resistance of the spring steel could be adjusted depending on the individual's tricep strength to extend the spring steel out.

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SIG-08
Sensory Loss and Technologies

DEVELOPMENT OF A COMPUTER-BASED INTERPRETATION SYSTEM FOR DEAF-BLIND INDIVIDUALS

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ABSTRACT

Communication is the basis of human interaction. The barriers to communication that deaf-blind individuals face deny them of many independent interactions with the world. The project combines several recently available technologies into a system which reduces the need for an interpreter, thus allowing greater independence and interaction with the world.

BACKGROUND

Deaf-blindness is any condition in which a combination of visual and hearing impairments cause a severe communication and/or developmental gap (1990, IDEA, Sec. 622). This dual-sensory impairment causes deaf-blind individuals to experience the world in a unique way.

The problems deaf-blind individuals face include a feeling of isolation, a lack of independence, difficulty in obtaining education, and inadequate employment opportunities. In the past, overcoming these obstacles has been difficult, if not impossible. The underlying foundation of these problems is a barrier to communication. Combining recently developed technologies to facilitate communication will allow deaf-blind individuals to bridge the communication gap.

STATEMENT OF THE PROBLEM

Recent surveys estimate that there are 45,000-50,000 individuals who are deaf-blind in the United States (Baldwin, 1994; Watson, 1993). Communication is one of the largest barriers to independence that this population must overcome. One common approach to the communication barrier is to use an interpreter. However, due to circumstances such as scheduling difficulties and high demand for their services, interpreters are often a limited resource.

If the need for interpreters could be eliminated or reduced, the independence of deaf-blind individuals would be greatly improved. We have designed a computer based system which allows deaf-blind individuals to achieve this freedom.

RATIONALE

In order to be successful, the design process for this new communication technology has incorporated significant user input. This project involves both authors, (undergraduate students in Biochemistry and Computer Science, respectively), one of whom is deaf-blind, as both developers and users. Furthermore, it employed a technique known as *scenario-based design* (Carroll, 1995) in which the intended user does not have to articulate his/her needs, but participates in the development of performance scenarios. The project team brainstorms and writes a trial scenario describing the technology and the interactions of the users. (Users include both the deaf-blind individual and the those with whom he/she communicates.) The team assesses the scenario by "acting it out" and identifying aspects that are useful as well as noting problems. The scenario is then modified and evaluated in a repeat performance. This process is continued until a truly user-responsive scenario is achieved. This approach identifies important design issues that often would not have been obvious to users in more traditional interviews

and questionnaires.

Initial scenarios determined that current computer technology cannot replace the skills of human interpreters entirely. Scenarios where technology attempted to replace interpreters were unsuccessful. More appropriate were situations where technology could provide services that allowed effective conversation when an interpreter was unavailable. After a number of iterations, the following scenario was found to be very useful. It incorporates the flow of movement and actions comfortable to users, it respects personal space and normal conventions of social interaction, and it accommodates the limitations of commercial computer technologies.

The deaf-blind user is working in an office with a computer. A co-worker enters the room, triggering a device that sends a signal to the user, announcing the co-worker's presence. The user's choice of responses includes: acknowledging the co-worker, ignoring the co-worker, or indicating that the co-worker should come back at a more convenient time.

Once acknowledged, the co-worker lifts the handset, says, "Hello," and several processes begin simultaneously. In the background, without interrupting currently open applications, the computer chooses the appropriate voice file for the co-worker. Additionally, a second signal indicates that the co-worker wishes to speak to the user.

Once the user is ready to converse, a pre-defined key combination accesses the communication software. The communication window is a split screen with the co-worker's remarks occupying one half and the user's comments in the other. The Braille terminal displays the co-worker's name based on the selected voice file and conversation can then commence. As the user types comments into the window, the speech synthesizer converts the text to spoken language. As the co-worker speaks into the handset, speech recognition software translates the spoken words into text, which is output to both the monitor and the Braille terminal. Once the conversation is finished, the co-worker leaves, and the user returns to work.

DESIGN/DEVELOPMENT

The system described in the scenario was implemented as a laboratory prototype. The front end software integrates several components to translate speech to Braille, and keyboard input to synthesized speech. After careful consideration, the following hardware and software components were determined to best meet our needs.

Desktop design: an Intel based Pentium for office/workstation use

Laptop design: portable, lightweight, and widely available in many configurations for flexible use

Windows95™: multi-tasking operating system, fully compatible with preferred software packages

JAWS for Windows: translates windows for output on ALVA Braille terminals

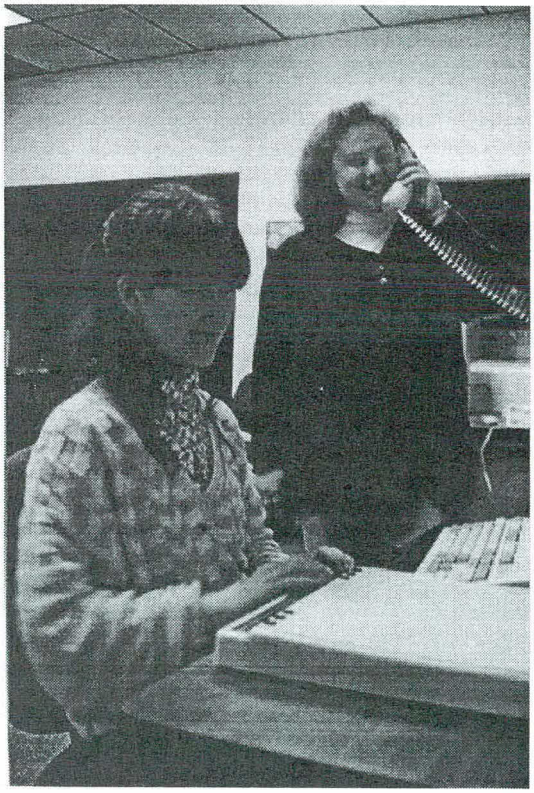
43-cell ALVA Braille Terminal: portable 43-cell Braille output device

DragonDictate® v2.0, Classic Edition: commercially available software package from Dragon Systems, Inc., allows complete voice control of system, most integrated and sophisticated voice recognition software available for the PC

Telephone Microphone Unit: For the desktop system: high-quality microphone placed into wall mounted telephone handset, plugs into the standard microphone input of the sound card in the computer, allows easy placement of the microphone near the mouth; For laptop system: a small hand held microphone

ASEL Text-to-Speech: speech synthesizer developed at the Applied Science and Engineering Laboratories

Microsoft Visual C++: powerful, object-oriented, windows programming language used to integrate the components of the project



RESULTS

One possible limitation of the system is that DragonDictate® requires speaking in isolated words. However, we found that the speed of conversation was still close to 50% of spoken conversations (100-150 wpm) and equivalent to interpreted conversations. Deaf-blind interpretation consists mainly of finger spelling at approximately 60 wpm. DragonDictate® can translate trained voices at speeds of 60 wpm, and untrained voices at 40 wpm. The speech synthesizer is limited only by the typist's speed.

DISCUSSION

Based upon both feedback from deaf-blind users and the number of deaf-blind people in the United States, we are confident that a market exists for this product. One of the many benefits of this system comes from eliminating the costs associated with hiring an interpreter. This, in turn, opens many doors, including increased educational opportunities and a wider range of available jobs.

In the future, many additions could be made to the system to enhance independence even further.

Attaching multiple microphones to one system would allow the user to attend a business meeting or other gathering. The system would filter out each voice and preface the Braille output with the speaker's name.

Instead of voice files specific to a single person, files could be location specific. The file would include phrases commonly heard at that location. A fast food restaurant would include such phrases as "May I take your order, please?" and "Your total is...", as well as words such as fries, dollars, and milkshake.

If a TDD/TTY and modem are added to the system, it could serve as a total communications unit for the deaf-blind individual, allowing communication not only in person, but also over the telephone.

The purpose of this system is to assist deaf-blind individuals in solving the unique communication problems they experience. The portability, user friendly design, and state-of-the-art technology inherent to the system combine to give the deaf-blind individual greater control over interactions with the everyday world and to establish personal independence.

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TACTICS: A TACTILE IMAGE CREATION SYSTEM

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ABSTRACT

Visual information is increasingly important yet methods for its access by blind persons are inadequate. This paper describes and evaluates TACTICS, a system for the automatic visual to tactile translation of digitized images. The results of experiments testing perception of TACTICS-generated tactile images are provided.

BACKGROUND

Access to visual information can widen the avenues of professional and social interactions for blind persons. Yet, while the volume of such graphical information increases, as with the ubiquitous Internet, methods for meaningfully exploring this information are not keeping pace.

Computer text is accessed using speech synthesizers and braille displays and printers. Graphical information, however, is virtually inaccessible, a significant barrier for the blind computer user.

The conversion of visual information to static tactile form can be time consuming, involving the assistance of a trained sighted person [1]. Research in the areas of dynamic tactile displays and multimodal feedback systems is active [2, 5], although technological advancement has been slow.

Investigation in the area of *tactual perception* [3] identifies important factors that can guide the translation of visual information into a meaningful tactile form [6]. These factors include the disparity of resolution between the eye and fingertip, optimal size for a tactile graphic, and how the mind classfies and uses visual information.

This paper describes a unique system for the automatic translation of visual images into tactile graphics, or *tactics*. The TACTile Image Creation System (TACTICS) combines lessons learned from the areas of human perception and tactile graphic production with image processing techniques. The results of four experiments designed to test this system are reported and discussed.

RESEARCH QUESTION

Can visual images be automatically translated into tactile images such that a blind person can make meaningful use of the result?

METHOD

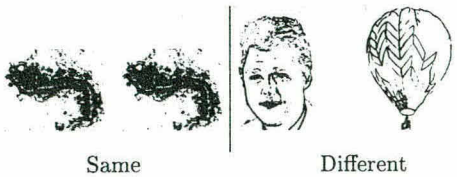
The process of converting a visual image into a tactile one using TACTICS requires three steps: (1) *acquisition*, where the original image to be viewed is obtained, in this case from image databases on the Internet and elsewhere, (2) *simplification* using a number of image processing techniques [4] to reduce the level of detail and complexity of the original (Figure 1), and (3) *rendering* in tactile form, during which the simplified image is output on microcapsule paper.

Four experiments were performed to



(a) None (b) Sobel (c) K-means (d) Aggregate

Figure 1: TACTICS image processing. Aggregate process is blurring, edge detection, segmentation and median filtering.



Same Different

Figure 2: Discrimination experiment examples.

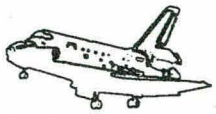


Figure 3: Identification experiment example. Which best describes this image?
(a) shuttle (b) shark (c) bus (d) Florida

measure how TACTICS processing affects four types of tactile image perception. Simple- and timed-discrimination tasks tested the effect of four forms of processing on the ability of a subject to discriminate between randomly matched pairs of tactile images, with and without a time deadline, determining whether each pair was the same or different (Figure 2).

An identification experiment measured the effects of the same processing on a subject's ability to identify the content of a series of tactile images, categorizing each into one of four possibilities (Figure 3).

Comprehension was measured using a series of tactile images, each with a brief textual description and questions testing the ability of subjects to explore them, then understand features, locate features, and reason about image content (Figure 4).

Ten subjects were used, ranging in age from 22 to 60 and with little or no previous experience with tactile images. Seven subjects were male and three were female. Three were blind and seven were sighted and blindfolded. Forty trials of the simple- and timed-discrimination and identification experiments, and ten of the comprehension experiment were performed for each subject. Empirical and observational data was collected during the experiments.



Figure 4: Comprehension experiment example.
Description: This is a personal computer.
Understanding: This is a:
(a) desktop computer (b) notebook computer
Location: Locate the keyboard.
(a) (successful) (b) (unsuccessful)
Reasoning: Is the computer on or off?
(a) computer is on (b) computer is off

RESULTS

Tables 1, 2, and 3 contain the results of the simple- and timed-discrimination, identification, and comprehension experiments. These results are reported in exhaustive detail in [6].

DISCUSSION

Subjects performed well on all tasks, indicating that the image processing techniques used in TACTICS are beneficial to discrimination, identification and comprehension of tactile images.

Discrimination for all subject groupings improved with use of the more involved aggregate processing compared with the other forms tested, indicating that simplification improves discrimination. While overall performance degraded slightly with the added pressure of the timed-discrimination task, blind subjects tended to perform somewhat better, perhaps a result of a greater inherent reliance upon the sense of touch for perception in general.

The identification experiment proved the most difficult for subjects, with the best results again for the aggregate process. Sighted subjects performed 15% better

Table 1: Correct response rates: simple- and timed-discrimination experiments. (Chance rate is 50%.)

	Simple				Timed			
Processing	*Blind*	*Sighted*	*Overall*	*p*	*Blind*	*Sighted*	*Overall*	*p*
None	53%	53%	53%	2.9e-1	43%	60%	55%	6.5e-1
K-Means	83%	82%	82%	6.0e-1	87%	73%	77%	4.9e-1
Sobel	63%	84%	78%	6.4e-2	73%	73%	73%	1.9e-1
Aggregate	90%	96%	94%	7.5e-1	93%	84%	87%	7.5e-1

Table 2: Correct response rates: identification experiment. (Chance rate is 25%.)

Processing	*Blind*	*Sighted*	*Overall*	*p*
None	10%	6%	7%	4.8e-1
K-Means	57%	54%	55%	7.9e-1
Sobel	43%	47%	46%	7.2e-1
Aggregate	77%	89%	85%	1.1e-1

Table 3: Correct response rates: comprehension experiment. (Chance rate is 50%.)

Processing	*Blind*	*Sighted*	*Overall*	*p*
Understanding	90%	80%	83%	6.5e-8
Location	69%	89%	83%	3.5e-9
Reasoning	79%	79%	79%	4.5e-14
Overall	80%	83%	82%	1.4e-15

than blind subjects, possibly due to the visual nature of the image content.

Subjects performed quite well on the comprehension experiment, suggesting that even brief textual descriptions are beneficial. Blind subjects performed better with content understanding tasks, perhaps due to a more practiced reliance on the sense of touch.

Observations made during the experiments include that both blind and sighted subjects (1) developed identical strategies for tactile image exploration, (2) provided unsolicited and accurate remarks about images indicating deeper comprehension than was measured, and (3) had corresponding ease or difficulty with many of the same tactile images.

The significance of these results is that they demonstrate that reasonable and comprehensible access to visual information *can* be provided to blind persons, and be done so without the intervention of a sighted facilitator. Thus, a blind computer user might one day "surf the web," browse a CD-ROM collection of computerized images, or navigate a GUI, unaided and with a better degree of comprehension than is currently possible.

We plan to investigate TACTICS as a visual pre-processing front-end for dynamic tactile displays, and to extend its development to a stand-alone user application.

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SIG-09
Wheeled Mobility and Seating

POWERED MOBILITY AND YOUNG CHILDREN WITH DISABILITIES

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ABSTRACT

A five year research project investigating cognitive readiness for powered mobility in young children with physical disabilities was recently completed. Twenty-six children between the ages of 18 to 36 months participated in a cognitive assessment battery and powered mobility program developed for the project. The results indicated that a certain level of spatial relations and problem solving skills were needed for safe, functional powered wheelchair mobility. The *Pediatric Powered Wheelchair Screening Test (PPWST)* and *Powered Mobility Program (PMP)* were the outcomes of the research project.

BACKGROUND

Previous research in developmental psychology has found that the ability to move about independently is a critical facilitator in a child's development and can impact cognitive, social and communication skills. Young children who are unable to move independently are at risk for developmental delays. Due to limited availability of clinical assessment instruments and research information, it is often difficult to determine when a young child with mobility impairments may be developmentally ready to learn to operate a powered wheelchair functionally. This project focused on identifying one of the components influencing functional powered wheelchair mobility. It was funded by the National Institute on Disability and Rehabilitation Research as a Rehabilitation Engineering Research Center on Technology for Children with Orthopedic Disabilities.

RESEARCH QUESTION

The objectives of the project were to better quantify the cognitive developmental skills necessary to learn to operate a powered wheelchair functionally and to develop an age-appropriate powered mobility program.

METHOD

Twenty-six children between the ages of 18 and 36 months participated in the study. In order to minimize the influence of sensorimotor integration problems, children with disabilities that impaired primarily physical abilities took part. The primary diagnoses included arthrogryposis, muscle diseases, spinal cord injuries.

To determine which cognitive developmental skills were more influential in learning to operate a powered wheelchair, an assessment battery was compiled (1,2). The original assessment battery consisted of five Piagetian-based scales evaluating cause-effect, object permanence, problem solving, spatial relations, and symbolic play. The Piagetian-based approach was selected because it is a well-researched, validated theory of early childhood development and is appropriate for children with disabilities (2).

The *Powered Mobility Program (PMP)* was designed to introduce children to a wide range of wheelchair skills through exploratory play (4). The *PMP* consisted of 34 tasks that represented a hierarchy of mobility skills. The *PMP* approach involves spontaneous

exploration of movement and play, progressively introducing tasks to transition the child to more functional skills needed to safely maneuver a power wheelchair. The child's abilities were scored according to the amount of hands-on assistance and verbal cueing needed to safely maneuver the wheelchair. The scoring definitions describe the child's ability to functionally operate the wheelchair and could be used to support the purchase of a powered wheelchair. They also objectively describe why a child may not yet be safe in a powered wheelchair and may be more appropriate for another type of mobility device.

RESULTS

The Rasch statistical analysis was applied to the data from the cognitive developmental assessment battery using the BIGSTEPS program (5). The Rasch analysis achieved several purposes. It eliminated items that were "misfit" and/or not variable in terms of difficulty. Additionally, it converted ordinal date to interval data by giving weighted scaled scores. Following this analysis, the five Piagetian scales remained, but had been reduced from 148 possible item responses to 35 items. The remaining 35 items demonstrated high internal consistency within their respective scales.

To determine which cognitive scale domains predicted performance on the wheelchair tasks, a stepwise multiple regression was performed. Scores on the five cognitive tasks were used as predictors, and the score on the wheelchair battery was used as the criterion. The two cognitive scales of spatial relations and problem solving were significant and accounted for 57% of the variance (R^2=0.57; F=14.37, p<.0001). Consequently, the final cognitive screening battery consisted of the spatial relations scale and the problem solving scale containing a total of fifteen items. This screening battery has been titled the *Pediatric Powered Wheelchair Screening Test (PPWST)*.

DISCUSSION

The research study showed that when children (who have only physical disabilities) demonstrated a certain level of problem solving skills and an understanding of spatial relationships, they were more successful at learning to operate a powered wheelchair safely. If powered mobility is a consideration for a young child, these two skill areas could be targeted in early intervention programs. The *Pediatric Powered Wheelchair Screening Test (PPWST)* is composed of the relevant test items from the results of the study (6). The *PPWST* is designed to act as one component of a comprehensive powered mobility evaluation of a child with physical disabilities. It is important to state that while the cognitive developmental skills identified in the project are important, they are not the only elements involved in successful powered mobility. Temperament, coping skills, motor access, sensorimotor integration, parental involvement, and environment are also instrumental factors to consider when evaluating a child for a powered wheelchair.

The *Powered Mobility Program (PMP)* can be used as clinical guidelines for adults and children with a variety of disabilities (6). The PMP skills and scoring can be used as for objectively recommending a powered wheelchair or for focusing on those areas that need further training. The approach emphasizes motivational learning and relies upon the child's readiness to learn given the opportunity.

Further research is currently being conducted on the reliability and validity of the *PPWST* and *PMP* through a three year multicenter trial. The goals of the new project are to strengthen the predictive power of the PPWST by adding

components to evaluate coping and symbolic representational skills. The project is also addressing the applicability of these instruments to other populations by including children with cerebral palsy. Six sites in the United States and Canada are participating in the study.

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A DEVELOPMENTAL APPROACH TO FUNCTIONAL POSITIONING FOR YOUNG CHILDREN

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ABSTRACT

This paper will present a framework for providing positioning and wheeled mobility equipment to young children based on developmental theories. Goals: provide functional positioning for young children - provide assistive technology that is developmentally appropriate - look at patient as a whole with social, cognitive, communicative as well as physical needs - use resources wisely. By understanding and applying developmental theories, Assistive Technology Providers (ATP's) can provide the right amount of technology at the right time and plan appropriately for the future.

BACKGROUND

Meaning of Function for the Pediatric Population

Function can be defined as the "normal and specific contribution of a bodily part to the economy of a living organism." (Webster, 1985). Vegetative functions include breathing, swallowing, digestion. Developmental *f*unctions include physical growth, posture and motor control, mobility, cognition and language, and the move towards independence. Additionally, social/interactive *f*unctions exist (see below) which are of equal importance but often neglected during AT evaluations

Attention to the Concept of an "Interactive, Shared Reality" (ISR) (Emde, 1987).

The individual not only exists in an environment that has an effect of her/him, but s/he impacts the environment. It is not simply one organism acting on the other, but the evolving *interaction* between individuals that defines the human ISR. Babies are born preadapted to social interaction, eg. infants participate actively in a social support system with caregivers. By seven to nine months this develops into "intersubjectivity", or "mutual faith in a shared world" (Emde, 1987). At this age infants begin developing a personal memory which contains knowledge structures of a "we".

Where delayed or failed development alters development of a mutual faith, technology can be applied to support gains in physical, cognitive, communicative and social growth.

The Environment

The physical environment often imposes constraints, or demands compromise to "ideal" recommendations. Size and levels of living space, transportation issues, school, age and number of caregivers are just a few such considerations. This article will not focus here.

OBJECTIVE

The objective of this work is to provide a framework, based on developmental theories, which Assistive Technology Practitioners can use when providing positioning equipment and mobility bases to infants and young children.

APPROACH

Infancy (birth to age 1)

Functional Development: During the first year, a child experiences rapid physical growth, amazing changes in oral/motor abilities, and initial independent mobility. The ISR is expanding beyond the initial diad to the family unit. Goals for the child include providing developmentally and maturationally appropriate supports which allow development of anti-gravity extension, then flexion, then balance and the beginnings of mobility.

Additionally, safe and appropriate dependent mobility in the home and outside it is critical at this age. Supports must be provided under a variety of circumstances: to facilitate safe bathing and feeding, increased social interaction and mobility.

As Assistive Technology Providers, our objective is to meet the above goals in a cost efficient manner using "normal baby" equipment as much as possible, since it is built to provide full external support to individuals

lacking head and trunk control. Extra support is then provided as needed. It is usually prudent to wait until the child is older before deciding on adapted mobility bases and seats (and spending a lot of money); exceptions include severe conditions when little/no improvement is expected (eg. ancephaly).

Positioning: Infant seats can be used with rolled cloths to provide extra control. Ethafoam blocks can be used to add support to high chairs, and footrests can be added to provide babies with a firm base of support. Corner seats with trays allow kids to work on upright sitting and upper extremity activities as early as 6 months even without development of trunk control. However, these adapted seats can be very expensive.

Mobility: Strollers are developmentally appropriate mobility devices. If more supports are needed, extra straps, foam positioning blocks, or full seating inserts can be added.

Transportation: Children can and should always be transported in normal car seats.

Toddlerhood (1 to 3 years)

Functional Development: Toddlers experience continued rapid growth with an increase in independent exploration and mobility. There is rapid acquisition of cognition and language. The ISR grows with the addition of a (mostly parallel) peer group through infant stimulation programs, daycare, siblings and extended family. Goals at this age emphasize continued provision of developmentally appropriate supports with increased emphasis on mobility and play. All equipment must allow for growth and change. This is a transition time away from "normal baby" to commercial adaptive equipment. Our objective must be to meet goals with more emphasis on the client and less on parental convenience.

Positioning: Children at this age progress from stability through mobility. Often external stabilizers are required to allow the child to begin moving any body part independently: head, extremities, or trunk. Developmentally appropriate equipment includes child-sized rocking chairs, ride-on toys, growth-adjustable seating systems, and wheelchair frames.

Mobility: Appropriate mobility bases for toddlers include manual wheelchairs (or continued stroller use) for dependent use (upright or tilt-in-space), manual wheelchairs for independent propulsion (often front wheel drive), and power wheelchairs (or power vehicles).

Transportation: Normal car seats can still be used unless deformities are severe.

Preschool (3 to 5 years)

Functional Development: Skeletal growth slows compared to earlier stages. Rapid acquisition of cognition and especially language abilities continues. This is a time for children to assert independence. The need for independent mobility should no longer be pushed aside in favor of bipedal ambulation goals, for it is only through *doing* that a child can develop a self-image as one who can master a challenge by his/her own efforts. This produces motor, affective, *and* cognitive changes which then predispose for more efforts. The ISR provides for independent and cooperative play; accommodating pre-school goals, teachers, and peers is paramount.

During preschool years there is increased emphasis on independent transfers, mobility, speed, social interaction and independence. Major goals include preventing deformities and providing external supports to use any/all available function for independence and communication. This is often a time of emotional transition for the family, accepting that the child's disability will require prolonged clinical and technological intervention. It may be a time to time to change equipment from dependent to independent.

Positioning: The main objective is to provide durable, adjustable equipment which will work in both home and school settings. Seating systems will most likely interface with a wheelchair. School therapists and teachers should provide input. Seating systems often must include footstraps, anterior chest supports and headrests for safety during bus transportation even if not needed specifically for posture. Systems often now include lap trays for doing schoolwork or for holding communication equipment. In addition, toilet and bathing adaptations should be made when appropriate to facillitate these aspects of development.

Mobility: Manual wheelchairs for dependent use may be fixed vs. adjustable tilt;

manual chairs for independent propulsion are encouraged; power wheelchairs should be *routinely* considered when other means of functional mobility are not feasible.

Transportation: May need to transition to adaptive car seats, which are still the preferred travel method. In wheelchair, eg. for mandated preschool, chair and tie-down evaluation are critical.

DISCUSSION

We authors believe that thorough knowledge of the subject in its entirety is critical to a thorough evaluation for, and recommendation of, AT needs for children. This is knowledge of an individual with a particular disability at a specific age, with specific physical, environmental, social, and interactive needs. Failure to address all areas will result in recommendations which do not meet the goals of everyone involved with the child's world, or which do not stand the test of time. In our experience, "normal baby" equipment is often not used sufficiently in the infant years, and the ISR is routinely ignored or not considered out of ignorance. It is our intent that this paper will enhance the evaluation skills of ATP's for young children.

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CONSUMER PARTICIPATION IN IDENTIFYING MANUAL WHEELCHAIR PRESCRIPTION PROCESS PRIORITIES

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ABSTRACT

To gather consumer feedback and opinion on developing a more consumer-responsive wheelchair prescription process, a group of five people, including two professionals, who are manual wheelchair users, were brought together for a focus group. They participated in a three step process in order to identify and prioritize ideas on how to improve the current prescription system. The three steps consisted of a brainstorming session, a multi-voting round, and finally, a ranking round.

BACKGROUND

In the 1980's, changes and problems in the health care system created an elimination of services, limited resources, and decreased quality. Facilities began focusing more on surviving than on providing appropriate services (2). Consumers were dissatisfied with the decreased quality, limited services and resources. For this reason, they applied pressure to the medical and rehabilitation facilities, which became the crucial step for service delivery to redirect their focus on outcomes management and quality assurance (2).

Since this redirection, one method that has been explored to provide quality services is the concept of consumer-centered or consumer-responsive services. This type of service, if appropriately implemented, meets the needs and goals facilities are striving to achieve: high quality and cost-effective services (3). Involvement by consumers in the delivery of rehabilitation and assistive technology (AT) is strongly believed to enhance the delivery and the outcomes of the process. Consideration of the consumer's goals, opinions and choices can result in "improved efficiency, less wasted effort, and better use of limited resources" (5).

Many facilities are still struggling with implementing this type of service. The majority of the difficulties that have been expressed are due to a lack of clear guidelines to ensure that the consumer is the center of the service (4).

METHOD

Sample

Of twelve persons identified to participate in the focus group, seven members were unable to attend due to unexpected weather conditions and other last minute conflicts. Of the five who attended the focus group, four are currently manual wheelchair users, and one is now a power wheelchair user. Four other people were present: two mediators and two staff members to help with scribing and recording. We believed that the group of five was sufficient for a session due to the fact that they were all expert consumers with a variety of backgrounds and experiences. A second session with the remaining participants was not planned due to the time and funding limitations placed on this study. Please refer to Table 1 for demographics on each focus group member.

Procedures

To initiate the gathering of information, a three-step process from the Nominal Group Technique (NGT) was followed (Delbecq et al., 1986):

1) brainstorming/discussion of ideas
2) multi-voting
3) ranking

The brainstorming session began with six topic areas being introduced to the participants. The members were asked to think of at least ten ideas for each topic area and then circle their top three choices. After brainstorming two topics, it was apparent that the participants were anxious to brainstorm with fewer restrictions. We

followed their lead and proceeded with a verbal session of brainstorming and discussion. As ideas were shared, they were recorded and numbered on a flip chart. Each flip chart page was taped to the front wall of the room to allow all ideas to be in constant view. In total, 31 ideas were recorded.

The second step in the process, the multi-vote, was used to establish conformity among the group members.

Diagnosis	Age	Age at Diagnosis	Wheel-chair
T-12 Paraplegia	36	20	Manual
T-4/T-5 Paraplegia	53	29	Manual
T-12 Paraplegia	45	33	Manual
Spastic Spinal Degeneration	41	30	Manual
Spina Bifida	52	Birth	Manual/ Power

Table 1. Focus group participant demographics.

The following procedure was used to obtain our goal: first, each member was asked to write down the corresponding number to their top fifteen choices from the original list of thirty-one; when all members had made their selections, the votes were collected and tallied; each item that received three or more votes was sent onto the next round of multi-voting; the fifteen choices were then recorded and renumbered on the flip chart; the same procedures were followed in order to obtain the initial goal of seven top priorities. The multi-voting and tallying resulted in a final list of six priorities due to the three vote requirement.

To further organize the final six items, we used a modified NGT ranking tool. Each member received index cards with the numbers one through six printed on them. They were first asked to choose the item they viewed as most important and write its corresponding number onto the card designated as number one. Next, they were asked to write the corresponding number of the item they felt to be the least important of the remaining five onto the card designated as six. Finally, they were asked to rank the remaining items using the cards marked two through five. Ties were found after an initial tally and a re-vote was conducted by fax and phone. The final order was based on the arrangement of the votes from the initial vote and the re-vote with the last two items tying for fifth, eliminating a sixth position.

RESULTS

The six items agreed upon in their final rank order:

1. Focus on the Person

All rehab activities and prescription process steps should deal directly with, and focus on, the person, not the activity or the technology, in this case the wheelchair. The client's interests and goals should come first.

2. Consumer Testing of Different Chairs

The consumer needs to take home different chairs in order to test drive them in areas outside of the rehab center, such as their home, office, community, etc. This will help the consumer determine which chair is best suited for them.

3. Education on Different Chairs for Different Activities

A wheelchair was equated to a pair of shoes by one group member: "You have different shoes for different activities - tennis, hiking, work, etc...." The consumer needs to be given information on, and experience with, the different types of wheelchairs that are used to perform and participate in different activities (sports activities, sit to stand, transferring, indoor vs. outdoor, etc.). This will enable them to make wise and informed choices.

4. Home Evaluation

The team should present the opportunity to go into the person's home and/or office to pinpoint accessibility issues related to the specific chair(s) being considered.

5. Inclusion of an Experienced Wheelchair User as Team Member

One of the team members should be an expert wheelchair user who has first-hand experience in wheelchair use. This team member could answer questions that professionals may either have no experience with or may be reluctant to discuss.

Peer Counselor/Mentor as Part of the Team

A peer counselor or mentor should be a part of the team to allow the consumer to discuss his/her concerns, including fears and anxieties. The counselor should also introduce the consumer to others who have been through the process and/or are using the same chair(s) they are considering.

DISCUSSION

The six priorities voted on provide a good framework for gathering more consumer input and for developing more consumer-responsive prescription processes. The most important thing that therapists and other team members should do is focus on the person. This seems to be a recurring theme in all six priorities. When teaching new tasks and skills, they need to be centered around the unique abilities, lifestyles and goals of the client. When prescribing a wheelchair, the same is true when measuring, recommending styles and accessories, or deciding on colors. By letting the consumer test different chairs and try them outside a rehabilitation center environment, the consumers' skills, goals, and preferences are the focus. Providing education on different types of chairs that are used to perform different activities gives the consumer some hope for lifestyle choices and options. By providing a home or office evaluation, the consumers' environment - personal, social, and vocational - are being considered. Having an experienced wheelchair user as a team member, or at least a consultant, will help the client feel more relaxed and secure with the decisions that are made. They will have someone that can relate to them, as well as provide important hands-on information and experience with different types of wheelchairs and activities. Finally, by providing a peer counselor or mentor, the team is focusing on the client by showing concern for their fears, anxieties, and interests by listening and introducing them to other consumers and also to consumer organizations.

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Consumer Satisfaction in Multidisciplinary and Nonmultidisciplinary Team Approaches in Manual Wheelchair Prescriptions

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ABSTRACT

To compare consumer satisfaction with the type of assistive technology approach (multidisciplinary or nonmultidisciplinary) used in a first-time manual wheelchair prescription processes, a questionnaire was administered to 21 subjects. A portion of the Wheelchair Prescription Consumer Satisfaction questionnaire was used to determine if a multidisciplinary team approach truly enhances the consumers satisfaction with the service delivery process, and to determine if the evaluation process was more thorough with the team approach.

BACKGROUND

Multidisciplinary team approaches and consumer satisfaction levels are just two of the concepts that rehabilitation facilities have been studying in order to implement high quality, effective consumer-centered services. These concepts are especially important when prescribing a first manual wheelchair because consumers are not aware of all the options available (i.e., lightweight, sports chairs, rigid or folding frames), or all the functional requirements (i.e., transportation, residence accessibility, personal goals) that need to be considered.

According to Johann (1995), one of the most pertinent keys to consumer-centered, high quality services is the implementation of a team approach. The team can include, in addition to the client, the client's family and/or caregiver, an occupational therapist (OT), physical therapist (PT), speech-language pathologist (SLP), rehabilitation technology supplier (RTS), rehabilitation engineer (RE), physician (MD), etc. The benefits of "an interdisciplinary team [are to] bring together diverse skills and expertise [in order] to provide more effective, better coordinated, better quality services for clients." (1)

Peters and Waterman (qtd. in Scherer and Galvin, 1994) point out in their book In Search of Excellence: Lessons from America's Best-Run Companies that to be successful, the number one goal for any company should be to provide 100% consumer satisfaction.

Two ways of achieving consumer-responsive services that are being reported in clinics that seem to be working are: a team approach to evaluating and recommending services and technology; and studying the satisfaction levels of their consumers. The use of a team cannot only improve consumer satisfaction but "...the team provides a total view of client needs and allows the consumer a forum for establishing his or her needs in such a way as to address . . . equally important aspects of health care..." (3).

In order to continue the movement toward consumer-centered wheelchair prescription, there is a need to study consumer satisfaction with the assistive technology (AT) prescription system. It is necessary to determine if a team approach is truly enabling consumer satisfaction. Results of such a study will help rehab professionals see the benefits of adopting a multidisciplinary team approach for moving toward a consumer-centered delivery process.

RESEARCH QUESTIONS

1. Is there a difference in consumer satisfaction between the types of AT services, multidisciplinary vs. nonmultidisciplinary, being used in the wheelchair prescription process?
2. Is there a difference in the areas evaluated (i.e. needs/wants, physical characteristics, trying out different chairs, evaluating transportation and place of residence) between the two types of AT services?

METHOD

Sample

Twenty-one subjects, out of a proposed thirty, have been entered into this study to date. The subjects are divided into two groups (15 in each): those who received a multidisciplinary team approach for their first manual wheelchair prescription; and those who did not receive a multidisciplinary team approach. The multidisciplinary group has 6 subjects entered while the nonmultidisciplinary group has been completed with all 15 subjects entered. Group placement was determined by the following definition of a multidisciplinary team: at least two professionals, (i.e. OT, PT, RE, RTS, etc.) in addition to the consumer, who are actively involved in the evaluation and prescription process. The diagnoses of the 21 subjects include: paraplegia (8), quadriplegia (4), spina bifida (5), transverse myelitis (1), cerebral palsy (1), multiple sclerosis (1), and spastic spinal degeneration (1).

Procedure

The Wheelchair Prescription Consumer Satisfaction Questionnaire (WPCS) was developed specifically for this portion of the study. It contains three sections: History (i.e., diagnosis, feelings about disability, etc.); Prescription Process (i.e., amount of consumer involvement, satisfaction level, etc.); and First Wheelchair (i.e., satisfaction, maneuverability, comfort, etc.).

Each subject chosen for this study was scheduled for an interview which consisted of the administration of the WPCS. Each interview lasted approximately 30-45 minutes. This paper only describes a portion of the second section of the WPCS, the Prescription Process.

RESULTS

These preliminary results have gone through informal analysis. At the completion of the data collection the results will be put through formal statistically analysis.

Of the six subjects in the multidisciplinary team approach group, 67% stated that they were satisfied with their first manual wheelchair prescription and evaluation while 33% stated that they were very satisfied. See Figure 1.

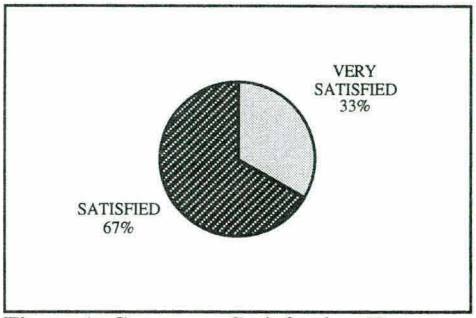

Figure 1. Consumer Satisfaction-Team

The 15 subjects in the non-multidisciplinary team group had varying opinions of their first wheelchair prescription: 21% stated that they were very dissatisfied; 14% were dissatisfied, 21% were neither satisfied nor dissatisfied, 44% were satisfied, and 0% felt very satisfied. See Figure 2.

83% of the subjects in the team approach group noted that there needs, wants, and goals were discussed with them, whereas only 21% in the non team group noted that these areas had been discussed. See Figures 3 and 4.

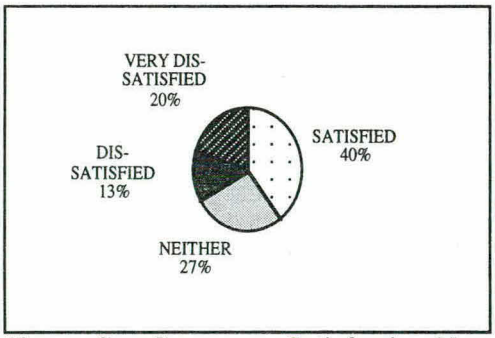

Figure 2. Consumer Satisfaction-Non Team

66% of the team group subjects and 64% of the non team group subjects stated that their physical characteristics, such as height, weight and specific measurements, were considered.

Of the subjects in the team approach, 66% were able to try out different chairs before making a final decision, while only

21% of the non team members were able to try different chairs.

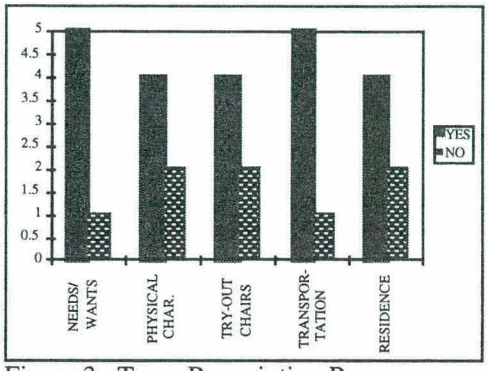

Figure 3. Team Prescription Process

Of the team approach members, 83% stated that their mode of transportation was discussed and evaluated while only 14% of the non team members transportation was considered.

66% of the team group subjects stated that their place of residence was evaluated for accessibility issues while only 21% of the non team group members residences had been evaluated. See Figures 3 and 4.

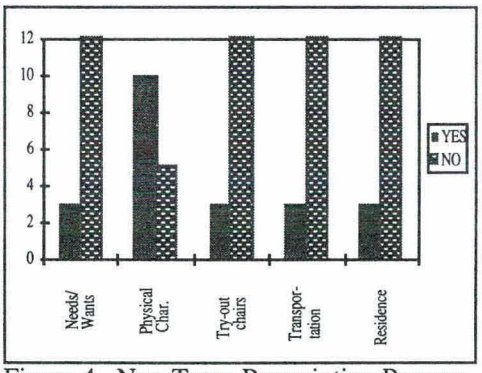

Figure 4. Non Team Prescription Process

DISCUSSION

Even though the data has only been informally analyzed, and there is currently a size difference between the two subject groups, these preliminary results show promise for further analysis.

Subjects in the multidisciplinary group when compared to the nonmultidisciplinary group displayed higher percentages of satisfaction. None of the subjects in the team approach group stated that they were dissatisfied with their first prescription process.

All but one of the features (physical characteristics) showed higher incidence of being included in the first evaluation process.

These results indicate that a multidisciplinary team approach provides a broader range of disciplines working together for a common goal. By doing so, more areas were evaluated and discussed during the prescription process (i.e., needs/goals, trying out different chairs, transportation needs, etc.) in turn making the consumer more satisfied with the service.

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ACKNOWLEDGEMENTS

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CONSUMER RATINGS OF KEY CHARACTERISTICS OF FIVE "IDEAL" MOBILITY-RELATED ASSISTIVE DEVICES

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ABSTRACT

Five wheeled mobility-related assistive technologies have been previously determined by RERC-TET to be in need of further product development. During 1996, they were each further evaluated by approximately 150 consumers representing all U.S. geographic regions. The devices evaluated are manual wheelchairs, wheelchair cushions, battery chargers, wheelchair tires, and tie-downs and restraint systems. The methods used and preliminary results are discussed in light of implications for manufacturers, vendors, and assistive technology providers.

BACKGROUND

More attention is now being paid to the usability of devices. According to Scherer [1], people select technologies based, first, on how well they satisfy their functional needs and preferences, then according to the product's attractiveness and appeal. The use or abandonment of a technology is then determined by its usability and performance. If it meets the person's performance expectations and is easy and comfortable to use, then a good match of person and technology has been achieved [2].

This view of technology selection and use is diagrammed in pyramid form as a usability hierarchy, where lower level criteria need to be met before a person is motivated to move up the hierarchy. Otherwise, the likely outcome is technology avoidance or abandonment.

AT USE/
NON-USE [1]

Usability &
Performance

Appeal

Need

Two previous papers [3,4] presented the methods used by the Rehabilitation Engineering Research Center on Technology Evaluation and Transfer to determine and develop consumer criteria for the improvement of device usability in categories of devices where consumer dissatisfaction is high. Consumers evaluated 13 device categories which RERC-TET had previously determined to most need further development and improvement (through surveys of State Tech Act programs and Independent Living Centers nationwide). From the results, the RERC-TET selected the top ten devices consumers determined were most in need of improvement. Five of the devices are related to wheeled mobility.

RESEARCH QUESTION

What characteristics of the following five wheeled mobility-related devices do consumers believe are in most need of improvement or development?

- Manual wheelchairs
- Wheelchair cushions

CONSUMER RATINGS

- Wheelchair tires
- Wheelchair restraints and tiedowns
- Battery chargers

METHOD

Since April 1, 1996, four focus groups of 12-15 consumers each, representing varying geographical regions within the U.S., met to discuss detailed characteristics of the five wheeled mobility-related devices. Focus groups were conducted from Anaheim, California and Tucson, Arizona in the Western part of the U.S. to Tulsa, Oklahoma and Milwaukee, Wisconsin in mid-America to Norfolk, Virginia and White Plains, New York in the East.

At least 80 percent of the focus group members had three or more years of experience with wheeled mobility-related devices. Their focus group discussions were organized around device characteristics in the following 11 criteria:

Reliability
Effectiveness
Operability
Durability
Affordability
Physical comfort/acceptability
Ease of maintenance/repairability
Securability
Learnability/assembly
Portability
Physical security/safety

Audiotapes of the focus group discussions were reviewed a minimum of two times to extract consumer-defined characteristics of the "ideal device." These characteristics were then written in the form of statements and organized into survey questionnaires containing 150-180 questions, depending on the particular device. The questionnaires were then distributed to additional consumer expert users throughout the U.S. Consumers responding to the surveys read each statement and rated how strongly they agree it is a characteristic of the ideal device on a seven-point scale ranging from "strongly disagree" to "strongly agree. " Data analyses focused on statements within the eleven criteria where consumers had the highest agreement regarding their importance as characteristics of the ideal AT device or service. Analyses of statements were also done free of criteria headings. Statements that achieved 70% or better consumer agreement were used to define the "ideal devices" for our purposes.

RESULTS

At least 100 completed surveys were returned per device. The results of the survey data clearly revealed many specific areas in which each of the five devices could be improved from users' perspectives. For purposes of this paper, the focus is on general results across all five devices. Areas in need of improvement centered around:

- Aspects of the device and service delivery system that determine whether or not a consumer would choose the ideal product over those currently available. In particular, consumers valued detailed information which would enable them to make better purchasing decisions
    - results of product testing
    - product maintenance information
    - reputation of the manufacturer
    - expertise of the vendor
    - warranty/guaranty coverage
- Consumer requirements for the physical characteristics, operations and aesthetics of the device itself
    - Clarity of instructions for use and the availability of a user manual
    - adequate training in device set-up and use

  - Instructions for how to maintain the device
  - Information on how to repair the device and/or have it serviced
- Desirable support for the product from manufacturers and vendors
  - Knowledge of whom to contact for service and replacement parts
  - Quick turn-around times for service and parts delivery
  - Availability of back-up devices.

In addition to more specific results in each of these areas, the findings indicate varying preferences of consumers according to their background and psychosocial characteristics.

DISCUSSION

Consumers judge the usability of products from the point of device selection to their ultimate performance in a variety of environments and use many cues for determining the appeal a device has for them. Important early influences on judgments of usability are the amount and quality of services offered by manufacturers and vendors and the nature of the "product support" they offer.

RERC-TET's analyses of consumer-derived criteria for "ideal devices" revealed that most current products in the marketplace fall short of the ideal. RERC-TET is working to partner with manufacturers and vendors to use the specific product requirements we obtained for each device to get better and more desired and preferred products to end users. RERC-TET will also disseminate these findings to consumers who can use the information to make product comparisons, and ultimately, better product selections.

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Redesign of The Standard Hospital Wheelchair

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ABSTRACT

A survey was conducted in which healthcare workers from hospitals and nursing homes evaluated the standard wheelchair. By analyzing these surveys the transport wheelchair was redesigned to incorporate features to improve patient comfort and attendant ease of use in the hospital and nursing home environments. A complete structural analysis was performed on the chosen design to ensure durability for its intended use. A prototype was built to demonstrate how the chair was redesigned as well as providing insight into how the chair could be improved further.

BACKGROUND

The standard wheelchair is a universal type design which is used in many places from hospitals to amusements parks. Typically, these standard chairs are constructed of stainless steel tubing and have vinyl seats, which my be slightly padded, riveted to the frame rails. The chairs are designed to be either powered by the user with handrails on the wheels or pushed by an attendant utilizing push handles in the rear. Generally, there are folding footrests which may or may not contain padded leg rests.

For the most part, all standard chairs are similar in design with slight differences in footrest and push-handle design and adjustability. Some chairs offer plastic side guards to protect clothing from wheels, or swing away armrests for enhanced maneuverability at a table. There are a variety of commercial seat cushions, seat backs and headrests also available for these chairs.

A questionnaire was created for employees at five local hospitals and nursing homes. This survey sought data regarding catheter/IV holders, oxygen tank carriers, blankets or pillows, wheelchairs on ramps or elevators, and use of leg lifts.

A total of 30 questionnaires were completed by employees of these facilities. Some of the comments are listed below:

Catheter Bags

No place to attach catheter

Tube gets caught in wheel

Accommodation of pillows/blankets

Blanket gets caught in wheels

Chart carrier

Not included

Difficult to use once patient is seated

Use of brakes

Brakes do not hold tight enough

There were also a number of complaints regarding price/availability/funding to acquire wheelchairs. Only 7% of the people surveyed found the current folding designs useful and many responded requesting an easier folding design. Although folding the wheelchair seemed not to be a problem, many workers had difficulties *unfolding* the wheelchairs. Through the surveys and interviews with these workers it also became apparent that the patients who utilize these wheelchairs rarely transport themselves and some institutions even discourage it for liability reasons.

Based upon these survey results, it was determined that a wheelchair could be designed that is more suitable to the hospital environment than is currently available.

DESIGN OBJECTIVE

The objective of this project was to develop a wheelchair design that would

maximize patient comfort and attendant ease of use specifically within a hospital environment.[1] Some of the pertinent task specifications follow:

Task Specifications:

1. The seat must be wide enough (20") to accommodate the 95th percentile of patients comfortably.
2. A chart carrier must be included that will allow the medical chart (10" x 12") to be inserted/removed, by the attendant, effortlessly, from the pushing position, even when a patient is sitting in the chair.
3. The chair must accommodate a 2000 ml catheter bag of approximately: 10" x 10" x 3" and weighing approximately 2 kg.
4. The chair shall have brakes that can hold the chair stationary on a 7° incline with a 230 pound patient in the chair. The seven degree incline is based on the standards for handicapped ramp construction. The choice of 230 lbs. is based on the 95th percentile weight of law officers. (For comparison, the 95th percentile weight of male truck drivers is 227 lbs.).
5. The operation of the brakes should not be affected by tire wear.
6. The brakes should be able to be easily applied by the attendant while pushing the chair so that it can be slowed down on hills/ramps.
7. The chair should weigh less than 35 pounds for easy handling and maneuvering with or without patients on board.
8. The chair must allow use of pillows (24" x 18" x 5") and blankets (5' x 5') without either item getting in the way of other equipment or wheels, etc.
9. The chair should be able to be folded/compacted so that floor space for storage is minimized.

METHODS

When reviewing the comments from the surveys, it was discovered that many of the complaints were related to the folding of the wheelchair. Therefore, the chair was designed to be folded front to back as opposed to the typical side to side folding. This design allowed for a firm backed seat and seat back with thick soft padding. This would prevent agitation and development of decubidis ulcers that are typical for patients who spend most of the day in a wheelchair. This chair would also have a one piece pushbar similar to that of a shopping cart. This type of pushbar is more ergonomic than the current style which bends the wrist in an awkward position and requires the handle to be gripped tightly. Instead, the attendant could push the bar with the palm of the hand in a natural position.

To implement a front to back folding design an eight bar linkage was utilized. This linkage consisted of two parallelograms sharing a common link. To reduce this system to one degree of freedom an eighth link was added. Placement of this link was crucial in determining the rates that each parallelogram would fold at. By affixing the seat to one of the top links, the chair would be able to be folded in a similar fashion to a toilet seat - a common action for most people (see figure 1).

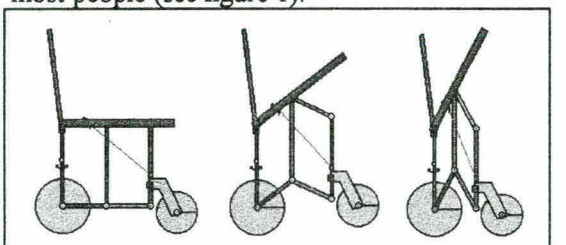

Figure 1 - Computer Simulation of Design

To expand the possibilities of this folding mechanism the rear wheels were chosen to be 8 inches in diameter and the casters 5 inches in diameter. This also eliminated problems of clothing, blankets, catheter tubing, etc. becoming caught in the spokes of the rear wheels. Although this removed the possibility of self transport, this was found not to be a problem, as mentioned previously.

The caliper style brakes would be hand operated with locking capabilities, acting on the rear wheel rims. These would be unaffected by tire wear. These would also be able to be used to slow the chair down as opposed to only holding it in place. Due to the firm backed seat-back, a rigid chart carrier could be attached to the seat which would remain easy to use if a patient was in the chair. The catheter bag tray would be mounted beneath the seat to allow for easy draining and safe use (see Figure 2).

EVALUATION

The finished prototype did not include footrests, an IV pole, or an oxygen tank carrier, as these could be easily added later. Although the kinematics of the wheelchair worked as planned, it did not fold as much as current standard chairs. The wheelbase shortened from 17" to 11" - a floor space savings of 36%. The addition of footrests would reduce this percentage. Current wheelchairs fold to approximately 50% of original track width. It was decided that if the front casters were oriented closer together, then multiple chairs could be 'pushed together', similar to shopping carts, increasing floor space savings.

It was also found that the seat height should be increased from 17 to 19 inches. This would allow the seat to be more comfortable for taller patients. By increasing this height, the geometry of the parallelogram linkage would change such that the folding of the linkage would be enhanced, allowing more floor space to be saved.

Because of its aluminum construction, the chair weighed 26 pounds without legrests. This is compared to approximately 45 pounds for current standard wheelchairs. Though it is difficult to quantify, the padded seat was much more comfortable than the vinyl seats offered on current designs. The brakes were also found to be more convenient. The chair would not 'run away' down ramps and could be locked quickly and easily. The final chair can be seen in figures 2-4.

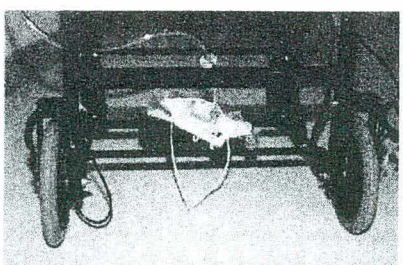

Figure 2-Final Prototype - Lower Rear View - Note the Catheter Bag Holding Tray and Caliper Brakes



Figure 3-Final Prototype

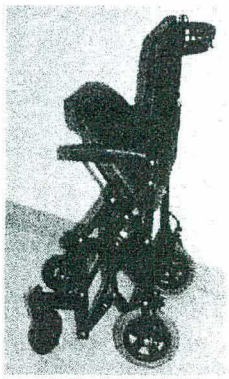

Figure 4-Prototype folding Demonstrated

DISCUSSION / CONCLUSIONS

It was found that there is a need to refine the current standard hospital wheelchair to increase patient comfort and ease of use by employees. This redesigned chair relieves many problems encountered with current designs by implementing such features as an ergonomic push bar and hand operated brakes. Because of the front to back folding design, folding and unfolding is more natural and much easier. The use of aluminum in construction reduced the weight almost 50% in comparison with current stainless steel wheelchairs.

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A FOUR WHEEL STEERING MECHANISM FOR SHORT WHEELBASE VEHICLES

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ABSTRACT

A steering linkage for a short wheelbase vehicle such as a wheelchair is presented. The device is designed to steer all four wheels of a vehicle using a single actuator. Misalignment between the wheels is negligible over the entire 180° turning range of each wheel. The design, theoretical analysis and construction of a prototype are described.

BACKGROUND

The ability of a powered wheelchair user to maneuver in tight spaces is closely related to the chair's drive and steering configuration. The most common drive configuration, differential rear wheel drive, consists of fixed and driven rear wheels with front caster wheels. Direction changes are made by individually varying the speeds of the rear wheels. In this configuration the point about which the wheelchair pivots lies on the line perpendicular and running through the center of the rear wheels. The minimum turning radius is achieved when the pivot point is directly between the rear wheels. The minimum space required to turn the wheelchair is then determined by the maximum distance from that point to any other point on the wheelchair. This is usually the front corner of the base or the user's feet hanging off the front of the chair.

In order to minimize the turning radius for the rear wheel differential drive configuration, the point between the rear wheels must be located as close to the geometric center of the chair as possible. Several commercially available power chairs have achieved reduced turning radii using this approach. Another benefit of this approach is that a larger portion of the total weight of the wheelchair is born by the drive wheels and less by the caster wheels. The more weight there is on the caster wheels, the more difficult it becomes to change directions when caster wheels must flip directions. The approach, however, causes the designer to take extraordinary steps to provide stability. Typically, stability is achieved by counter balancing the user's mass over and in front of the main drive wheels with the mass of the batteries behind the main drive wheels. It may be necessary to provide caster or sprung wheels in the rear of the chair to avoid tipping backwards while accelerating forward. The addition of these extra wheels may also compromise the chairs ability to climb over low obstacles if the wheels are small.

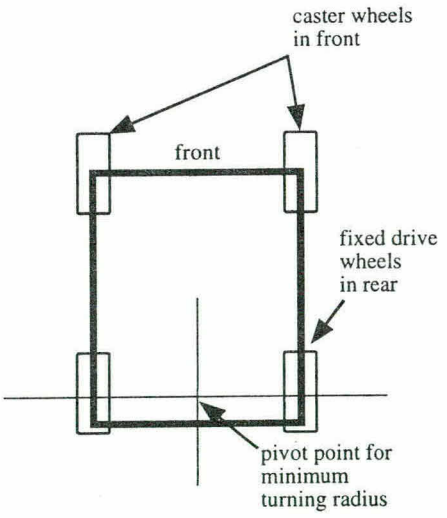

Figure 1 - Rear wheel differential drive configuration

An alternate approach to minimizing the turning radius is to steer all four wheels. It avoids the problems associated with caster wheels yet retains minimum turning radius, maximizes

stability, and provides for enhanced obstacle climbing capability.

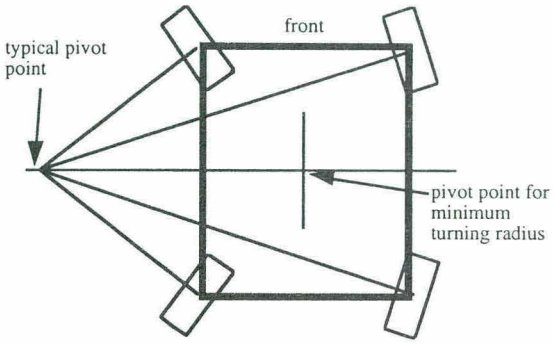

Figure 2 - Wheel alignment for four wheel steering about a single pivot point

STATEMENT of the PROBLEM

The challenge in designing a four wheel steering mechanism for a powered wheelchair is to design a device with the ability to turn each wheel through 180° while minimizing misalignment of the wheels. Steering linkages such as those used in automobiles owe their simple design to the relatively small turning angles required by that type of vehicle. For highly maneuverable small vehicles such as wheelchairs, the range of steering angle is much greater. Furthermore, the wheels must maintain proper alignment over the entire range of steering angles to avoid undesirable scrubbing when the wheelchair moves. The wheels are properly aligned whenever the perpendicular bisectors of all four wheels intersect at a single point. In four wheel steering, this point lies on a line between the front and rear wheels running perpendicular to the fore-aft direction of the base. This is illustrated in Fig. 2.

RATIONALE

The problems associated with designing a complicated mechanical linkage to achieve four wheel steering can be avoided using individual computer controlled steering actuators on each wheel. However, the costs of such a system are likely to be higher than those for a mechanical system due to the costs of the additional three actuators and channels of control. The specific design objectives for this project were to develop and evaluate a four wheel steering mechanism driven using a single actuator and achieving minimal misalignment over the entire range of steering angles. Although the prototype system implements four wheel steering, two wheel steering could be implemented with only a slight modification to the design.

DESIGN and DEVELOPMENT

A photograph showing a section of the steering linkage is shown in Fig. 3. The complete linkage consists of two sliding members (A), four cam follower slots (B) cut into a flat plate (C), and two links (D) for each wheel.

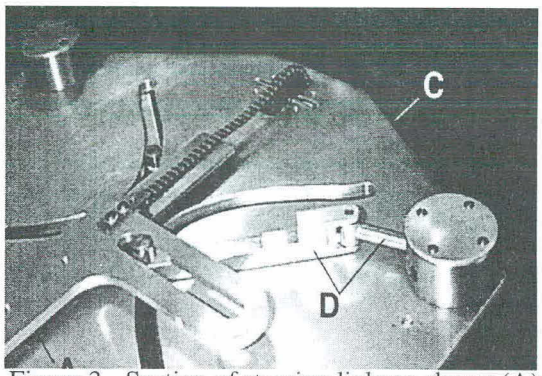

Figure 3 - Section of steering linkage shows (A) sliding member, (B) cam follower slot, (C) flat plate, (D) link members

Initial design was achieved using graphical methods in a CAD program. Subsequent analysis of the graphical methods resulted in the formation of a general mathematical description that allowed for the cam follower slot to be determined given arbitrary link lengths and wheelchair dimensions. Using the model, two prototype linkages were developed. A full-size physical model of just one out of four sections of the mechanism (i.e. the linkage section necessary to steer one wheel) was constructed to investigate the feasibility of manufacturing the device. Based on positive results from that exercise, a full-scale working prototype integrated into a wheelchair power base was designed and constructed so that evaluation of the concept could be completed under actual operating conditions.

EVALUATION

The losses in the linkage were estimated using a static analysis of torques and forces. The relationship between force applied to the sliding member of the linkage was determined as a function of the torque on each wheel for operating points throughout the full range of motion. The result for the linkage dimensions of a 3 in. lower member, 6 in. upper member, 20 in. wheelbase and 18 in. track is shown in Fig. 4. The curve in the figure estimates the sum of linear force required on the sliding member of the linkage per unit torque on the wheels (the sum required by all four wheels) as a function of the angle of the inside wheel relative to the straight ahead null position. As the near wheel moves through 45°, the outside wheel moves through 135° to avoid misalignment. At the extreme positions, the perpendicular bisectors of each wheel intersect one another at the geometrical center of the wheelchair base. This analysis demonstrates that there is not any significant loss of mechanical advantage between actuator force and resulting torque on the wheels.

Further evaluation will be undertaken once the linkage is fully integrated into the test power base.

DISCUSSION

The innovative feature of this design is its ability to drive all four (or two) wheels using a single steering actuator. Its successful implementation will allow for the development of a four wheel steered power base with maximum maneuverability, uncompromised static stability, and optimum obstacle climbing capability.

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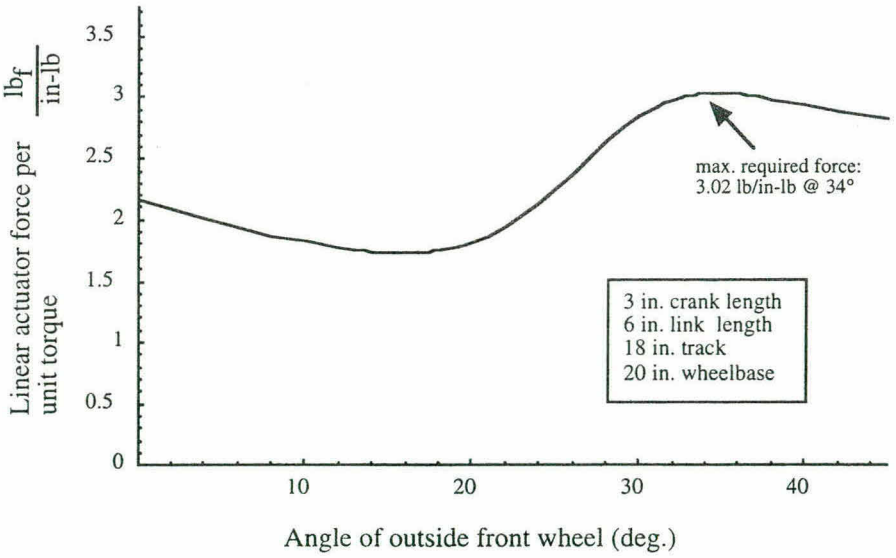

THE FLEXIBLE CONTOUR BACKREST FOR WHEELCHAIRS:
A new design offering adequate posture and comfort

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ABSTRACT

This paper presents the development of a new backrest for wheelchairs : the **flexible contour backrest**. This new concept has been designed to offer postural stability, comfort and function while keeping sling back upholstery's advantages. Using a design methodology often used at École Polytechnique de Montréal, a first prototype has been made. The new concept accommodates a person's back contours (from normal geometry to moderate kyphosis) by using vertical aluminum stays and straps. Lateral thoracic supports are created by using curved back posts. The preliminary results show that the flexible contour backrest may offer adequate posture and comfort.

PROBLEM

The use of the conventional sling backrest for wheelchairs may compromise the posture and the comfort of users (Engström, 1995; Harms, 1990; Zacharkow, 1984 and Zollars, 1993). In fact, the conventional sling backrest promotes rounding forward of the spine, posterior tilting of the pelvis, which can lead to back and neck pain, and even long-term deformities of the spine and pelvis (Zollars, 1993). Also, it does not offer sufficient lateral trunk support to prevent, manage or correct trunk alignment problems. With all these problems, the development of special seating for handicapped people has become important. The technology in seating has rapidly evolved around cushions or combinations of rigid interfaces and cushions with great results (Valiquette, 1992). It is usually accepted that, from a posture standpoint, it is the best solution. Unfortunately, this change deprives many wheelchair users of the advantages of the slings. Indeed, slings are foldable, light, economic, discreet and simple (Valiquette, 1992; Zacharkow, 1984 and Zollars, 1993). For these reasons, many wheelchair users do not want to use back cushion. However, after a few years, many of them complain of back or pelvis problems (pain, misalignment, deformation). In this context, the conception of a new backrest for wheelchair is worthwhile. Adjustable-tension back upholstery are actually available on the market. These backrests are foldable and can accommodate normal geometry of the back or mild kyphosis by the use of adjustable straps. In spite of these improvements, they often give poor lateral trunk supports and some adjustments are still missing to maintain neutral pelvic position and lumbar lordosis.

METHOD

a) Design methodology

To design a new backrest, a specific design methodology was used (École Polytechnique de Montréal, 1992). This methodology is composed of five steps. The first step, the problem formulation, consists of identifying the user needs and establishing design objectives in order to formulate design criteria. The second step, the brainstorming, consists of identifying possible solutions to the problem. The third step, the feasibility study, is necessary to eliminate solutions that are not scientifically,

technically or economically viable. The fourth step, the preliminary study, allows to find the best solution, that is to say the solution that optimizes the design criteria. Finally, the last step is the actual making of the prototype.

b) Principal objective and design criteria

The principal objective consists of designing and making a new backrest that optimize posture and comfort while keeping advantages of sling back upholstery. From the needs identified, several design criteria and a table of evaluation were established. This table is necessary to find the best solution. For each design criterion, a percentage was associated depending on the importance of this criterion in comparison with the others (table 1).

Table 1 : Evaluation table for solutions

Design criteria	(%)
Posture Adjustments Pelvic and trunk alignment Pressure distribution	45
Easiness of use by users easiness to propel maintenance of adjustments easiness to fold weight	20
Simplicity simplicity of the fabrication techniques number of principal components necessary time to make adjustments	20
Dynamism	5
Discretion	5
Airing	5
Total	100

In order to evaluate how much each solution will obtain out of 100, we have established quantitative landmarks for each subcriterion. Although this approach is somewhat subjective and can vary from one designer to the next, it is nevertheless, a starting point for the design.

THE NEW CONCEPT

From the brainstorming session, height design concepts emerged. Out of these height concepts, only three passed the feasibility study (*Flexible backrest with form components*; *Improved backrest with adjustable straps*; *Flexible contour backrest with adjustable straps and stays*). Solutions were developed in order to accurately evaluate design criteria (preliminary study). The third solution was retained because of its high percentage (81.5%) compared to the others solutions (56.2% and 74.6%). A first prototype of the third solution has been made (see figure 1). The basic idea of this solution principally rests on the fact that the back posts of the wheelchair offer lateral support. The back support is reproduced by using adjustable straps and vertical stays.

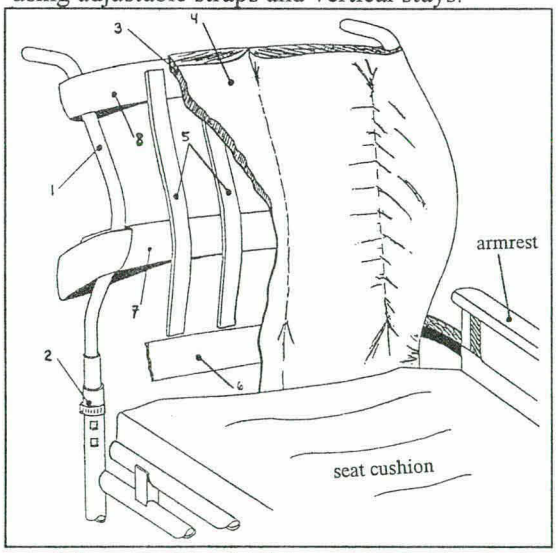

Figure 1 : The flexible contour backrest

To offer an adequate lateral support, the back posts (1) are curved in the sagittal plane. Furthermore, it is possible to rotate the posts in order to change the width of the backrest. This feature may completely eliminate the hammock effect. A mechanism (2) has been designed to allow this action. The backrest is composed of foam (3) and Nylon tissue (4) and there are four

cases to put stays (5) inside. Each stays is made of aluminum and has a height of 12 inches by a width of 5/8 inch. The rigidity of the stays depends on the thickness and we have noticed that 1/16" is sufficient to support back curves in a lateral plane while it is easy to modify the stays in order to reproduce different curves. To obtain an adequate support, it is not sufficient to only use stays and this is why three straps (6,7,8) have been added. The lumbar strap (7) can be adjusted in height to offer better pelvic stability and lumbar geometry accommodation.

WORK IN PROGRESS

Until now, preliminary results show that the flexible contour backrest may offer an adequate posture and comfort. These results are based on several experts' assessments (researchers, occupational therapists, clinicians and mechanical engineers). In order to accurately evaluate the posture and comfort of the new concept, a pilot study has been started. Results will be compiled during the coming months.

Evaluation of posture and comfort

A protocol of measures has been developed to evaluate the concept on posture and comfort. A first evaluation of posture is made by measuring the pressure distribution and the spinal profile. To measure the pressure, two pressure mats are used (FSA system, accuracy of ±5%), one for the seat and one for the back. To digitize the spine, a mechanical arm is used (Microscribe3D, accuracy of 0.64mm). To evaluate the comfort, a short questionnaire is presented to each subject. Fifteen normal subjects will participate in the initial evaluation; subsequently, the backrest will be tested on subjects with a disability.

DISCUSSION

The flexible contour backrest adequately meets our conception objectives. It seems to offer adequate posture and comfort as well as being adjustable and easy to use. The flexible contour backrest is suitable for people who present mild to moderate seating problems. It is best for users with manual wheelchairs who are active enough to need a light, foldable, airing, comfortable and discreet backrest and do not want to use back cushions. This design could provide them a good posture while at the same time benefit from the advantages of the slings. This technology could also be suitable for other users, by example elderly people, as it could be less restrictive than conventional seating for wheelchair propulsion.

The flexible contour backrest is one of the first backrests designed in a context using a scientific approach. Its design takes into consideration posture and user needs. It is also designed in order to take factory production into account; marketing will rapidly come. With this new concept, the pertinence of using flexible backrests to control sitting posture is shown to be advantageous. Future evaluations will seek to demonstrate that this new concept is able to offer the same postural control and comfort as actual seating cushions do.

ACKNOWLEDGMENTS

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Frame Failures of Welded Tube Manual Wheelchairs

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ABSTRACT

Throughout the five year life expectancy of the typical wheelchair parts are often replaced or repaired. However, a frame failure is not economically cost effective to repair and would most likely compromise the structural integrity of the wheelchair. In the course of testing manual wheelchairs at the Human Engineering Research Laboratories Wheelchair Design and Testing Laboratory we have observed that the most common type of frame failure occurs at the welds. Nine lightweight wheelchairs were tested. Six of the chairs were produced using braze welding techniques and three of the chairs were fabricated using tungsten insert gas processes.

BACKGROUND

Of 51 manual wheelchairs that have been fatigue tested at the Human Engineering Research Laboratories 21, or 41% of the total, experienced failures at weld locations on the frame and 15 or 29% of the wheelchairs that experienced weld location failures failed before completing the 200,000 cycles on the Double-Drum test. All of these failures ended the useful life of the wheelchair.

The test standard is the ANSI RESNA part 08 or ISO 7176-8. The two fatigue tests within this standard are the Double-Drum test and the Curb Drop Test. The Double-Drum test is performed before the Curb-Drop test.

The Double-Drum machine simulates the wheelchair traveling over a bumpy surface. The test consists of the wheelchair loaded with a 100kg test dummy being placed on two 250mm diameter drums. Each drum is fitted with a 12mm high x 36mm wide slat which extends the width of the drum. As the drums turn the slats run under the wheelchairs wheels. The front drum rotates 2% to 7% faster than the rear drum preventing synchronization of the slats (i.e. pseudo random loading.) The test consists of 200,000 revolutions as counted on the rear drum.

The Curb Drop test consists of lifting the wheelchair and the 100kg test dummy 50mm and dropping the wheelchair and dummy to the concrete floor. This test continues for 6666 cycles

RESEARCH QUESTION

Because of the materials used and the large number of weld failures what type of commonly employed welding methods provides the best results?

METHOD

A total of nine common lightweight type wheelchairs were tested.. The wheelchairs were three Quickie Breezys priced at $925.00 each and, three Everest & Jennings EZ-Lite wheelchairs at $910.00 per unit, and three Invacare Rolls 2000 $1001.00 per unit.

All of the wheelchairs were of like models and equipped with identical components i.e. 8 inch polyurethane solid tire castors and 24 inch MAG type rear wheels with pneumatic tires, swing-away legrests and sling type upholstery. The Breezys weighed 15 kilograms per unit, the EZ-Lites weighed 19 kilograms per unit, and the Rolls 2000 weighed in at 17 kilograms per unit.

The Rolls 2000 is made from non-heat treated AISI 1018 steel with furnace brazed welds and the EZ Lites are made from non-heat treated AISI 1020 steel tube and braze welded. The Breezys are made from non heat treated AISI 1018 drawn over mandrel (DOM) tube using robot welded tungsten inert gas (TIG) methods.

All of the chairs were tested as they came equipped from the factory and according to ANSI/RESNA, ISO standards for fatigue testing.

If the wheelchair completed 200,000 cycles on the Double-Drum machine the wheelchair was placed on the Curb-Drop machine for 6666 cycles. This pattern was repeated until failure of the wheelchair frame.

RESULTS

The Invacare Rolls 2000 #1 experienced frame failure at 132,008 cycles on the Double-Drum test. The failure/separation occurred at the right rear backrest tube and the top horizontal frame tube. The fracture occurred around the perimeter of the brazed joint and with-in the heat affected zone (HAZ) of the weld. A fracture/separation was also located at the bottom horizontal tube where it was joined to the back vertical tube. This fracture was similar to the fracture in the top tube.

The Invacare Rolls 2000 #2 experienced frame failure at 132,833 cycles on the Double-Drum test. This failure was located on both armrests at the point where the armrests are brazed to the backrest vertical tube. This separation was a failure from within the braze of the joint .

The Invacare Rolls 2000 #3 experienced frame failure at 197,074 cycles on the Double-Drum test. The failure/separation occurred at the right rear backrest tube and the top horizontal frame tube. The fracture occurred around the perimeter of the brazed joint and within the HAZ of the weld. A fracture/separation was also located at the bottom horizontal tube where it was joined to the back vertical tube. This fracture was similar to the fracture in the top tube.

The E&J EZ Lite #1 completed 200,000 cycles on the Double-Drum machine and 6666 cycles on the curb drop machine. The wheelchair failed at 135,915 cycles during the second round of Double-Drum testing. The fracture/separation occurred in the right and left vertical backrest tubes where they were welded to the top horizontal tubes.

The E&J EZ Lite #2 failed at 125,045 cycles during the Double-Drum testing. A fracture occurred at the bolt hole in the front cross brace tube which resulted in complete separation of the cross brace.

The E&J EZ Lite #3 failed at 59,539 cycles during the Double-Drum testing. The fracture/separation occurred in the right and left vertical backrest tubes where they were welded to the top horizontal tubes.

The Quickie Breezy #1 Completed 200,000 cycles on the Double-Drum machine. After 3245 cycles on the Curb-Drop machine the right side top frame tube separated from the rear vertical tube. The fracture occurred in the HAZ of the tube parent metal.

The Quickie Breezy #2 completed 200,000 cycles on the Double-Drum machine. During the post test inspection very small fractures were detected with a magnifying glass around the weld where the top left horizontal tube is joined to the rear vertical tube. After 6666 cycles on the Curb-Drop machine the crack had progressed significantly in to a spiral fracture upward to the end of the vertical frame tube where the backrest tube is inserted. At this point testing was ended.

The Quickie Breezy #3 Completed 200,000 cycles on the Double-Drum machine. During the post test inspection a hairline fracture completely around the weld, in the HAZ, of the right side horizontal tube and rear vertical tube was detected. Testing was ended.

DISCUSSION

Of the 9 Lightweight chairs tested to structural failure 8 failed at the welds. Of the nine chairs only one passed the ASNI/RESNA, ISO standard.

Welding is a complicated metallurgical procedure. For the welding process to be optimized many variables needed to be controlled. The welding process may be divided into two main categories These categories are the fusion welding processes and adhesive bond welding processes. Fusion welding is characterized as the heating of the parent metal to the melting point and a filler metal is added to the joint gap. These welds are produced by electric arc welding, tungsten inert gas (TIG) and metal inert gas (MIG) welding. This type of welding produces three distinct metallurgical zones; the fusion zone (the area of molten parent metal and the molten filler

rod), the unmelted heat affected zone or HAZ, and the unaffected parent metal. Adhesive welds are produced by bringing two clean metal surfaces together and allowing a liquid to flow within the joint and solidifying to form a metallic bond between them. This method is basically an adhesive method with the Van der Waals forces at the molecular level providing the bond. This type of welding is achieved by soldering or brazing techniques.

Both of these welding methods produce an HAZ around the weld. After the joint is welded the difference in the rate of cooling from the weld to the parent metal create uneven grain growth and stresses within the HAZ. The propagation of fractures that occur in a repeatedly flex cycled structure often originate from the stresses and uneven grain growth created within the HAZ (**see figures 1-3**). Furthermore both types of welding can produces microscopic notches and inclusions within and adjacent to the weld area. Notches and inclusions are often a source of fractures in metals.

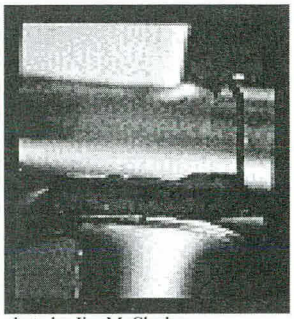

photo by Jim McCluskey

Figure 1. Brazed weld fracture of the parent metal at the HAZ. E&J EZ-Lite

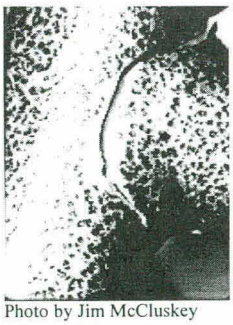

Photo by Jim McCluskey

Figure 2 Fracture within the HAZ, robotically TIG welded. Quickie Breezy

The automatic TIG welding techniques, in general, produce cleaner welds with less inclusions and notches. Heating is minimized by pulsing the arc and providing just enough heat to melt the parent metal and the filler rod, therefore minimizing the HAZ and the stresses created within. (**see figure 2**)Also the accurate control of the heat creates a good flow of the filler rod and mixing with parent metal produces relativity smooth welds where notching is greatly reduced. Furthermore TIG welding produces little or no slag because the gas shielding leaves no residue. Slag and other impurities from the fluxes used in other weld processes are often sources of inclusions at the weld location.

The testing of wheelchairs similar to the chairs in this paper continues which will provide a larger sample in the future

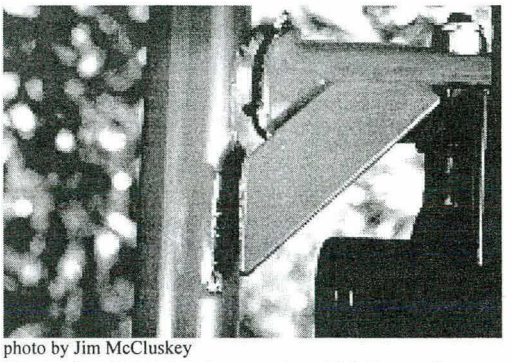

photo by Jim McCluskey

Figure 3. HAZ fracture and weld failure of a brazed joint. Invacare Rolls

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DESIGN OF A DYNAMIC SEATING SYSTEM FOR CLIENTS WITH EXTENSOR SPASMS

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ABSTRACT

A compliant seating system was designed and constructed for an adolescent with cerebral palsy. The system consists of a spring mounted bi-angular back mounted using off-the-shelf hardware. The system allows the client to extend during spasms and return to a functional seating position upon relaxation. Several design parameters are discussed in relation to the performance of the device. The system has been effective in reducing the client's generalized tone, improved posture and reduction in hardware maintenance.

BACKGROUND

Conventional practice has been to design seating systems for clients with a high degree of extensor tone such that the seating system constrains the client to a fixed position. A posture which allows no abnormal movement is desired. To this end the client is seated with hip flexion of 90 deg. or more, often using a wedge seat, knees at 90 deg. and a tight seatbelt. The objective is to maintain the desired pelvic position (Cook & Hussey, 1995).

Recently, a compliant seating system for a child with cerebral palsy has been designed. The system consists of a linkage-spring mechanism which allows the seat and back to rotate with respect to the wheelchair frame. Details of the design are not reported, however, the author reports favorable results (Orpwood, 1996). There are no commercially available seating systems which allow relative motion between the back and seat, however, modern office equipment designs based on ergonomic considerations provide spring-loaded backs to increase comfort for office workers who remain seated for long periods of time (Westra, 1996).

STATEMENT of the PROBLEM

The client is a 15 year old girl with a diagnosis of spastic athetiod cerebral palsy. She was referred to the Assistive Technology Center (ATEC) at Spaulding Rehabilitation Hospital for evaluation of her seating, mobility, access and communication needs. The initial evaluation indicated that her muscle tone (extensor spasticity) was the major component inhibiting her ability to maintain sitting or use her upper extremities for access. The client would have extensor spasms (trunk and lower extremity) that would escalate in intensity resulting in her weight bearing only on the distal third of her thigh and scapulae area while seated in her wheelchair, overflow of tone resulted in her arms being positioned out to her sides with elbows flexed (high guard). Her present system was designed to control her tone (a Quickie Zippie tilt-in-space with SHS KSS seating), but was unable to withstand the loads. The broken posterior seat hardware allowed the seat to pivot and the client could achieve almost total hip extension while in the wheelchair. Each time she would relax and sit back into the system her hips moved forward, never returning to the back of the system. The footrests also experienced breakage. The goal was to design a seating system that would allow the extensor spasms to occur and then return her to the correct seated posture.

DESIGN

The system was designed to attach to the existing wheelchair frame using off-the-shelf hardware. A bi-angular back was purchased (Adaptive Equipment Systems, Baltimore, MD) to allow the client's shoulders to extend back

over the pelvis during spasms. This back is designed to be set to a fixed angle, however, our initial design allowed the back to rotate backwards about its horizontal axis. Two linear extension springs were mounted to the back at approximate shoulder height and attached to the frame along the back posts. A seat belt is provided to maintain good pelvic position, however, the torso is allowed to extend during spasms. A schematic diagram of the system is shown in Figure 1.

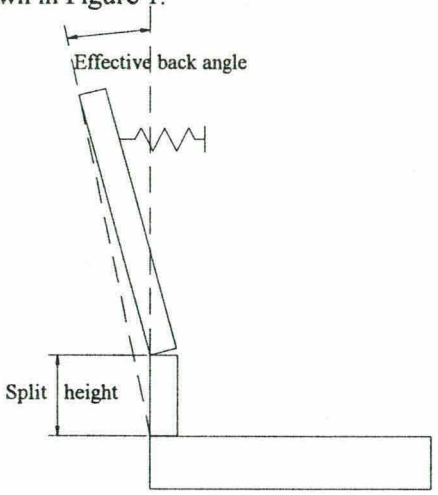

Figure 1. Schematic diagram of dynamic back.

DEVELOPMENT

Various factors are considered in the design of the system including location of the back hinge, effective rotation angle of the back, maximum force or torque exerted on the client, preload on the spring, and maximum energy absorbed or stored by the springs. For comparison, various designs have been evaluated to determine the effects of these parameters. The basic system assumes a solid, straight back (not bi-angular) with an initial seat-to-back angle of 90 deg. pivoted at the seat. The range of angular excursion is 20 deg. With a bi-angular back, the "effective" seat-to-back angle is measured from the seat to a point on the back which is 15" above the seat where the springs are mounted. See Figure 1. Pivot points from 0 to 7" above the seat were studied.

In order to compare different designs, all data were normalized to an equivalent value of the restoring torque. In addition, the preload was assumed to be 10% of the spring force at maximum extension.

EVALUATION

Figure 2 shows the restoring torque for the solid back and three different positions of the bi-angular back hinge (3", 5" and 7").

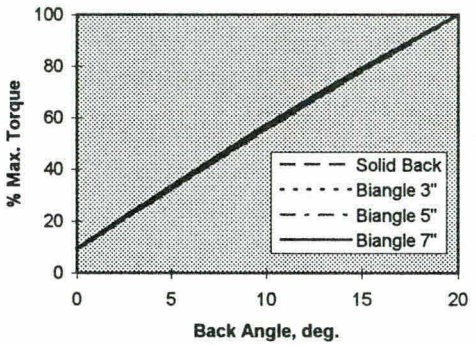

Figure 2. Torque on wheelchair back.

The force is an approximately linear function of the effective seat-to-back angle. The restoring torque is essentially equivalent for all designs. Thus, the forces felt by the client during the extension and recovery phases of the spasm are also equal. Although the total force is equal, the bi-angular back causes this load to be distributed over a smaller area of the back when compared to the solid back. The linkage design suggested by Orpwood (1996) would have a non-linear torque vs. extension angle curve. Given the assumptions of equivalent maximum torque, it can be noted that a non-linear linkage design would exhibit lower forces during the initial motion, increasing the effective stiffness of the mechanism with larger angles.

Figure 3 shows the amount of energy absorbed by the springs during the spasm. Note

that the bi-angular back design requires stiffer springs to achieve the same amount of restoring torque due to the shortened moment arm of the back. The angular rotation of the upper back portion is greater than the effective back angle. Thus, more energy is stored in the system, however, note that this energy is returned to the user as s/he relaxes. The differences are small at low excursions but become larger as the angle of flexion increases. Clinically, it is advantageous to absorb the maximum amount of energy without increasing the apparent load felt by the client. Note, however, that placing the pivot point too high will result in discomfort for the client as the force is distributed over a smaller area of the back. Furthermore, the pivot point should not be placed any higher than necessary for good pelvic control.

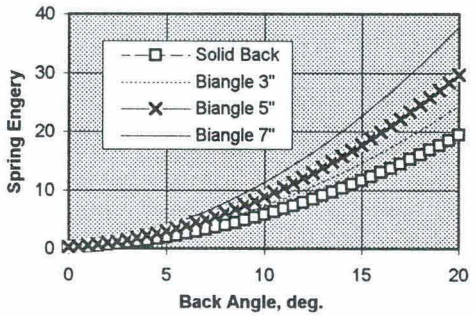

Figure 3. Total energy stored in springs.

Two prototype devices were constructed and evaluated by the client. The first had a pivot point at 7" above the seat, the second utilized a rigid back with a fixed angle of about 10 deg. at a height of approximately 5". Due to hardware availability, the same springs were used for both prototypes.

DISCUSSION

In the initial trial, the client was seated in the first prototype for over one hour under clinical observation. During this time she was able to maintain full contact with the seat, even with spasms which reached the full extension of the mechanism. In addition, she was able to use her arms more effectively, resting them on her tray and approaching midline with her hands.

After using the system for several days, a generalized decrease in extensor tone was noted, resulting in a decrease in head control. Tilt-in-space was used to maintain good head position. The client was seated in the prototype for over 4 months with no maintenance problems related to the design. A final design was fabricated with a rigid biangular back, pivoting at the base. After an additional 4 months in the final system, the client continued to exhibit generalized decreased muscle tone.

Although favorable results were obtained with one client, additional studies are needed to determine whether the dynamic (compliant) back is an effective strategy for improving tone (and subsequently function) in the extensor dominant patient.

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ROLE OF ARTEFACT IN REHABILITATION ENGINEERING DESIGN

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ABSTRACT

The use of seating artefacts in acquiring client information on which to base design of customized seating is being investigated. Artefact is used by the client group as well as by rehabilitation engineering team members to enhance communication. This study has highlighted three major categories of artefact use: 1) to specify a design requirement, 2) to clarify an issue or concept, 3) to explain an experience. This study has found that artefact was used most frequently to clarify issues.

BACKGROUND

Designers build "design models" such as drawings, mock-ups, prototypes of their products and build predictions about the user into "user models". (Hasdogen, 1996). In designing customized seating for people with disability the same process of modelling is applicable. However the user model is difficult to predict and interaction of the design model and user model is very specific and inflexible. To design a successful product requires an accurate user model.

Two issues face the designer of equipment for a person with a severe disability; (1) lack of adaptability of the person to match standard equipment and, (2) the complexity of the equipment interface required to accommodate the person's disability. Tackling these issues requires (a) good observation of the person using assistive devices, (b) good communication to gather detailed information about the person in the environments in which they use equipment and, (c) insight to understand and assimilate the personal handicaps into design solutions for customized devices.

Design success hinges on two factors. First the integration of specialized knowledge and negotiation of differences among "domain specialists" in the rehabilitation engineering inter-disciplinary team (Sonneweld, 1996). The second is rehabilitation engineering team members' capacity to cross from a traditional vantage point as "outsider" observers of the client (based on their biomedical training) to the client's experiential world (Peters, 1995). The user model can be developed for each client via a holistic approach of team members gaining wider "insider" experience with the client and accurately interpreting this experience as design information that enhances outcomes of device customization for the client.

Observation of interaction of seating clinic participants with seating artefacts lead us to consider that the activity served to enhance communication between team and client group, and provided "insider" experience relevant to equipment design.

RESEARCH QUESTION

We wanted to analyse the use of seating artefacts by participants in a seating clinic to look for patterns and common categories of use. The existence of patterns of use may enable specific tools to be developed to enhance the integration of this information in design processes

METHOD

Videotapes of client assessments at a rehabilitation engineering service were used as sources of data for a study of artefact use. The selection of assessment sessions to video-tape was random over a two year period. In this period changes occurred in personnel, and improvements to equipment design and service provision resulted from reflection on practice.

The rehabilitation engineering team was inter-disciplinary, comprising a rehabilitation engineer, orthotist, occupational therapist, physiotherapist, technician. Attendance of members at client assessments varied. The client group comprised the client and when available accompanying retinue of parents, carers, therapists. Assessments, allowing for

serendipity, generally followed a procedure structured into the client file format used to record observations, comments and data.

Videotapes were analyzed to see how team and client group members used bits of equipment to advantage in an assessment The bits referred to as "artefact" included for example: an armrest on a wheelchair that was pushed and pulled to demonstrate it moved when the client leaned on it, a photograph of a client taken a year previous to illustrate growth and change, a mother's hands held to simulate the desired orientation of a headrest. Anything actively utilized by clinic participants to extend understanding about equipment needs became artefact. Sometimes the client was considered artefact because of the intimacy of association of the physical state of the client's body with the seating to be designed.

Analysis was conducted by viewing the videotapes and noting:

- What people said before, during and after use of an artefact
- What happened before, during and after use of the artefact.
- The type of artefact.

The videos were viewed many times to gather all the data on artefact use.

RESULTS

Table 1 shows the use of artefact in seven client assessments. which are listed in chronological order, Client A being the first and G the most recent. 'Assessment time' refers to the first part of the team - client group meeting during which the team try to understand the client's situations in which a wheelchair and seating are used, problems experienced and needs to be addressed. 'Times artefact used' refers to the number of occasions some artefact was used in the assessment time. "Used" means the artefact was handled (includes touched, pointed to) and handling accompanied exchange of information from the handler to other persons. 'R.E. team use' and 'client group use' show the ratio of artefact major and minor users. 'Count' is the number of separate artefact items that received attention. Artefact usage excluded activity associated with the client's musculo-skeletal evaluation and measurement of body dimensions. Columns 'specify, clarify, explain, other' categorise the outcome of the artefact use.

DISCUSSION

In the videotapes viewed, artefact use accompanied discussion or was an illustration or demonstration of some aspect of using equipment or specifying features of equipment. Artefact use appeared to fall into four categories:

- to specify a requirement to be designed into seating,
- to clarify a problem, function, concept, idea and the like,
- to explain an experience with the equipment, client use of the equipment,
- preparation of the artefact such as assembling or orientating parts for use in context of the assessment.

Of these four, artefacts were most frequently used to clarify issues.

client	assess-ment time	times artefact used	R.E. team use	client group use	count	specify	clarify	explain	other
A	26:00	19	74%	26%	9	23%	50%	23%	4%
B	15:45	13	23%	77%	7	20%	53%	27%	0
C	24:40	21	81%	19%	8	22%	52%	22%	4%
D	24:25	29	59%	41%	8	23%	54%	23%	0
E	37:20	17	35%	65%	8	21%	37%	42%	0
F	30:00	111	36%	64%	17	23%	38%	19%	20%
G	29:30	78	28%	72%	25	27%	30%	35%	8%

Table 1 Artefact Use.

In five of seven video-tapes, the client group used artefacts more than the inter-disciplinary team. It is possible that the client group communicate complex ideas more easily by combining visual expression (artefact use) with oral expression and they do this more often than the team because they are being requested to explain issues and needs.

There is variability between cases in the amount of artefact use and the extent of artefact enhancement of communication by various participants. While variability must be expected due to differences in clients, client group abilities and comfort in interacting with the R.E. team and the equipment, the data shows that the R.E. team and the client group actively engage artefact as a normal process. Ehn (1991) referring to 'design language games' considered mock-up (artefact) played an important role in discussion of a design, because (1) it mirrors "real things", (2) it supports interaction and reflection for the participants.

Handling artefacts and watching others handling artefacts provides opportunity for clients and R.E. team members to get hands-on experience, which helps for a deeper understanding of a client's issues and hence increased likelihood of designing for a successful outcome. Creating an environment where clinic participants feel willing and able to play a 'design language game' through creative play with artefact is proffered as a way of enhancing design information capture.

Cases 'A' and 'C' show two situations where creating an artefact environment requires special attention. In both cases the client was severely physically disabled hence their ability to interact physically with artefacts was minimal. In case 'A' the client group seem to relinquish an active role to the R.E. team. In case 'C' the client looked at and pointed to pieces of equipment and relied on the R.E. team to manipulate the artefacts. Setting up the 'design language game' may require extra effort to make it inviting to reluctant client group participants. When the R.E. team use artefact at the direction of the client, they must ensure their actions mimic the situation and experience of the client.

CONCLUSION

Detailed analysis of videoed assessment phases of a seating service reveals ways in which artefacts including existing seating, wheelchairs, documents, are used as aids to communication. Artefacts seem to play a significant role in some assessment sessions. The amount of use varies widely between sessions. This variability may be explained by the nature of the particular case, client or care-giver group. Frequently the client group make greater use of artefacts to complement talk in conveying complex issues and needs. The significance of artefact usage in rehabilitation engineering clinics warrants further investigation.

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Survey of Standing Wheelchair Satisfaction by Individuals with Spinal Cord Injury

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ABSTRACT

The assistance of standing wheelchairs to spinal cord injured subjects (SCI) was investigated through a national survey of individuals returning their manufacturers warranty card to two companies making standing wheelchairs. Ninety-nine out of 260 individuals returned completed questionnaires. Seventy-seven percent were paraplegic and 21% were quadriplegic. Eighty-four percent of those responding currently use their standing device. Less than 10% of users experienced any side effects from standing such as nausea, fainting or headaches. Most felt that the standing position had a positive impact on self-esteem, self-image and morale. There was also at least the perception that standing had direct medical benefits such as decreased urinary tract infections and spasticity and a reduction in bed sores. Also, 79% of subjects highly recommended use of standing devices to others with SCI. The positive response of individuals using standing wheelchairs, is a strong recommendation for the assistive technology community to make these devices more available to individuals with SCI.

BACKGROUND

The development of assistive technology devices has been a leading factor in the increased independence of persons with disabilities (1,2). For those disabled with spinal cord injury, the wheelchair has been the most important assistive mobility device. An important extension of the wheelchair is a standing device or the standing wheelchair. Major features of a standing device include the advantages of upright posture, the mobility it can provide in the upright position and the shift of weight bearing stress. There are a variety of different standing wheelchairs and devices commercially available. Many of the devices use a hydraulic system to raise the person to the upright position either by pumping or by pulling a lever. There are also electric standing wheelchairs for the more severely injured that can raise the individual to the upright position by pushing a button.

Reported benefits include a number of physiological parameters such as improved bladder function, decreased calcium in the urine and leg spasticity, and fewer bed sores. Others have reported possible contributions of standing on a person's esteem and self image. Despite the reported benefits, standing wheelchairs for individuals with spinal cord injury are not widely prescribed. There are some concerns about adverse medical problems such as fractured leg bones, foot ulcers and fainting. However, there are few reports of these problems creating major limitations on the use of standing devices.

Currently several manufacturers produce standing wheelchairs and related devices and their use is increasing gradually. Thus, it continues to be important to investigate the benefits, costs and problems of these devices. We evaluated by questionnaire these issues for individuals who had purchased a standing wheelchair. The questionnaire was mailed to a group of SCI subjects in the United States that had returned the warranty card to their manufacturer. Two manufacturers of these devices were included in this study.

METHOD/APPROACH

A survey consisting of 42 questions was developed for subjects with SCI who purchased standing wheelchairs. There were demographic questions, those to reflect how long and the amount of daily standing, perceived effects on medical problems such as, spasticity, urinary tract infections, stone formation, bowel regularity, and various aspects related to quality of life. Adverse side effects such dizziness, nausea or bone fractures related to standing were also queried. Most of the responses to questions were placed on an ordinal scale. Two final questions were open ended and asked for any additional benefits or problems encountered with their device.

Questionnaires were sent to those who had purchased devices from 2 companies and who had returned their manufacturer's warranty card. These were: LDC Corporation of America (Folcroft, PA) manufacturer of the Lifestand standing wheelchair. This device looks like a typical wheelchair, however, pushing on handles to hydraulic plungers will bring the individual to the upright position. This device is not mobile in the upright position.

The second company, Altimate Medical Inc., manufactures a standing device (Easystand) that is mobile in the upright position. It does not double as a wheelchair and is best described as a mobile standing frame.

Analysis of ordinal scales consisted of percent responses for each category and cross correlation between ordinal scales and a classification of positive and negative comments from the open ended questions.

RESULTS

The majority of respondents lived with another person who either provides care (48%) or does not provide care (35%). Seventy-seven percent were paraplegic and the remainder quadriplegic. Eighty-four percent currently use their standing device and most (72%) did not need assistance transferring from a bed or standard wheelchair. Nonuse was based on the device being: no good, (3%), too difficult to transfer (4%), or medical problems which prevented use (4%).

Thirty-nine percent used their device 15 minutes or less per day, 33% between 15 and 45 minutes per day, 15% greater than 45 minutes but less than 1.5 hours and only 8% used it greater than 1.5 hours/day. Sixty-seven percent started using their device within 5 years after injury, and 40% had used it for at least 1 year. Perceived direct medical benefits included; decreased bladder infections (21%), more complete bladder emptying (21%), more regular bowel movements (23%), reduced leg spasticity (46%), and a better ability to straighten their legs (38%). None reported an increase in bladder infections, 1% indicated decreased bladder emptying and 3% indicated an increase in leg spasticity. One of the highest positive findings was the reported increase (69%) standing provided in their overall quality of life

With the final open ended comments 172 were positive (1.7 per individual), most being related to medical and quality of life issues. Seventy-seven were negative (0.8 per individual) and focused on areas of mechanics and construction of their device.

DISCUSSION

We believe that this is the first study to comprehensively examine by questionnaire whether the use of standing devices is associated with patient perceived benefits. Although the demographic data, medical history, and age of the respondents indicated a very diverse set of individuals with SCI, they indicated that there were a wide range of benefits from the use of these devices. The majority highly recommend their use to other individuals with SCI. Their were perceived

urological benefits which is consistent with Freeman (3) who found weight bearing stress initiated early after SCI would reduce the incidence of kidney stones. The ability to more completely empty the bladder is consistent with the known increase in bladder pressure that comes from an upright posture (4).

In almost all individuals the upright weight bearing stress was well tolerated. Few had problems with dizziness and headache and only one subject indicated that a bone fracture was related to the use of their device. In fact it is likely that a standing program initiated early after spinal cord injury would diminish bone loss, minimizing the possibility of bone fractures. Issekutz et al (5) demonstrated that passive could reduce hypercalcemia in the first 6 months following SCI suggesting that early standing could reduce long term osteoporosis in these individuals. Further support for this position is provided by Kaplan et al (6) who showed that axial weight bearing on the long bones decreased the hypercalciuria associated with immobilization.

Odeen and Knutsson (7) found that muscle stretch by weight-load in standing was able to reduce spasticity in paraplegics by 26-32 % based on the force needed for flexion of the feet and 42% of our respondents felt that standing reduced spasticity.

Finally, the problem of pressure ulcers are a primary reason for admission of SCI subjects to Veteran Administration Hospitals (internal review, unpublished). Many respondents felt that standing did reduce their bed sores probably from the fact that standing shifts pressure from the ischia tuberosities, trochanters and sacrum to the long bones of the legs.

In conclusion standing appears to have many psychological as well medical benefits for the SCI individual that provides an overall improved quality of life. The enthusiastic recommendation of standing by our respondents for others with SCI is a strong endorsement for continued use of standing devices.

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THE ROLE OF WHEELCHAIR CUSHION EVALUATION AND POST DISCHARGE EDUCATION IN PRESSURE SORE PREVENTION: A CASE STUDY

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ABSTRACT

The purpose of this paper is to describe how post discharge education and systematic wheelchair cushion evaluation may minimize the effects of pressure sore formation in clients with spinal cord injuries. The following case study and literature review support the conclusions that: 1) With current trends in rehabilitation, clients may be at greater risk for secondary complications, 2) Continuing education in vital in efforts to decrease the incidence and severity of pressure sore formation, and 3) Health care professionals must be aware of wheelchair cushion innovations and be willing to use new products in a systematic assessment with clients.

BACKGROUND

It has been reported that 20-30% of clients with spinal cord injuries may develop pressure sores in the first one to five years post injury.(6) During the initial rehabilitation phase, the role of the interdisciplinary team is not only to maximize function, but to educate the client about the physiological aspects of his or her disability and the prevention of secondary complications, such as pressure sores, that may develop as a result of the initial spinal cord injury (SCI).

With trends in rehabilitation tending towards decreased lengths of stay and increased inflation-adjusted hospital charges (4), many clients may not receive adequate equipment assessment or be able to retain important educational information amidst physical and psychological adjustment to a severe disability. This may, in turn, lead to higher risk for pressure sore formation, subsequent rehospitalization, and prolonged bed rest which may have detrimental physiological and psychological effects. (2)

While many studies have been devoted to pointing out risk factors for pressure sore development (3,6), little quantitative data is available on methods to minimize risk or the effectiveness of pressure relieving wheelchair cushions.

OBJECTIVE/METHOD

This case study takes a retrospective look at one client with a new SCI who was followed through initial rehabilitation to one year post injury. It describes steps that were taken through systematic wheelchair cushion evaluation and post discharge educational follow-up to minimize the effects of pressure sore formation. Information was obtained through observation, client interview, and review of physical therapy progress notes.

RESULTS

Mr. S. was an 18 year old male admitted to SCI rehabilitation 12 days status post a T11 burst fracture sustained during winter sports activities. The client remained in acute rehabilitation for 41 days during which he participated in the standard physical and educational rehab program. This included daily physical and occupational therapy, family education, peer counseling, and equipment assessment. His rehabilitation stay was uncomplicated and Mr. S. was discharged to home with his parents at a functionally independent level as reported on a discharge Functional Independence Measure (FIM).

Cushion/Education

Due to clients age and prior lifestyle, pressure sore prevention was a primary concern during rehabilitation. Education included formal group "Education Day", one on one sessions with members of the rehab team (formal and informal), peer counseling, and assigned readings over weekends. Areas covered encompassed pressure relief, bed and wheelchair positioning, basic anatomy and physiology, medications, bowel and bladder care, nutrition, wheelchair and wheelchair cushion maintenance, and community resources. A comprehensive wheelchair cushion assessment was also completed.

The assessment consisted of trials with six different wheelchair cushions and was carried out by the client and physical therapist. The evaluation of each product included: 1) Postural evaluation seated in the wheelchair, 2) Dynamic sitting balance in the wheelchair, 3) Client input regarding ease of transfer, cosmesis, comfort, and maintenance, 4) Evening and morning skin checks with documentation of any impaired skin, and 5) Force Sensing Array (FSA) computerized pressure mapping evaluation. With all factors considered, client was prescribed a Flexseat wheelchair cushion (16in wide x 16in deep). However, due to a lag between insurance approval, equipment procurement, and client discharge, Mr. S. was issued "loaner" equipment that did not meet specifications of the prescription.

Eight weeks post discharge, client was seen in physical therapy clinic for final equipment check-out. At this time, client indicated that he had recently noticed a small sacral sore lasting 2-3 weeks. Client was issued the prescribed Flexseat wheelchair cushion, reviewed educational materials regarding pressure relief and skin care, and instructed to follow-up by phone in two weeks. At this time, the sacral sore had healed.

The client was seen again three months later, in SCI clinic, reporting with a 3cm grade I sacral pressure sore. After repeat FSA evaluation, review of risk factors, and client interview, the rehab team was able to determine the most probable cause of the sacral sore. Eight weeks prior to this appointment, Mr. S. had resumed driving and was frequently in the car for up to 2 hours at a time. He did not sit on a protective seating surface, and did not perform any means of pressure relief. Client's peer counselor also noted that he frequently witnessed Mr. S. executing poor transfer technique (transferring over the tire). These issues were discussed with Mr. S. and his mother, alternative habits were suggested, and the physician recommended one week of bed rest at home.

Approximately four weeks later, client contacted physical therapy by phone and reported that the sore had healed. Six months later, the client had returned to school and there has been no reoccurrence of impaired skin integrity.

DISCUSSION

Secondary complications of spinal cord injury, specifically impaired skin integrity, can greatly affect a client's physiological and psychological well being post discharge. Therefore, it is the responsibility of the interdisciplinary rehabilitation team to educate the client about his or her disability in an effort to minimize the incidence and effects of secondary complications. This case study demonstrates the effectiveness of a comprehensive wheelchair cushion evaluation and the importance of post discharge equipment check out and educational follow-up.

With the continuing trends towards brief acute hospitalizations and relatively short rehab stays, it is difficult to monitor a client's understanding of educational material presented during initial rehabilitation. Clients are experiencing a stressful situation and may be in denial or shock. Many do not have the mental concentration needed to process complex information while pain and medications may

also interfere with acquisition and retention of educational materials. (7) A comprehensive educational program should be established at each facility and should extend beyond discharge with monthly classes offered for clients with new and old injuries alike. Peer counselors, printed and videotaped information, and community resources should be made available during all phases. The program must be the co-responsibility of an education committee and participants. (8) Telephone follow-up may suffice if clients do not reside in the immediate area of the rehabilitation facility.

When you consider that the cost of rehospitalization can amount to approximately $9683 for an average 11.9 day stay (3), health care professionals must be aggressive in clinically testing new equipment and substantiating claims of superior performance and protection. Wheelchair cushion selection should be systematic and involve FSA pressure mapping when available, posture and balance assessment in the wheelchair, and client feedback. The client should play an active role in cushion selection and be given the opportunity to complete trials on the various seating surfaces available.

Research must be done on the effectiveness of new and established equipment (specifically seating and mobility items), minimization of risk factors for secondary complications, and efficacy of established educational programs for individuals with spinal cord injuries.

Conclusion

Proper wheelchair cushion selection coupled with consistent client education and post discharge follow-up can significantly minimize the effects of impaired skin integrity in clients with spinal cord injuries.

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MATHEMATICAL MODEL OF LATERAL WHEELCHAIR STABILITY

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ABSTRACT

The International Organization for Standardization (ISO) is revising its standard for the determination of static stability. One substantial change is the manner in which lateral stability is measured, using a more oblique orientation of the wheelchair frame and a least-stable orientation of the casters. In this paper, we present a mathematical model of lateral stability (as defined by the revised ISO standard), in the hope that its use will assist researchers and manufacturers to better understand this complex issue.

BACKGROUND

Wheelchair stability is an important consideration in the safety and performance of wheelchairs (1). The International Organization for Standardization (ISO), in collaboration with its national counterparts (e.g. RESNA/ANSI), has established a standard for the determination of static stability (2). A revised standard (3) is at the penultimate Draft International Standard stage of approval. One substantial difference between the existing and the revised standards is the way that lateral stability is measured. The changes reflect the recognition that the traditional method is invalid when the caster(s) are placed much more medially than the propelling wheels (the extreme case being a three-wheeled wheelchair).

In the revised standard, therefore, the wheelchair is oriented obliquely on the test plane, such that the axis around which tipping occurs is parallel to the tilt axis of the test plane. The tipping axis runs from the point of contact between the rear wheel (in a rear-wheel-drive wheelchair, for instance) to the axle of the downhill caster. Because the casters swivel downhill during testing, the downhill caster is oriented in this position from the initial setup. The uphill caster is also oriented perpendicular to the tipping axis, but trailing downhill (because, when unweighted, the caster would swivel into this position anyway).

Computer-simulation techniques can be useful and economical tools for the investigation and analysis of static and dynamic systems (5-10). Such tools allow one to study situations without the cost and difficulty of acquiring and instrumenting the actual systems and to extend perturbations beyond the easily testable range.

RESEARCH QUESTION

In this paper, a general-simulation technique is presented for the estimation of the static lateral stability of a wheelchair-user system, modelling the revised ISO method.

THE MODEL

Measured parameters. The model requires a number of measurements, specifically the coordinates of the wheelchair user's body-segment endpoints (in 3-D space, from the origin of the coordinate system located at the right rear wheel axle of the wheelchair), the total body mass, the coordinates of the wheel axles, the wheel diameters, the coordinates of the center of gravity (CG) and the mass of the wheelchair frame (without wheels), the trail distance of the casters (defined as the horizontal distance from the point of contact between a line drawn parallel with the caster swivel when vertical and the ground to the point of contact between a vertical line passing through the caster axle and the ground), the distance from the point of contact of the downhill rear wheel with the ground to the point of contact of the downhill caster with the ground when oriented for lateral-stability testing, and the distance from the point vertically below the downhill caster

Mathematical Model

swivel axle to the line of progression of the downhill rear wheel of the wheelchair measured by extrapolating the line of progression of the downhill caster so that it intersects the line of progression of the downhill rear wheel. Anthropomorphic data from published sources (4) is also needed.

Calculation steps. The following are then calculated: the segment masses and coordinates of the segment CGs, the angle through which the downhill caster swivels to lie in the appropriate position according to ISO standards for testing lateral stability, the new downhill caster position, the new uphill caster position, the axis of rotation of the wheelchair (the line from the point of contact of the downhill rear wheel with the ground to the downhill caster axle in the proper position for lateral-stability testing), the appropriate CG (since the wheelchair is laterally rotated about the downhill caster axle, the weight of the downhill caster must be disregarded when calculating the center of gravity and the new coordinates of the CG of the uphill caster must be considered) and, finally, the lateral-stability angle.

The lateral stability is the angle through which the appropriate CG of the system travels about the axis of rotation such that the CG comes to lie in the plane determined by this line and another point in this plane vertical above this axis. Our approach to this problem involves defining two planes, determining the normal vectors for each of the two planes and calculating the angle between these vectors. A plane can be defined by three non-colinear points. Plane 1 contains the following three points: the appropriate CG for lateral stability, the point of contact of the rear wheel with the floor, and the downhill caster-axle position with the caster perpendicular to the axis of rotation of the test plane. Plane 2 (vertical) contains the following three points: the point of contact of the rear wheel with the floor, the downhill caster axle with the caster perpendicular to the axis of rotation of the test plane, and the point of contact of the downhill caster with the floor.

The final equation for right lateral-stability testing is shown in Equation 1, where LS_R = the lateral-stability (in degrees), the superscripts or subscripts R and L represent the right and left sides, $(X_{CG_L}, Y_{CG_L}, Z_{CG_L})$ = the CG position of the system (wheelchair + occupant) excluding the weight of the downhill caster and considering the position of the uphill caster according to ISO standards for lateral-stability testing, $(x_{DNC}, y_{DNC}, z_{DNC})$ = the downhill caster-axle position after the caster has been swung into position according to the revised ISO lateral-stability testing standards, and (x_{RG}, y_{RG}, z_{RG}) = the point of contact between the rear wheel and the ground.

DISCUSSION

The model appears to have excellent face validity. Preliminary evaluations of construct and concurrent validity are also encouraging, but further work is necessary. We are also merging this model of the revised ISO method of determining lateral stability with a previously reported computer model of rear, forward and lateral (original ISO) stability that has been more fully validated (7,9,10). We are in the process of implementing the entire model as a user-friendly Windows application requiring no more than a 386 computer. We hope that this model will assist wheelchair researchers and manufacturers in better understanding the complex issue of lateral stability.

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$$LS_R = \frac{180}{\pi} \arccos \left[\frac{\left| ((Y_{CG_L^R} - y_{RG^R})(Z_{CG_L^R} - z_{DNC^R}) - (Y_{CG_L^R} - y_{DNC^R})(Z_{CG_L^R} - z_{RG^R}))(z_{RG^R} - z_{DNC^R}) \right|}{\sqrt{((Y_{CG_L^R} - y_{RG^R})(Z_{CG_L^R} - z_{DNC^R}) - (Y_{CG_L^R} - y_{DNC^R})(Z_{CG_L^R} - z_{RG^R}))^2 + ((X_{CG_L^R} - x_{DNC^R})} \right.$$
$$\left[\frac{\left| + ((X_{CG_L^R} - x_{RG^R})(Y_{CG_L^R} - y_{DNC^R}) - (X_{CG_L^R} - x_{DNC^R})(Y_{CG_L^R} - y_{RG^R})) \right|}{(Z_{CG_L^R} - z_{RG^R}) - (X_{CG_L^R} - x_{RG^R})(Z_{CG_L^R} - z_{DNC^R}))^2 + ((X_{CG_L^R} - x_{RG^R})(Y_{CG_L^R} - y_{DNC^R}) - (X_{CG_L^R} - x_{DNC^R})} \right.$$
$$\left. \left[\frac{\left| (x_{DNC^R} - x_{RG^R}) \right|}{(Y_{CG_L^R} - y_{RG^R}))^2 \sqrt{(z_{RG^R} - z_{DNC^R})^2 + (x_{DNC^R} - x_{RG^R})^2}} \right] \right] \quad (1)$$

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DESIGN DEVELOPMENT OF A NEW BOWEL CARE/SHOWER CHAIR

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ABSTRACT

The purpose of this two year project was the design a new bowel care-shower chair that can be safely used by individuals with SCI and their caregivers. The chair was developed around the "seating-centered design" concept which acknowledges that a 'whole body' seating position properly distributes a person's weight necessary to prevent the development of pressure ulcers during the bowel care routine. Positioning the seat directly over the toilet bowl with existing models was a problem. The design team used a tubular frame and smaller wheels (55 cm-22") to do this. From this frame adjustable footrests with edgeless heel cups, lockable, swing-up armrests, lever-activated brakes, and an open weave backrest allow users to adjust the chair to their bodies quickly and easily. A footlift that facilitates washing the feet and legs was also developed. The new chair facilitates propulsion in wet environments with rubber coated handrings of 35 mm (1.375").

BACKGROUND

Bowel care-shower chairs are used by individuals with SCI, and others who cannot transfer to the toilet. In these cases they transfer to the bowel care chair and roll it over the toilet. Because the bowel care program takes up to 2 hours, proper seating posture is necessary for comfort and the prevention of pressure ulcers. During a pilot study, the team clinically evaluated existing bowel care/shower chairs and concluded that existing models posed a serious threat to users. Several features of these chairs were found to be less than optimal: space access for digital stimulation, access over a toilet, seat design and cushioning, armrests, footrests, backrest, brakes and the size of wheels and handrings. All these issues were addressed in the design of the new chair. Ortho-Kinetics of Waukesha, WI. worked as the collaborative manufacturer of this VA development project.



Prototype chair

STATEMENT OF PROBLEM/RATIONALE

There are over 200,000 individuals with SCI in the United States today. The majority of these persons have bowel incontinence, requiring bowel care an average of three times a week. The need to design a new bowel care-shower chair was justified by the findings of a survey conducted by the team with 147 veterans with SCI. In this survey numerous safety related problems with existing chairs were reported: (66%) of respondents felt unsafe self-propelling and (47%) in transferring from bed to chair or from chair to chair. (42%) indicated that the brakes were unreliable. (24%) reported development of pressure sores and cuts from the seats, and 35% indicated falls from bowel care-shower chairs. Of those who reported injuries due to falls, over 23% were hospitalized from 1 month to 4 years.

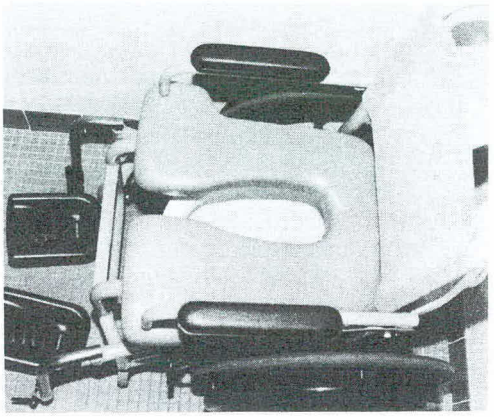
A new and properly-designed bowel care-shower chair was needed to significantly impact the quality of life, self-esteem, and physical well-being of individuals with SCI as well as to improve the efficiency of care-givers who assist in bowel care procedures.

DESIGN / DEVELOPMENT

The design team used an iterative process of prototype development and clinical evaluation to develop the new chair. A breakdown description of the chair's features according to the ANSI/RESNA Wheelchair Standards nomenclature is presented below:

1. Body support

1.1 Seat design & padding: Based on the design team's "Seating centered design" concept which acknowledges that a proper seating position is necessary to prevent pressure ulcers, the team designed a series of square and rectangular seats. These concepts were evaluated for multi-positioning and hand access. From the various designs, a final "C" shape seat was developed to allow hand access in three positions (front, left & right side) and safe transfer from another wheelchair.

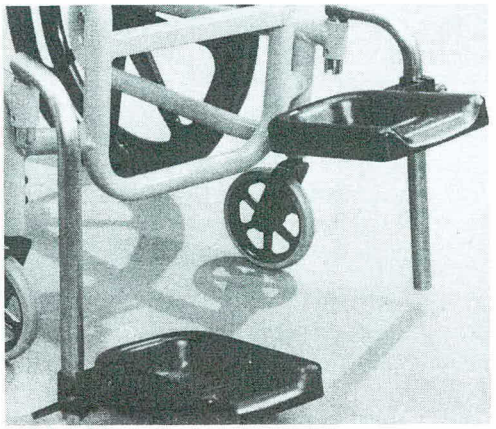


"C"shaped seat over toilet bowl

Various foam densities were evaluated during the process with a "pressure mapping system" to determine an ideal density. The selected seat foam distributes evenly the pressure created by the buttocks and the legs.

1.2 Armrest: A series of armrest concepts were developed and evaluated. The final design swings up during transfers and locks into the frame with a handle latch allowing users to push or pull against it while adjusting their seated position.

1.3 Footrests: With the goal of providing a larger foot support area and an overall contoured shape for safe positioning, a series of concepts were developed and evaluated. The final design has a deep, non-skid



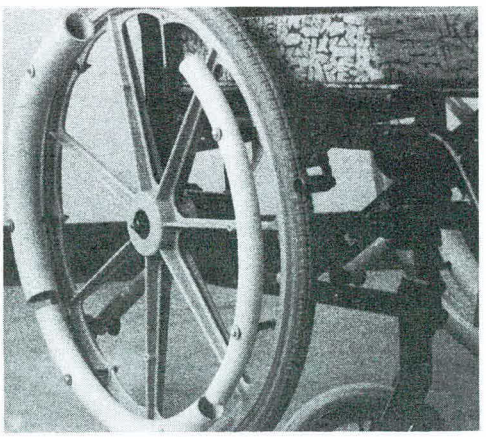
Footrest range of motion

support area with contoured surfaces that hold the user's feet safely in position. The height of each footrest is easily adjusted with threaded handles. In addition a footlift was developed to ease cleaning of legs and feet.

1.4 Backrest: An angled backrest has been selected to allow better positioning in the chair. The backrest is covered with an open mesh fabric that allows water to flow through for showering.

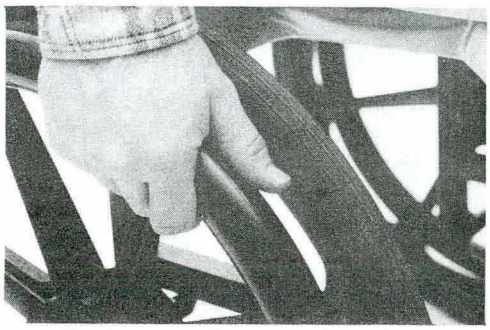
2. Driving system

2.1 Propulsion & driving wheels: Manual propulsion with two 56 cm (22") driving wheels has been selected. These smaller diameter wheels allow for close positioning to a bathroom wall, a critical need in centering the chair over the toilet bowl. The smaller wheels also provide more space for the user to reach under the seat. Two 15 cm (6") casters are mounted in the front.



Handring preference mock-up

2.2 Hand-ring development: A preference study with SCI veterans, using three hand-ring diameters (27, 35 and 42 mm) led to the 35 mm (1.375") as the preferred diameter for grasping. In addition a dipped rubber-coated finish reduces friction and facilitates grasping in wet conditions.

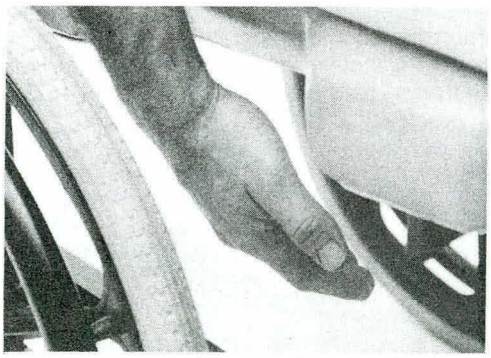


Hand wrapped around a large handring

2.3 Brakes: Frame-mounted lever hand-brakes have been selected for the new chair.

3. Bowel care - shower chair frame

A series of frame concepts were developed and evaluated for stability and proper seating position. The final design utilizes a steel tubing of 32 mm (1.25")to achieve the proper seating configuration. This frame allows hand access for digital stimulation without interference from the frame or wheels.



Hand access between the wheel and seat

3.1 Static stability: The frame was designed for static stability of 15 degrees in sidewards forwards and rearwards tipping.

3.2 Dimensions: Length: 109 cm (43")
Overall height: 102 cm (40")
Wheel to wheel width: 65 cm (25.5 ")
Wheel base: 43 cm (17")

CLINICAL EVALUATION

Eight prototypes were fabricated by Ortho-Kinetics, the collaborating manufacturer. They were clinically evaluated over a six month period by SCI veterans and caregivers at the Milwaukee and Tampa VAMC's. This evaluation involved the use of data instruments to collect caregivers' and participants' opinions. From the clinical evaluation, design modifications were made and are reflected in the final chair design.

TESTING WITH ANSI/RESNA WHEEL CHAIR STANDARDS.

The final chair design will be tested at the DVA/University of Pittsburgh Wheelchair Performance Laboratory with the ANSI/RESNA wheelchair standards before the chair is manufactured. DISCUSSION

This project clearly illustrated that a team effort among users, caregivers, designers and manufacturers can lead to the successful design of a much-needed patient mobility product.

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GEARED MANUAL WHEELCHAIRS: DESIGN REQUIREMENTS AND PROTOTYPE

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ABSTRACT

Reduced muscular strength makes the use of a manual wheelchair difficult or impossible for many potential riders. Everyday obstacles such as wheelchair ramps, door thresholds and soft carpet may require more strength and endurance than is available to these individuals.

Gearing down would make a manual wheelchair a feasible option for many in this group, allowing them to retain the exercise benefits, simplicity and relative affordability of a manual wheelchair. Secondary benefits may include a reduction in repetitive-motion injuries among riders due to reduced muscular force requirements. In addition, a geared chair has potential as a training device in rehabilitation. We describe realistic design requirements for a geared chair and describe the design of and our experience with a prototype device.

DESIGN REQUIREMENTS

We feel that any geared wheelchair must satisfy several critical functional requirements, which are summarized below. A number of geared systems have been conceived (particularly in the patent literature) which would clearly violate one or more of these requirements, rendering the design impractical.

1. It should be possible for the user to apply steering, propelling or braking forces at all times.
2. The width of the chair must certainly be kept below 32", the modern minimum doorway width. In practice, the chair should ideally be several inches narrower than this, since many existing older doorways are narrower than 32".
3. The added weight of the gearing system should be small compared to the base weight of the chair.
4. Independence of rotation of the two wheels should be mantained to allow turning in a small space.
5. The ideal system should be inexpensive compared to the standard wheelcair cost, and retrofittable to a standard chair with minimal modifications. The chair should use standard components insofar as possible. These requirements are dictated primarily by economics, an important consideration for most riders Also, it is not likely that manufacturers would invest in producing a chair with a significant number of unusual components.
6. The gearing system should not interfere with transfers into or out of the chair.
7. The system should be simple, reliable, and relatively maintenance free. It should be possible for the user to make elementary adjustments.

PROTOTYPE GEARED CHAIR DESIGN

In 1995 a team of mechanical engineering students built a prototype offset-drive geared-down wheelchair [Al-Awadhi et. al. 1995] (Figure 1). The chair utilizes secondary handrims connected to the wheel hubs through a toothed nylon belt and nylon pulley system. The chair has been tested with a gear reduction ratios as low as 0.69:1 (i.e. the rider's input force is multiplied by a factor of 1/0.69 = 1.45),

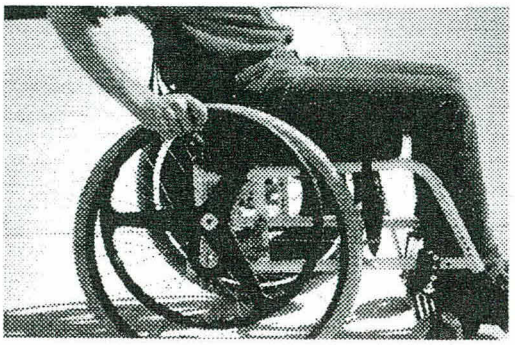

Figure 1: The Geared Chair Prototype.

and is designed to accept gears giving a 0.5:1 or lower ratio. In practice, lower gears than this reduced the chair speed to an unacceptably low level for most riders. The system is designed to be retrofitted to a manual wheelchair (we used a Quickie GPV); the mechanism itself consists of the wheel and a special axle plate which keeps the axle and offset arm stationary. The geared prototype adds a total of 5.5 inches to the width of original chair, giving a total width of 28.5 inches. The total added weight of the retrofit is 3.15 lb, an almost negligible amount.

The gearing consists of a fixed lower gear utilized by turning a second, smaller handrim outside the usual handrim. The normal gear ratio may be utilized by turning the original handrim or tire. The low gear may be optimized by changing one or both of the pulleys. The toothed belt is essentially an automotive timing belt, chosen for its positive drive characteristics (no slippage) and minimal weight and cost. Since the toothed belt distributes the load over almost half the teeth on the pulley, light and inexpensive nylon pulleys are adequate to transmit the torques involved. Another advantage of this transmission is that it is silent and requires no messy lubrication, unlike a chain and sprocket drive or spur gears.

One of the pulleys is screwed into the wheel hub flange, while the other is keyed to the shaft on which the secondary handrim is mounted. This shaft passes through a bushing on one end of the aluminum offset arm; the other end of the offset axle is keyed to the fixed wheel axle. The handrim bushing is mounted in a slot; sliding it up and down allows the belt to be tightened or loosened. The bushing is held in place by a simple motorcycle belt tensioning device. The wheel axle is fixed by keying its inner end to a special axle plate. The axle plate is designed so that the angular position of the offset arm can be adjusted in angular increments of 15° from 30° behind vertical through 90° ahead of vertical (i.e pointing forwards). This gives the physical therapist an additional adjustment in fitting the chair to the rider.

EVALUATION

The gearing system has thus far performed as expected and survived about six months of clinical and informal tests. Is is simple, inexpensive, lightweight and easily retrofitted to a standard manual wheelchair.The primary issue which needs to be addressed is the width. Although the width of 28.5" is less than the design criterion of 32", it is still enough to cause some problems in negotiating narrow doorways. It should be possible to reduce the width of the existing design by simply refining the design slightly, as well as by removing the original fixed handrim.

There were two unanticipated benefits of the geared design. First, the fact that the geared handrim on its offset arm could be mounted with its axis ahead of or behind the wheel axle gave the design an additional degree of freedom. Handrim location could then be adjusted by the physical therapist to fit the patient without moving the wheel axle, which affects the stability and handling characteristics of a chair. The usual forward/backward and up/down adjustability of the wheel axle and axle plate were retained as well in the new design.

The second unexpected benefit of the geared-down design was that riders uniformly found it easier to control the chair on a downhill slope. This is a consequence of the gearing,

which transforms a relatively light touch on the handrim into a strong braking force.

The geared chair has been tested and used by several SCI patients in rehabilitation at Harborview Medical Center in Seattle. We describe here the experiences and observations of the first two test riders.

The first individual's injury was classified as C3 incomplete; however, his functional level was C7 to T1, and he had use of his triceps. He had reached a point in his rehabilitation where he was able to ascend moderate inclines in a standard chair. He tested the geared chair using both the standard gear and the 0.69:1 low gear on a rough and bumpy hill on the sidewalk outside the hospital. He was able to ascend and descend the hill in both cases, but reported that the low gear made the ascent much easier and allowed him to control the chair during descent to a greater degree as well. He felt that 0.69:1.0 ratio was appropriate for him.

The second individual had a C6 injury and was at an earlier stage of rehabilitation. His physical therapist felt that he needed another four to six months of rehabilitation to be able to climb a wheelchair ramp, which he was completely unable to do at the time of testing. He had minimal gripping ability in his hands and propelled the chair primarily by using friction between his palms and the handrest. He was unable to ascend a wheelchair ramp even using the 0.69:1.0 gear ratio. The pulleys were then changed to provide a 0.64:1 ratio, at which point he was able to climb to the top of the ramp with assistance to keep from rolling back during moments of rest. It was felt that an even lower gear ratio would have made the ascent significantly easier for him, in combination with a ratcheting "hill-holder" brakes to keep him from rolling back.

CONCLUSION

We feel that there is a clear need for a geared manual wheelchair for a significant group of riders. Based on our experience in contructing and testing our prototype, the outlook is encouraging for further work on geared manual wheelchairs. We hope that this work will serve as a catalyst to stimulate further design and development of geared wheelchairs by other researchers and by the wheelchair industry.

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ACKNOWLEDGEMENTS

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CUSTOMIZING A POWER WHEELCHAIR WITH A BUILT IN COMMODE

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ABSTRACT

AC has spinal muscular atrophy, uses a power wheelchair and has very little use of her upper body. She needs a method whereby she can void during the day completely unassisted. After examining several options it was decided to build a permanent commode into her wheelchair. The hole position was determined during the seating assessment for a pindot custom molded cushion. A bowl is mounted to the wheelchair seat and urine travels through a hose into a reservoir to be dumped at a later time. A spill guard prevents urine from leaking between the cushion and seat.

BACKGROUND

AC is a 50 year old woman who has spinal muscular atrophy and uses a power wheelchair for mobility. She has very little use of her arms, hands and fingers so she is completely dependent on others for her toileting needs. Volunteer work and her vocational goal require her to spend several hours out of her home. Her aide will not always be available to assist her with toileting so AC needs a way to void without assistance.

Through discussions with her doctor and other medical professionals, it was determined that diapers would not work for AC because she has very sensitive skin. Catheterization was also ruled out because AC is susceptible to urinary tract infections. Voiding only at specific times of the day is problematic for AC since she has diabetes and is required to drink a lot of fluids.

Research of the market uncovered some devices, however, none were appropriate for AC because she does not have the mobility to manage them on her own. One custom solution has a cut out in the seat of the chair and in the cushioning (Loomer A, 1996). A folded diaper sits inside a pan which slides in under the hole. A piece of leatherette fashioned into a drip pan was used to protect the wheelchair base. Another custom solution was for a wheelchair which could not accommodate a pan arrangement because there was very little space underneath the seat (Loomer A, 1996). Again, it had a cut out in the seat of the chair and in the cushioning. A small plastic kitchen bag (6 quart or smaller) is threaded up through a flat collar and then stuffed with facial tissue. The collar fits into a spring loaded retainer on the under side of the seat.

The Love Lift (TM) power wheelchair is commercially available. It has a drop out seat so a person can move the wheel chair over top of a standard toilet to perform toileting functions. Another commercial solution is to use a cut-away seat cushion and a female urinal. In particular, the Bridge urinal and cut-away cushion from Beambridge are reported to work well (Fader, M, 1994).

AC previously used a power wheelchair with a custom system similar to the first one, however, there was no absorbent material inside the pan. A hose at the back of a removable pan was used to drain the urine. Since AC is not capable of managing her clothing she always wore a skirt, but no underwear. That pan design had a lot of problems: the wheelchair needed repairs 20 times in less than two years and it was rendered useless after only 4 years. The problems were recurrent and were mainly due to corrosion from urine to

the wheelchair's contacts, connectors and wiring. Two particular functions caused urine leakage: whenever the pan was removed residual urine in the hose spilled out and whenever the chair was tilted urine leaked between the wheelchair seat and cushion. In addition to corrosion, the urine leakage caused the seat cushion to become dry-rotted.

In spite of its apparent shortcomings and controversy, it was determined that the best solution for AC was a built in commode.

STATEMENT of the PROBLEM

To design a commode built in to the seat of a power wheelchair. It must be sanitary and must not leak under any circumstances.

DESIGN

The team players on this project were: the seating and power mobility evaluators, the wheelchair vendor, the cushion vendor, the designers, the vocational rehabilitation counselor and the case engineer.

An InvaCare Ranger X, a Labac power tilt system and a Pindot custom molded back and seat cushion were recommended for AC at the seating and mobility assessment. The location of the cushion hole was determined during the assessment since it could not be assumed to be central due to AC's seating posture. Pindot fabricated the cushion with the hole in it, thus, it is one homogeneous unit which cannot be penetrated by fluids (Figure 1).

All parts of the built in commode were made out of polypropelene unless otherwise stated. It was determined that AC did not react adversely to this material and it can be sanitized.

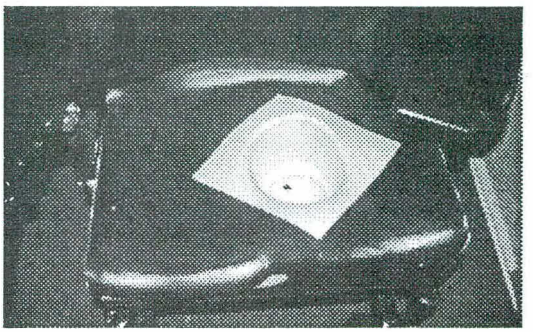

Figure 1

A hole was cut into the wheelchair seat which aligns to the hole on the cushion (Figure 2). This aluminum plate is covered with Naugahyde. The toilet bowl is mounted onto the seat with stainless steel screws. A chemical resistant hose attaches to the bottom of the bowl on a threaded nylon nipple (Figure 3). The other end of the hose connects to a reservoir with a nylon quick release valve.

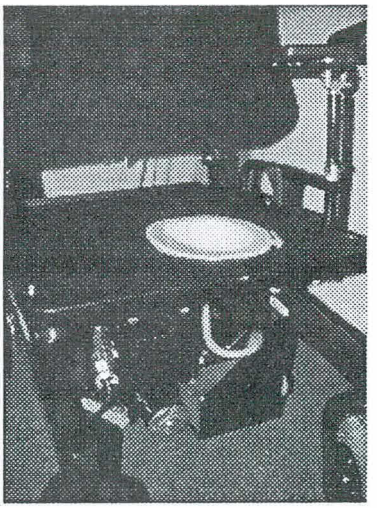

Figure 2

This reservoir is a 0.75 liter bottle with a screw on cap. It fits into a bracket which is mounted to the wheelchair frame behind the front wheel. The reservoir size was chosen dependant upon the

amount of space around the electronics and the front wheel, what was readily available in bottle sizes, and on AC's daily requirements.

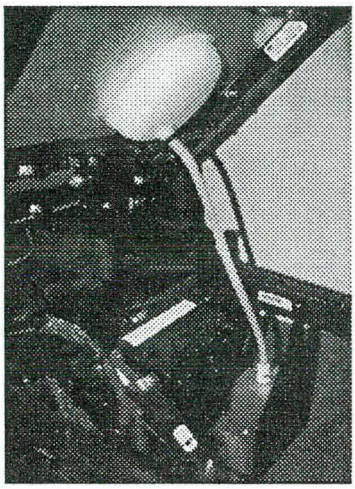

Figure 3

A spill guard is used to keep urine from leaking into the layer between the cushion and the seat plate (Figure 1). It is made of very soft foam and is contoured to fit snugly against the sides of the hole and the bowl. Several spill guards are provided to AC and they are re-usable and washable. The cushion has a fleece cover.

DEVELOPMENT

The vacuum forming process was used to form the bowl and spill guard. It was challenging to make the mold for the spill guard because it had to follow the contours of a custom molded seat.

Design time for the built in commode was 10 hours and fabrication time was 37 hours. The cost of materials was approximately $100.

EVALUATION

The client now goes to a private area to void and the urine flows straight into the reservoir. If her aide is available the reservoir bottle can be detached and emptied immediately. Otherwise, AC has it emptied later and there is no problem with odor or leakage. The unit is cleaned nightly with bleach. The spill guard needs replacing every few weeks.

The commode portion of the system works very well, however, there was a problem with the cushion whereby AC lost circulation in her right leg after sitting up in the chair for only about 5 minutes. A new Pindot seat cushion was made which has no contours. It was important to replace the cushion rather than modify the original cushion because it is necessary to have one homogeneous part that cannot be penetrated by fluids. The spill guard had to be re-formed to match the replacement cushion shape.

DISCUSSION

Future plans for the commode include a switch for the client to automatically empty the reservoir and a more sturdy spill guard.

"The use of a wheelchair with a bedpan underneath (a permanent commode) is, fortunately, dying out" (Fader M, 1994). But, fortunately for AC, the permanent commode is not extinct.

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VARIABILITY OF GEOMETRIC MEASUREMENTS ON WHEELCHAIR USERS

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ABSTRACT

In order to quantify the person's position in his wheelchair, a measurement method has been developed. Pre-defined landmarks are digitized on the subject and are used to represent the 3D position of the person in his wheelchair. In this method, different types of errors contribute to modify the geometric measurements. The purpose of this study is to evaluate these errors and their impact on the precision of the various geometric parameters. Three different tests has been performed to measure the posture reproductivity, the variation of the landmarks identification and the accuracy of the digitizing procedure. The results showed that variability of most of the parameters is below 2 degrees where the sagittal rotation of the pelvis and the hips flexion presenting the highest variability and the thigh and knee angles the lowest.

BACKGROUND

The general purpose of seating is to improve pressure distribution, alignment (stability) and comfort. Through the decades studies has showed the relationship of body orientation on pressure distribution with respect to seating. Hobson [1] demonstrated in his studies that relationship exists between forward and lateral flexion and pressure values. He showed reduction of maximal values when the subject sat in forward flexion or when the backrest is inclined. In the study of Koo [2] the impact of the pelvis's orientation and type of cushions on the pressure distribution has been studied. Several studies confirmed a direct relationship between the posture and pressure distribution [3,4] but not many evaluated the whole body position in the wheelchair. In order to quantify the person's seated position in his wheelchair, a measurement method has been developed. Pre-defined landmarks are digitized on the subject and used to represent his 3D position in his wheelchair. When the body position is studied, different types of errors can contribute to modify the geometric measurement values. The purpose of this paper is to evaluate these errors and their impact on the precision of the various geometric measurements. In a second time, in order to eventually evaluate the postural pattern of wheelchairs users, preliminary results of six handicapped subjects will be presented.

METHOD/APPROACH

Sample and Instrumentation

In order to study the repeatability of measurement, a sample group of five healthy subjects (4 males and 1 female) was composed. The mean age was 28 years (range from 24 to 33 years). Anatomical landmarks are used to defined the geometric measurements (table 1).

Table 1: Anatomical landmarks

Anatomical landmarks
Lateral malleolus (left & right)
Condyle of femur (left and right)
Greater trochanter (left and right)
Iliac crest (left and right)
Anterior superior iliac spines (left and right)
Middle trunk (4 dots left and 4 right)
Acromion (left and right)
Cervical vertebrae (C7)
Sternum (inferior and superior extremity)

To digitize these landmarks a mechanical arm (Microscribe3D, Immersion Corporation) was used. The system has sensors which track the position and orientation of the stylus. The position of the different landmarks were recorded with respect to a gravitational Cartesian coordinates system The accuracy of the Microscribe3DL is 0.64mm (0.025 '') and the workspace is a sphere of 1.67m (66'') of diameter. For this reason, the system has to be placed on each side of the wheelchair so it can reach all landmarks. Mathematical transformation between right and left sides is

possible due to intermediate reference systems defined on each side of the wheelchair support.

Parameters

Fourteen parameters are measured in order to quantify the posture of the user in the wheelchair.

Pelvis lateral tilt : (1) Defined as the angle between the line joining the left and right ASIS and the transverse plane. (2) Defined as the angle between the line joining the left and right iliac crests and the transverse plane.

Pelvis transverse rotation : (3) Defined as the angle between the line joining the left and right ASIS and the frontal plane. (4) Defined as the angle between the line joining the left and right iliac crests and the frontal plane.

Pelvis sagittal rotation : (5) Defined as the angle between the transverse plane and the plane formed by the left and right ASIS and the left and right trochanter. (6) Defined as the angle between the transverse plane and the plane formed by the left and right ASIS and the left and right iliac crests.

Trunk lateral tilt : (7) Defined as the angle between the sagittal plane and the plane formed by the inferior and superior extremity of the sternum, the middle of the two ASIS and C7.

Trunk transverse rotation : (8) Defined as the angle between the frontal plane and the best fit plane formed by the 4 points marked on each side of the trunk.

Left(9) and right(10) knee angle: Defined as the angle between 2 lines joining the malleole, condyle of femur and trochanter projected on the sagittal plane.

Left(11) and right(12) hip angle: Defined as the angle between 2 lines joining the condyle of femur, trochanter and the iliac crest projected on the sagittal plane.

Left(13) and right(14) thigh angle : Defined as the angle between the line joining the condyle of femur and the trochanter and the transverse plane.

Testing procedures

Three tests were performed to establish the reliability of the measurement procedure. For all tests, the wheelchair was fixed on the same support and the variation of the computed values of the different parameters was evaluated.

Test1 : The objective of the first test was to measure the reproductivity of the seated position. (a) The landmarks presented on table 1 were marked on each subjects with a pen. To make the location process more consistent for each test, the same clinician was asked to locate these landmarks. (b) The subject was asked to sit in the wheelchair and the landmarks were digitized in 3D with the mechanical arm. (c) The subject was asked to stand up and walk for 2 minutes. The experiment was repeated four times from step (b).

Test2 : The aim of the second test was to evaluate the variation in the identification of the landmarks: two approaches were used. i)The landmarks were marked with a pen by the clinician and the subject was asked to sit in the wheelchair. The marks were digitized and then erased. The test was repeated three times from beginning. ii)The subjects was asked to sit in the wheelchair for all the duration of the experiment. The clinician digitized the landmarks four times with the mechanical arm without doing pen marks on the subject.

Test3 : For the last test the action of digitizing was evaluated. The subjects was asked to sit in the wheelchair for all the duration of the experiment and landmarks were marked by the clinician. Each marks were digitized four times with respect to the sequence presented on table1.

For each parameters and each tests, a table was construct (table2) [5] . In order to measure the variability, all 20 measurements were centered around zero by subtracting the average of the measurement. Variability of each parameters was then obtained by calculating the standard deviation of the centered data as a group of 20 measurements.

Table2 : Results obtained for each parameters

	Trials				
subjects	**1**	**2**	**3**	**4**	
1	P_{11}	P_{12}	P_{13}	P_{14}	$m_1 \pm \sigma_1$
2	P_{21}	P_{22}	P_{23}	P_{24}	$m_2 \pm \sigma_2$
3	P_{31}	P_{32}	P_{33}	P_{34}	$m_3 \pm \sigma_3$
4	P_{41}	P_{42}	P_{43}	P_{44}	$m_4 \pm \sigma_4$
5	P_{51}	P_{52}	P_{53}	P_{54}	$m_5 \pm \sigma_5$

RESULT AND DISCUSSION

Figure1 presents the variability of each parameters for each three tests. The numbers on the x axis referred to the parameters presented above.

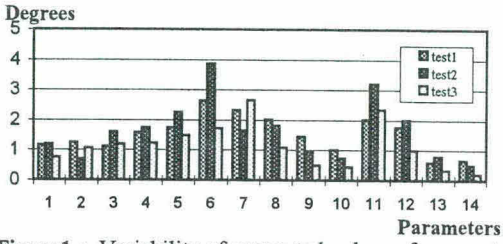

Figure1 : Variability of computed values of parameters measured in degrees for test1, test2-i and test3.

These results indicates that variability less of 2 degrees is measured for most of the parameters. Parameters 6 and 11 which are the pelvis sagittal rotation and the hips flexion respectively, present the higher variability. The common landmarks used in computation of these parameters is the iliac crest. This landmarks is one of the most difficult to be accurately identifiable and then hardly repeatable since it is a flat bone without higher prominence and surrounded with many soft tissues. Results shown on table 3 confirm this hypothesis and presents the trochanter, iliac crest and inferior sternum as less accurate landmarks. Best results are obtained for parameters associated with the thigh (13),(14) and knee angles (10). Some of these observations (figure 1) can be compared with the results of Koo[2]. In his measurement procedure the parameters were repeatable with a deviation of 1.6° for the pelvis sagittal rotation and of 1.4° for the obliquity. In this research the values for the pelvis are obtained with a standard deviation of less than 1.5° which is as accurate as Koo's method. Figure 2 presents the variability of the parameters between the first six handicapped subjects (preliminary results). As posture differs from one to an other, we have obviously obtained variability between the subjects. This method is consistent because, this variability is higher than the variability presents by each parameter.

Table 3: Variability of the identification of the landmarks measured in mm for test2-ii.

	Standard deviation (mm)		
	subject1	subject 2	subject3
Greater trochanter	10.4	10.1	7.2
Iliac crest	10.1	17.8	9.5
Inf. Sternum	7.7	7.8	4.6
ASIS	7.4	9.6	4.0
Sup. Sternum	5.3	5.2	2.3
Condyle of femur	5.0	4.7	2.0
Acromion	3.2	3.7	7.3
Malleole	2.3	1.4	1.1

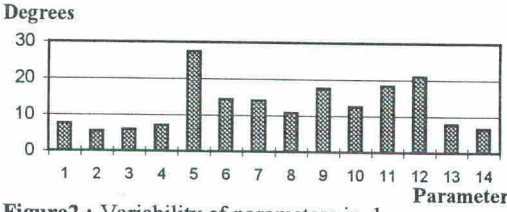

Figure2 : Variability of parameters in degrees measured for the first six subjects.

CONCLUSION

Results confirmed that the geometric measurement method presented in this paper is a non-invasive, simple and accurate procedure. Since the results of the preliminary study done on wheelchairs users are higher than the variability of the parameters themselves, this method can be used to quantify positioning and defined postural patterns of wheelchairs users with adequate precision.

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BIOMECHANICAL CONSIDERATIONS IN SEATING AIDS FOR ELDERLY PERSONS

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ABSTRACT

Physical disabilities ultimately express themselves as changes in the biomechanics of physical-task performance. Quantitative measures are sorely needed because they can serve as indicators of subtle changes in one's functioning over time. The purpose of this paper is to present an overview of the literature related to the biomechanical aspects of sitting comfort, sit-to-stand transfer and propulsion in the elderly population.

BACKGROUND

As the population ages, mobility may be reduced due to acute illnesses, trauma, or progressive conditions such as arthritis. As a result of these conditions, time spent sitting is likely to be increased. The classification of elderly as being persons over the age of 65, has been arbitrarily defined by the tradition of industry and retirement policy. There is no natural definition, because the aging process, and its onset and speed, vary with different populations (Rogers et al., 1996). Generally, elderly people can be classified according to the level of functional mobility they have, as (1) ambulatory; (2) mobile but nonambulatory; (3) nonmobile and dependent, i.e. without energy or ability to wheel or walk by themselves (Redford, 1993). Three types of chairs exist that satisfy these user groups: the static lounge chair (1), the self-propelled chair (2) and the mobile reclining lounge chair (3). To match the needs of the elderly, these technologies are intended to increase sitting comfort, to ease transfers and the sit-to-stand task, as well as to enhance the propulsion efficiency (Holden et al., 1988). Shaw and Taylor (1992) however reported that 80% of elderly nonambulatory people experienced at least one problem related to discomfort, reduced mobility, poor posture and safety risk. Difficulty in rising from a chair affects up to 2 million of noninstitutionalized persons aged 65 and older (Alexander et al., 1996). Munton et al. (1981) found that the prevalence of egress and ingress in the elderly and arthritic people were 42% and 32% respectively. Schultz (1992) reported a prevalence of 54% in bed transfers for the institutionalized elderly people, while Simmons et al. (1995) found that the wheelchair propulsion activity level for the nonambulatory elderly users represent 4% of their sitting time.

RESEARCH QUESTIONS

What are the biomechanical determinants and factors that relate to comfort, ease of transfer, sit-to-stand and propulsion ?

DISCUSSION

Comfort

Elderly people spend many hours each day sitting. Comfort becomes an important aspect of their daily life. In general, the methods employed to measure comfort are subjective. Holden et al. (1988) proposed recommendations for the features of chairs that promote comfort for the elderly (i.e. seat inclination, seat to backrest angle, seat height,...). Moreover, it is generally believed that reducing sitting pressure, especially under the ischial tuberosity increases sitting comfort. In a survey of wheelchair seating problems of the institutionalized eldery, Shaw et al. (1991) reported that the subject experienced seat discomfort (28%), seat and back discomfort (33%), hindered mobility (33%), sliding forward (21%) as well as pressure sores (16%). From this, Shaw (1991) conducted another study whose primary objective was to identify quantifiable indicators of seat comfort in 50 institutionalized elderly subjects. Seat comfort was rated by the subjects, and peak pressure sitting data was collected. This study failed to

confirm the hypothesis that higher peak pressure correlates with greater discomfort. In another study, Shaw (1993) compared four different seat cushions commercially available in terms of pressure measurement and comfort. The peak sitting pressure results failed to fully support the hypothesis that select commercially available seat cushions (the foam and the gel/foam) would provide lower pressure than those traditionally provided (eggcrate cushion) or folded cloth pads. This situation is not restricted only to elderly people. In the automotive seating industry, there has been a struggle to determine seat comfort in an objective manner. Pywell (1993) compared pressure distribution data to the subjective interpretation of seat comfort in a sample of 100 participants. The correlations found between pressure data and subjective comfort were not high enough to be the basis for any design decisions. Perhaps these correlations are poor because comfort is a time-cumulative variable while peak pressure is an instant measurement. Moreover comfort and discomfort need to be treated as different and complementary entities as highlighted by Zhang (1996).

Sit-to-stand and bed transfer

The sit-to-stand task is probably one of the most difficult activities that elderly persons are often confronted with (Rodosky et al., 1989; Riley et al., 1991). Although muscle activity and movement strategy have been examined during the activity of sit-to-stand in the elderly, the relative ease or difficulty of performing this activity remains unclear. Kerr et al. (1991) found that electromyographic (EMG) studies, while providing useful information on phasic muscle activity, appear to have little to offer in evaluating the relative ease or difficulty of rising from a seated position. In fact, EMG studies suggest that healthy elderly (Linden et al.,1994), and healthy elderly and young women (Gross, 1993) moved similarly when rising from a chair at self-selected and fast speeds. In contrast, Schultz et al. (1992) found that older adults place a higher priority on the postural stability than do young adults. This stability was achieved by locating the ground reaction forces more anteriorly with respect to the ankle at the instant of lift-off. In fact, Lundin et al. (1993) showed that the functional reserve was increased in the elderly when the trunk was flexed. Seat height is frequently mentionned as the most important chair design factor influencing egress. The optimal height is generally obtained by subjective rating of difficulty in rise (Alexander et al., 1996). Hughes et al. (1994) defined three strategies during sit-to-stand in the elderly: momentum transfer (efficiency), stabilization (control) and combination of both of them (efficiency/control trade-off). It appears firstly that subjects do not change their strategy when seat height was lowered; secondly the success in rising is not correlated with either subject height or leg length. However, the knee extensor strength appears to be the major limiting factor in the ability to rise from a chair for the functionally impaired elderly (Hughes et al., 1996). Other types of transfer (bed-transfer) or assistive devices (grab bar) are evaluated by rating the video-based motion of elderly subject (Alexander et al., 1992; Sanford et al., 1995).

Propulsion

Although there is abundant research addressing the biomechanics of wheelchair propulsion (Sanderson & Sommer, 1985; McLaurin & Brubaker,1991; Spaepen et al., 1996; Robertson et al., 1996), little has been done in the case of elderly people. In fact, Pawlson et al. (1986) found that the principal reasons why ambulatory persons use wheelchairs are : risk of falling, and getting around faster. There are 1.8 million nursing home residents in the United States, and fewer than 50% are capable of independant ambulation. For these residents, wheelchair propulsion is the only form of self-initiated mobility available. Although 46.2% of residents are able to propel the wheelchair independently, and an additional 26.2% require graduate physical guidance, the percentage of wheelchair activity does not exceed 4% (Simmons et al., 1995). The most obvious explanations for such

low activity levels are the difficulty the residents have in propelling their wheelchairs, and the physical barriers that exist to do so.

CONCLUSION

This study indicates clearly that subjective rating of comfort and ease of transfers need to be assessed more deeply in ordrer to enhance the correlation with biomechanical parameters. In return, these parameters must be sensitive to change in design criteria.

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A COMPARISON OF INDIVIDUALS WITH NEW C5-7 INJURIES VS. INDIVIDUALS WITH OLD C5-7 INJURIES

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ABSTRACT

This study seeks to quantify a normal resting posture using the Cobb Method and correlate this posture with pulmonary function, and seating components. Initial data has been collected on five subjects, two subjects 2-3 years post and three subjects 10-15 years post injury. Preliminary scoliosis and kyphosis measurements and spirometer measurements show nominal differences between the two groups at this time. This can be attributed to the current small sample, which will expand to 25 subjects as of April 1997, and the retrospective methodology. A longitudinal study may demonstrate greater differences over time.

BACKGROUND

It is clinically accepted that sling backrests promote a distinctive posture with a C-shaped kyphosis, posteriorly tilted pelvis, and pelvic obliquity[1,2,3,&4]. Over time, these postural manifestations can lead to back pain, decreased vital capacity, and decreased upper extremity functioning[2]. While these have been documented as clinical observations, there has been little research which substantiates these observations. The majority of published literature seems to focus on the effects of posture on pressure and tissue damage, while conference proceedings have pre-sented on common postures and positioning of individuals with cervical spinal cord injuries. Previous studies have predicted the pulmonary function of individuals[5] with a cervical spinal cord injury, but none have specifically correlated pulmonary function and posture.

RESEARCH QUESTION(S)

Through the comparison of newly injured individuals with cervical spinal cord injury to individuals injured 10-15 years ago, this study seeks to determine the correlation between sitting posture and:
1) pulmonary function, and
2) seating components.

METHOD

Population:

This sample consists of individuals with complete and incomplete C5-C7 quadriplegia who were recruited through area hospitals. Each subject was placed in one of the following two groups: 1) Persons injured 2-3 years ago, or 2) Persons injured 10-15 years ago. These two groups were chosen to enable comparison between persons with new injuries and old injuries. Subjects who were 2-3 years post injury had plateaued regarding neurological recovery and functional gains, and had received their initial seating and mobility components.

Procedure:

Demographic information, prior medical history, and previous seating components, were recorded through a check off and fill in the blank questionnaire. Demographic information and prior medical history will be incorporated into the statistical analysis upon completion of data collection to control for confounders of the outcome measures (i.e.: smoking, injuries since SCI). Previous seating components were recorded to assist in identifying if the use of these components had an impact on our outcome measures.

The subject's current wheelchair, positioning equipment, and their resting posture in his/her wheelchair were also documented.

The subject was then transferred onto a standard measurement wheelchair where pulmonary func-tion and posture were recorded. The purpose of the measurement wheelchair was to provide a standard position for the documentation of postural deformities. The chair was set in a five degree tilt with a ninety degree hip to back angle. The subjects sat on a planar three inch foam cushion with their knees set at a seventy degree angle and

their femurs at zero degrees, parallel with the cushion. Each subject was asked to assume a comfortable resting position which felt similar to a resting position in his/her personal wheelchair.

FVC and FEV1 were recorded with the subject blowing into a portable spirometer. Each subject blew into the spirometer for three trials, with a one minute rest between each trial.

Posterior and lateral x-rays recorded the entire spine from the occipital to the sacral end plate. Kyphosis, scoliosis, and pelvic obliquity were collected using the Cobb angle method.

RESULTS

Mean Scores of 2-3 years post injury versus 10-15 years post injury

	2-3 Yrs	10-15 Yrs
Pelvic Obliquity	8.0°	6.5°
Scoliosis	21.5°	13.3°
Kyphosis	43°	66.3°
FVC	2.22	2.86
FEV1	2.12	2.74

N=5

Three of the five subjects use a standard sling back, while two of the subjects use a sling back with velcro tension straps. One subject was 10-15 years post injury and one subject was 2-3 years post injury. All of the subjects presented with complete or incomplete C5-6 quadriplegia. Results thus far are preliminary with 20 subjects forth-coming through April, 1997.

DISCUSSION

Preliminary data demonstrates conflicting results. Kyphosis increased as years post injury increased, but this was not true for scoliosis or pelvic obliquity. The 10-15 years post injury group also demonstrated greater pulmonary function than the 2-3 year post group.

The pulmonary function results were due to one subject who demonstrated a FVC of 4.24 and FEV1 of 4.04. This was two liters greater than the other four subjects. Without this data, the differences would have been negligible.

Incoming data will provide a more thorough picture and allow for the use of inferential statistics. Optimally, this study would like to be repeated following subjects over a longitudinal time period, but due to funding and time constraints, a longitudinal study was not possible with this study.

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USE OF A PRESSURE MAPPING SYSTEM FOR PROBLEM IDENTIFICATION AND SEATING INTERVENTION

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ABSTRACT

Use of pressure mapping systems has increased in the past few years as the benefits of this technology increase the validity of the evaluator's clinical judgment. According to Minkel and Ferguson-Pell, "almost eighty percent of the time, the changes in distribution validate the expected outcome of the intervention, twenty percent of the time the results will not be as expected, and a potential mistake is avoided."1 The following case studies will provide examples of how the use of a pressure mapping system validated and contributed to appropriate recommendations for seating systems.

BACKGROUND

Client A, K. S., is a 27 year old female with a diagnosis of spastic cerebral palsy affecting all four limbs. She was referred to the Seating Clinic for evaluation of a new power wheelchair and seating system. K.S. has a history of frequent decubiti on her sacrum and she had muscle flap surgery approximately one year prior to the evaluation, which had not healed completely. Her seating system, at the time of the evaluation, was a Jay gel cushion and Jay back with lateral and lumbar support on a power Rolls Ranger II. In addition she was using an inflatable ring on top of the Jay cushion in order to alleviate pressure in the sacral area.

The evaluation revealed that K. S. has range of motion limitations in all four extremities in addition to a left hip dislocation. Her pelvis is rotated forward on the right with both lower extremities windswept to the right. Her sitting posture demonstrated increased kyphosis with rounded shoulders and forward head, as well as decreased lumbar lordosis, posterior pelvic tilt and sacral sitting.

Client B, L.S., is a 22 year old woman with a diagnosis of spastic cerebral palsy. L.S. was referred to the seating clinic for evaluation of a new seating system, particularly a seat cushion, due to current and frequent breakdown on her buttocks. When L.S. came to the evaluation, she was sitting on a Jay gel cushion which was approximately one year old, and was using an Invacare Action power wheelchair. In addition, L.S. was sitting on the sling from a Hoyer lift, (which is used for all her transfers), as well as on a soft pillow. Both of these items were placed on top of the Jay cushion. The prescription from her physician recommended the ordering of a Roho cushion.

L.S. demonstrated the ability to obtain good upright posture with facilitation, and need for support once positioned. After approximately five minutes of sitting, however, L.S. returned to sacral sitting and weightbearing on her sacrum versus on her ischial tuberosities. Visual inspection of the area of concern demonstrated that the breakdown was not in typically weightbearing areas, nor in areas of bony prominences which

would lead to a pressure sore. Evaluation of the skin in the buttocks area revealed a 3 inch long by 1 1/2"-wide area of redness and draining sores. A few of the sores had blood tinged exudate, with some scabbing noted. The primary area affected was located approximately 2 inches distal to the rectum, on the posterior and medial aspect of the gluteal crease bilaterally.

OBJECTIVE

Both of these women were evaluated in the seating clinic using a seating simulator, pressure mapping system and currently available manufacturers' seating systems. The Force Sensing Array (FSA) pressure mapping system was a critical tool used during the assessment. In both cases, the FSA was used to assess areas of pressure in the current and evaluation seating systems. The primary goal in both cases was to reduce pressure, either through new seating systems, or to improve posture while seated, and, therefore; prevent skin breakdown in the future.

METHOD/APPROACH

During the evaluation, the FSA was used with both clients on a variety of seating cushions, as well as their current cushions. Since the FSA is a dynamic system, postural changes made during the evaluation were immediately evident on the computer screen, as were the resultant effects on pressure distribution. All data collected during the evaluation was stored in a separate file for each client for future reference.

In the case of K.S., areas of highest pressure were noted in the sacral area regardless of the cushion tried. When her posture was changed by adding a slight anterior tilt to the seat, opening up the seat to back angle slightly, and adding increased lumbar support, the pressure distribution improved dramatically. With the changed posture, the pressure was more evenly distributed, with weightbearing primarily on her ischial tuberosities, rather than on her sacrum. Even after several minutes of movement in the seating simulator, with K.S.'s posture demonstrating minimal change toward habitual sacral sitting, the readings on the FSA continued to show even pressure distribution.

FSA readings on L.S. indicated no significant areas of increased pressure when positioned on her current cushion and additional Hoyer sling and pillow. It was noted that L.S. tends to weightbear primarily on her sacrum. Additionally, when placed on the physician recommended cushion, the FSA indicated increased pressure in weight-bearing areas. Another cushion was tried, with similar results to physician recommended cushion.

Due to the fact that L.S. is dependent in all care, she reported extended periods of sitting in her wheelchair without pressure relief since recently acquiring a job. In addition, L.S. reported wearing pantyhose frequently, along with the need to wear Depends undergarments. Although she is not incontinent of bowel or bladder, she frequently has extended periods of skin exposure to moisture.

RESULTS

As a result of the evaluation, it was recommended that K.S. would benefit from a new seating system. The recommended system included a Varilite Solo seat cushion with solid insert, and an Ultimate back with lumbar support. Since a new power wheelchair was also ordered, it was recommended that the seat to back angle be set at 110 degrees. Most importantly, a padded, double-pull pelvic positioning strap was recommended to assure that K.S. did not slide forward in her chair and maintained the upright posture. Other components of the wheelchair were modified to inhibit her extensor tone which leads to her sacral sitting.

The recommendations for L.S. did not involve any seating modifications.

DISCUSSION

The FSA was a tool used to provide clinical data to support modifications to K.S.'s seating system. It confirmed the therapists' clinical reasoning that a change in K.S.'s posture would result in improved pressure distribution, and ultimately decrease the incidence of skin breakdown. A positive outcome was achieved as noted by current use of the prescribed seating system for six months, with no reports of skin breakdown.

For L.S., the FSA was again used as a tool to provide clinical data, but in this case, the results showed even pressure distribution in her present system, indicating the tissue distress is not linked to pressure, but to other causes. The outcome in this situation resulted in no changes in her seating system which subsequently resulted in savings to the insurance company. Through information gained from the evaluation and her medical history, it was determined that possible causes of the skin irritation were prolonged exposure to moisture, heat build-up, or some type of systemic infection. Documentation of the evaluation and FSA results were provided to L.S.'s physician with subsequent follow up by the seating team.

The pressure mapping systems not only provided objective data to support therapists' clinical reasoning, but also validated recommendations for the specific seating components. Use of the FSA has become standard practice in our seating clinic, and has allowed for successful outcomes and more versatility with seating recommendations.

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ADAPTATION OF A CLINICAL SEATING SIMULATOR INTO A RESEARCH TOOL

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ABSTRACT

Simulation tools have been developed by universities and industrial research departments in order to provide a better evaluation of wheelchair user seating. Promed, with the SEM (Simulator for Evaluation and Measurements), is one of them. The SEM has to be adapted from a clinical tool to a research tool. Instruments measuring geometrical parameters on the SEM and pressure distribution on the seat and the back surfaces are installed on the simulator. Along with this, a visualization software allows to display in a single image all graphical and numerical information and measurements. The research tool will be useful in the objective and quantitative evaluation of existing seating devices and in the definition of new ones, better suited.

BACKGROUND

Seating simulation is an iterative assessment process in which the seating team observes the dynamic interaction between the client and the seating devices (Ward 1994). In fact, it allows verification of the effects of seating and seating devices changes on the wheelchair user.

It is well accepted that the primary goal of seating simulation is to obtain the optimal seating for the wheelchair user (Presperin 1990, Saftler 1988). It is also useful in the characterization of the appropriate seating devices.

Seating simulation allows modification of one parameter at a time over several parameters. Compromises can be achieved between ideal seating and functional restraints. Simulation being an interactive process, the user acceptance can be verified. Assessment efficiency is as well improved by reducing errors and establishing a better information transfer between the therapist and the manufacturer. Finally, it provides an objective argument on the selected solution.

Few companies (Pin Dot Products, Thallahassee Therapeutic Equip.) and research centers like Dundee Limb Fitting Centre (Bardsley 1982), University of Virginia (Reger 1985), Rehabilitation Technology Center and Rockwood Hospital (Shapcott 1990), have developed seating simulators. They differ from each other on the possible adjustments (angular and linear) and measurements. For instance, Reger (1985) designed a device integrating pressure mapping system on the seat and the back of the simulator.

Promed, a company from Montreal, Canada, has developed a clinical seating simulator called SEM (Simulator for Evaluations and Measurements). It has to be modified for research activities regarding seating and seating devices. Acquisition of measurements must be precise, quick and connected to a PC. Also, a computer graphic visualization software must be developed in order to visualize the whole set of measurements taken on the SEM and the simulator itself. So, the main objective of the project is to adapt the SEM into a research tool for seating and seating devices evaluation.

MATERIAL AND METHOD

Instrumentation

By reviewing the different simulators found in the literature, it was possible to identify the most important geometrical parameters that have to be measured on the SEM by a computer assisted acquisition system. Nine parameters were indeed chosen, consisting in four angles and five linear distances. The angles are : back-to-seat angle, tilt angle, legrest angle and footrest angle. The distances are : seat depth, back height, seat height, armrest height and legrest length.

An accuracy of ± 0.5° is desired for angular measurements and of ± 0.125" for linear measurements. These values are based on data found in the literature. In fact, the device developed by Shapcott (1990) has an accuracy of ± 2° for angles and one of ± 0.5" for linear distances.

In order to obtain those geometrical measurements, rotary potentiometers were bought from Newark Electronics, installed on the SEM and connected to a laptop (for portability) via a data acquisition board purchased from National Instrument (DAQCard 700).

Also, a pressure mapping system was bought from Vista Medical, the Force Sensing Array (FSA). It consists in two matrices, one composed of a 15X15 array of sensors for the seat and the other of a 16X15 array for the back. So, with this system, pressure distribution over the seat and the back can be simultaneously recorded via a data acquisition system and a software.

Finally, a 3D digitizer is used to measure the exact location of the pressure matrices on the simulator, so pressure distribution can be modeled to be shown by the visualization software. Measurements of several landmarks on the matrices over contoured cushion can lead to the model of its 3D shape. These landmarks are obtained with a 3D digitizer, purchased from Immersion Corp. (Microscribe 3DL). It consists of an articulated arm able to reach any point in an half-sphere of 66 inches of diameter. The data can be sent to different commercial softwares, like Notepad, Word, Excel, Matlab.

Visualization software

The visualization software has to gather the different sources of information and make a display of graphical and numerical results. Matlab was chosen as the software support because it allows to do easily 3D graphics, to use graphical control interfaces, matrix computation and importation and exportation of data. The software has indeed to bring together data coming from geometrical measurements on the SEM, pressure distribution measurements and position measurements of the matrices.

RESULTS

Figure 1 shows the SEM on which measuring instruments are installed along with the 3D digitizer. Figure 2 is a display of a typical pressure distribution obtained with the FSA system while figure 3 is an example of the graphical and numerical representation of all measurements obtained with the visualization software.

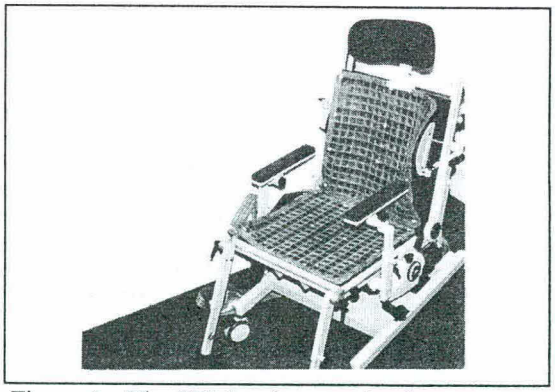

Figure 1 - The SEM and measuring instruments

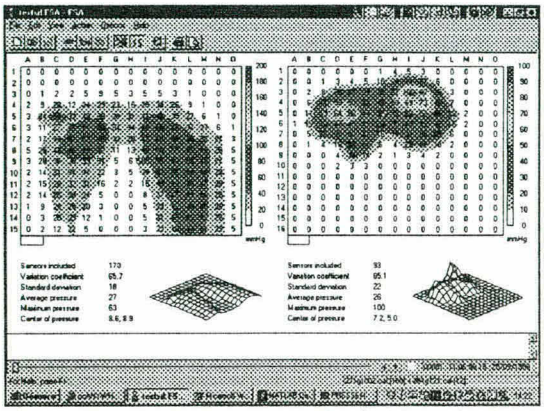

Figure 2 - Typical pressure distribution obtained with the FSA system

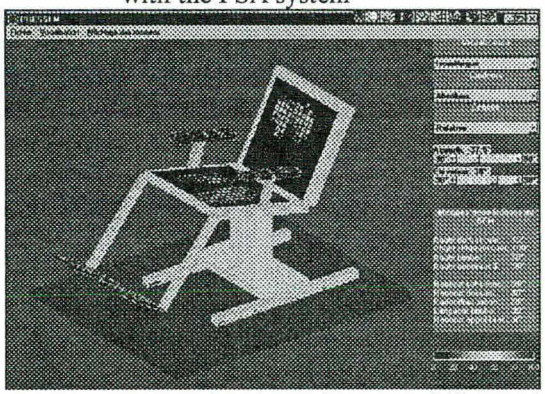

Figure 3 - Example of graphical possibilities of the developed visualization software

DISCUSSION

Preliminary observations shows that the research tool is reliable and respect the desired accuracy. Acquisition of geometrical measurements is efficient, quick and compatible with a laptop for portability. The visualization software allows the user to select the data files, view the model under any specified angle along with numerical results for the different geometrical measurements. There are possibilities of printing results, making zooms on a specified region and viewing the pressure distribution separately. Also, interaction with the digitizer is settled in the program. The software has been developed with the idea of including in a near future the geometry of the several existing seating devices and the geometry of the wheelchair user itself who is being evaluated. This can be done by using the articulated 3D digitizer or an optical acquisition system.

CONCLUSION

The SEM was adapted from a clinical tool to an accurate, efficient and portable research tool for seating evaluation and the use of different seating devices. In doing so, some geometrical parameters on the simulator were quantified along with the pressure distribution on the seat and the back. Data acquisition systems were used to link the simulator to a PC. A visualization software gathers all these information and display in the same image graphical as well as numerical results. The research tool will be useful in the evaluation of existing seating devices, identification of necessary changes on them and making recommendation for the design of better suited seating devices. Along with data coming from the geometry of the user, the improved SEM will be used as an efficient and accurate research tool to evaluate the effects of repositioning on seating.

Acknowledgments

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TESTING POLYURETHANE FOAMS FOR CUSHION DESIGN

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ABSTRACT

Polyurethane foams are used as an inexpensive way to reduce interface pressure in seating applications. Specimens of three different polyurethane foams were cut to four different sizes and compressed according to ASTM protocols to determine their stiffness. Test results varied according to the relationship between the sizes of the test specimen and the testing equipment. It is recommended that investigators create a testing situation which reflects their application when determining the cushioning capabilities of these materials.

BACKGROUND

Polyurethane foams are used extensively as inexpensive cushioning materials for wheelchair seating (1). In the design process, a major focus is the reduction of decubitus ulcer formation by reducing pressure. Knowledge of stiffness and cushioning capability of these flexible cellular materials will assist in this goal of the design (2-6).

To measure these material properties, a number of investigators have relied on the ASTM standard, ASTM D-3574-95, "Standard Methods of Testing Flexible Cellular Materials--Slab, Bonded and Molded Urethane Foams," (7) and its predecessors. For this study, the Indentation Force Deflection Test--Specified Deflection was used as a large deformation test where the foam is compressed by 65% of its original thickness. The Indentation Force Deflection Test--Specified Force was used as a small deformation test where the foam is compressed by a force up to 220 N. For both of these tests, the ASTM standard calls for a specimen that in no case shall have dimensions less than 380 mm X 380 mm X 20 mm.

Several investigators with interest in rehabilitation applications have had reasons to reduce the specimen sizes while using the ASTM standard. Ferguson Pell et al. (3) used 50 mm x 50 mm X 25 mm thick specimens of urethane foams to determine their material properties for the design of modular wheelchair cushions. Chung (4) used 203 mm diameter X 76 mm thick specimens of polyurethane foam to determine their material properties in his investigation of tissue-cushion interface pressure. Smith et al. (6) used 305 mm X 305 mm X 100 mm specimens of several polyurethane foams to investigate the effect of coatings. Kang et al. (5) used 40 mm X 40 mm X 50 mm specimens of a polyurethane foam to determine the relationship between the supporting properties and the loss of surface area in the foams.

RESEARCH QUESTION

The purpose of this study was to examine how the size of the specimen tested would affect the material properties. Traditional engineering materials do not exhibit the large elastic region (25% - 65% strain or more) of these cellular foams. Due to this large elastic region and the specification of a minimum specimen size and an indenter size in the ASTM standard, it was believed that specimen size may affect the stress-strain relationship for large deflections.

METHOD

ASTM Standard

As specified by the ASTM standard (7),

the foam specimen was supported by a 330 mm X 330 mm aluminum plate with 6.4 mm diameter holes on 12.7 mm centers, and a 203 mm diameter aluminum circular plate was used as the indenter. For the smallest specimens tested, the weight of the circular indenter caused a large initial deformation, so a 50 mm X 50 mm X 10 mm aluminum indenter was used for those specimens.

For the large deformation and small deformation tests, each specimen was preflexed and tested according to the procedure in the standard (7).

Procedure

In the present study, three types of polyurethane cushioning foams were investigated. These foams were Fire Resistant (FR) Polyurethane (PU), #6 PU, and PU Beige.

The test proceeded with four different sizes of specimens. Specimens larger than the indenter were 380 mm X 380 mm X 100 mm and 305 mm X 305 mm X 100 mm. After these samples were tested, 100 mm thick disks with a 203 mm diameter were cut from the 305 mm X 305 mm X 100 mm blocks. The smallest samples were 40 mm X 40 mm X 50 mm blocks which were cut from the disks. All testing was completed with Instron Universal Testing Machines. An illustration of the test setup is shown in Figure 1.

Four different specimens of FR PU and three different specimens of each of the other materials were tested. Each of the two tests was repeated six times for each specimen. Over the period of testing, temperature and relative humidity varied in the test facility from 17-24 C and 43%-86% humidity.

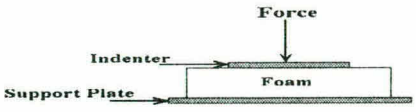

Figure 1. Experimental Setup

RESULTS

Average values from the six data sets for the FRPU samples are shown in Stress vs. Strain curves in Figure 2.

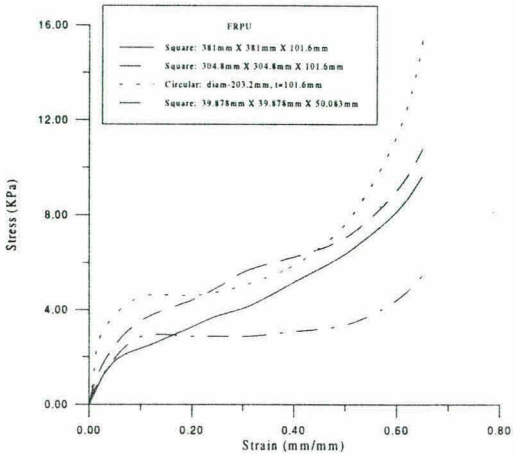

Figure 2. Stress-Strain Curve for FRPU.

Similar results were obtained for the #6 PU and PU Beige specimens.

When looking at the different size specimens, there are two distinct trends for each of the materials. At large strains, the two larger blocks corresponded to a much larger stress than the disk and smaller block. For example, at 50% strain, the stress is 2 to 2.5 times as great for the larger specimens. This tendency was consistent for all of the samples tested.

In general the stress-strain curves for FR PU, #6 PU, and PU Beige all behaved similarly to the foam materials investigated by Ferguson-Pell, et al. (3). There is a three-phase load-deformation characteristic due to the bending, buckling, and collapse of the cellular structure of the foam. This began with an initial period of linearity followed by a change in slope at about 2% strain. Then a second linear region began. In this region the materials exhibited a reduced stiffness. At slightly over 50% strain, the stress-strain relationship began to exhibit nonlinearity with a stiffening of the material. None of the materials exhibited any plasticity.

DISCUSSION

Chung suggested that when a foam specimen has a larger cross-sectional area than the indenter that a shear force is created between the material and the sides of the indenter as the specimen is deformed (4). This is shown schematically in Figure 3. The results described previously follow this tendency. Note that while a different indenter was used for the smaller blocks, its cross-section was still larger than the block cross-section. Thus the resulting stress-strain curves are not affected by varying the indenter size.

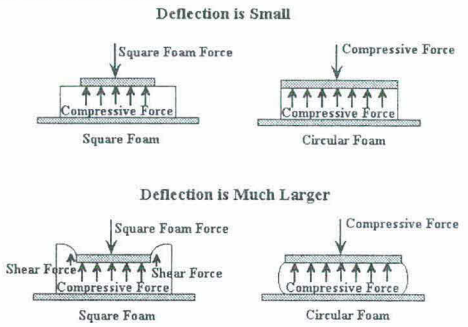

Figure 3. Existing forces when different size specimens are compressed.

In the design of a wheelchair cushion for pressure optimization, the cushion is usually developed to envelop the buttocks (1, 2, 4). Thus material properties should be used for the case of material specimens that are larger than the test indenter. The shear stress included in the measurements will also exist when someone sits on a cushion.

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Back Support System Effects on Seating During Manual Wheelchair Propulsion

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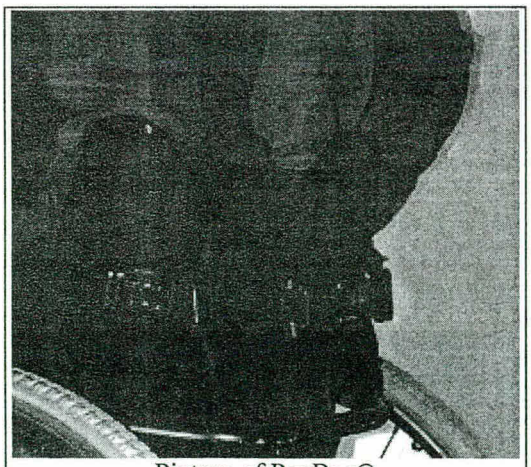
ABSTRACT

The back support system, PaxBac®, was designed to address the postural support problems that wheelchair riders experience when using sling-back upholstery. The purpose of this study was to test the effect of the PaxBac® system on the seating position of wheelchair riders with spinal cord injuries. Three subjects manually propelled their own wheelchairs on a stationary wheelchair dynamometer. Video data were collected and a Peak5 system was used to analyze the kinematic data of the head, hip and elbow during wheelchair propulsion with and without PaxBac®. Statistical analysis was done to compare the minimum, maximum and range of motion of the three angles using an ANOVA two factor with replication and an ANOVA single factor. The results from this study show a change in seating orientation, but no change in range of motion.

Introduction

Wheelchairs are an important form of mobility for people with spinal cord injuries. However, long term manual wheelchair use may lead to secondary disabilities. Carpal tunnel syndrome, rotator cuff tendinitis and tears, decubitis ulcers and spinal deformities have all been associated with improper manual wheelchair set-up [1]. The back support system was designed to address the postural problems wheelchair users experience when using chairs with sling backrest upholstery [2]. It is clinically accepted that sitting in a wheelchair with a sling backrest promotes rounding forward of the spine and posterior tilting of the pelvis which can lead to back and neck pain and even long-term deformities of the spine and pelvis [3]. With a properly designed and adjusted lumbar pad , normal static seating posture can be achieved. In order to obtain proper seating posture, the wheelchair seat and backrest angels must be considered [3][4]. Primarily, wheelchair seating studies have been done using static seating posture[4]. Ride vibration, postural support, pressure distribution, ergonomics and material breath ability are important parameters which affect the wheelchair user's assessment of comfort and risk for secondary disability [5]. Changes due to dynamic seating posture can cause long term damage and deformity such as tissue necrosis, nerve damage and spinal deformity[4]. Dynamic wheelchair seating incorporates accelerations and cyclic loading compounding exiting static loads. Manual wheelchair propulsion is a dynamic seating condition. Several studies have shown that changes in wheelchair seating parameters can alter the wheelchair stroke mechanics[4]. This study examined the influence of the PaxBac® on dynamic seating posture (head and hip angle) and stroke biomechanics (elbow angle) . It was hypothesized that there would be significant differences between the head, hip, and elbow angles among the subjects with or without the PaxBac®.



Picture of PaxBac®

Method

Data were collected of three male manual wheelchair users who gave written consent prior to the study. A profile of each of the subject is given in Table 1 below.

Table 1: Subject Information

Subject	Age (yr)	Height (inch)	SCI-Level
1	33	77	T6-7 complete
2	39	72	T9-L1 incomplete
3	34	76	T5 incomplete
Subject	Yrs w/ SCI	Back Support use (mo)	
1	11	8	
2	26	13	
3	17	6	

Before testing each subject highly reflective markers were attached to the ear, acromion process, lateral epicondyle, wrist, greater trochanter, the head of the fibula, the wheelchair hub and the pushrim.

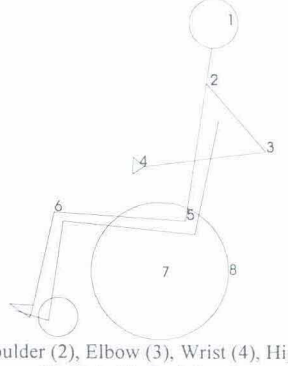
Subjects were filmed while manually propelling their own wheelchairs on a dynamometer at each individual's self-chosen speed. The distance between camera, a TR700 Sony Handicam Hi8mm, and the wheelchair dynamometer was 97 inches. Data were collected for 120 seconds (60 seconds with the PaxBac® on and 60 seconds with it off). Three consecutive strokes in the middle of trials were used for analysis. Joint angles were determined from the video data using a Peak5 motion analysis system. An ANOVA single factor was used to analyze the subjects three strokes.

Results

This Study used kinematic data to compare the minimum, maximum and range of motion of the elbow, hip and head angle during wheelchair propulsion with and without the PaxBac®.

There was a significant difference (p=.021) for the group between the with and without for the elbow minimum angle and the subjects were significantly different (p= .01). The individual stroke analysis of elbow angle minimum with and without PaxBac® showed Subject #1 as significantly different (p=.005), but Subject #2 (p=.962) and Subject #3 (p=.060) were not. There was no significant difference for the group's with or without elbow maximum angle, but the subjects were significantly different (p=<.01). The individual stroke analysis of with and without showed that Subject #3 was significantly different (p=.007) while Subject #1 (p=.233) and Subject #2 (p=.167) were not. There was no significant difference for the group's elbow range of motion, but the subjects were significantly different (p=.016) were not. There was no significant difference for the group's elbow range of motion, but subjects were significantly different (p=.016) from each other. There was no significant difference for the individual strokes of the subjects in the range of motion of the elbow during propulsion.

Figure 1



Ear (1), Shoulder (2), Elbow (3), Wrist (4), Hip (5), Knee (6), Hub (7), Pushrim (8)

Angles: Elbow: 2-3-4; Hip: 1-5-6, Head: 1-2- Horizontal Axis from marker #2.

The group's with and without hip minimum angle was significantly different (p=<.01) and the subjects were significantly different (p=<.01). All the individual strokes of the subjects were significantly different: Subject #1 (p=.021), Subject #2 (p=<.01).and Subject #3 (p=.012). The group's with and without hip maximum angle was significantly different (p=<.01) and the subjects were significantly different (p=<.01). The individual strokes of the subjects were all significantly different: Subject #1(p=.004), subject #2 (p=.0001), and Subject #3 (p=.0001). There was no significant difference between the with and

without for the hip range of motion, but the subjects were significantly different (p=.001).

The group's with and without head minimum angle was significantly different (p=<.01). The individual strokes of the subjects were all significantly different: Subject #1 (p=.039), Subject #2 (p=.003) and Subject #3 (p=.039). The group's with and without hip maximum angle was significantly different (p=.047) and the subjects were significantly different (p=<.01). The individual strokes of Subject #2 were significantly different (p=.007) while Subject #1 (p=.179) and Subject #3(p=.907) were not. There was no significant difference for the group (p=.247), but there was a significant difference between subjects (p=<.01). The individual strokes of Subject #3 were significantly different (p=.022) while Subject #1 (p=.246) and Subject #2 (p=.135) were not.

Table 2: ROM of the Angles for 3 consecutive Strokes

Angle (degrees)	Subject	with (max-min)	without (max-min)
Head	1	257-223	248-218
	2	276-250	267-242
	3	275-225	265-227
Elbow	1	170-105	
	2	163-117	168-110
	3	155-93	162-99
Hip	1	117-108	111-104
	2	92-86	108-102
	3	93-87	92-89

Discussion

The hip minimum and maximum angles were significantly different but the range of motion was not due to the fact that the subjects sat in the wheelchair differently when the back support was on versus when the back support was off. The different seating posture in the wheelchair caused a different orientation in space but the subjects went trough similar ROM. This different seating position or orientation in space with the wheelchair caused the head minimum and maximum angle to be significantly different but the ROM was not. The back-support changed the subjects' seating posture in the wheelchair , but further studies need to be done to investigate if the changed seating posture affects the propulsion technique. The results from this study do not show any change in propulsion technique when the back-support was used, the subjects were seated in a different orientation in the spectrum. In this pilot study, only the elbow angle was analyzed for wheelchair propulsion mechanics, further analysis of wheelchair propulsion variables need to be investigated to determine if the PaxBac® changes the propulsion technique.

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WHEELCHAIR PROPULSION: HEMIPLEGIC vs TWO-HANDED PATTERN

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ABSTRACT

Nine wheelchair users who propelled their wheelchairs with one arm and one leg (hemiplegic pattern [HP]) were compared with 9 who used two hands. Those in the HP group were more likely, when propelling forward up an incline, to deviate to the hemiparetic side, to use more propulsive cycles per unit distance, to need support from a spotter to maintain position, to use a siderail and to roll back between cycles. When stopping while moving backward on the level or incline, they were more likely to deviate to the unaffected side. These findings have implications for wheelchair training, prescription and design.

BACKGROUND

In our clinical experience, most wheelchair users with hemiplegia use both the unaffected arm and leg to propel their wheelchairs, with the leg providing a steering as well as a propulsive force. To facilitate this propulsive pattern, the wheelchair legrest on the unaffected side is usually removed and the seat height is lowered to allow the foot to effectively reach the ground. But the application of force to a single pushrim can cause the wheelchair to deviate toward the affected side. This tendency may be aggravated by the perceptual neglect of obstacles on the left that may be associated with left hemiparesis. Surprisingly, although there have been a number of studies about wheelchair propulsion, few have addressed persons with hemiplegia (1,2).

RESEARCH QUESTIONS

The object of this study was to qualitatively compare the hemiplegic pattern (HP) of wheelchair propulsion with that using two hands (THP), hypothesizing that wheelchair users using the HP would be more likely than those using the THP method, when propelling forward on the level or up an incline, to deviate to the hemiparetic (H) side, use more propulsive cycles per unit distance, experience foot slippage and, on an incline, be more likely to require support to keep from rolling back, to grab the siderail and to roll back between cycles. When stopping from forward movement, those in the HP group are more likely to deviate to the N side on the level. When proceeding backward on the level, the HP group is more likely to deviate to the H side but, on an incline, to deviate to the N side (because the propulsive force is due to gravity, slowed and controlled by the N side). When stopping from backward movement, those in the HP group should deviate to the N side on the level or on an incline.

METHODS

Subjects and wheelchairs. We studied 18 wheelchair users with their informed consent, 9 of whom habitually propelled their wheelchairs with the HP and 9 control subjects who propelled their wheelchairs with the THP. The subject and control groups were matched by age (within 5 years) and gender. All subjects used rear-wheel-drive manually propelled wheelchairs; none were equipped with one-arm-drive mechanisms or grade aids.

Procedure. Each subject was videotaped from the left lateral perspective while performing 4 tasks: propelling the wheelchair forward and backward, on the level and on a 5° incline. We reviewed the videotapes, recording observations about the following parameters:

a. deviation: of more than ~10° from the line of progression and the direction (H if to the hemiparetic side, N if to the unaffected side).

b. propulsive cycles per unit distance: the number of propulsive cycles (arm/leg for the HP group or arm propulsions for the THP group) by the subject to travel forward a fixed distance (~2 m).

c. foot slippage: if the foot slipped on the floor or ramp during propulsion or stopping.
d. wheel slippage: whether, on attempting to stop, the wheels continued to slide after they had ceased to roll.
e. support when locks off: on the incline, before propelling forward, whether the subject was able to unlock the wheel locks without requiring the spotter to prevent rollback.
f. grabbing the siderail: on the incline, before or while propelling forward, whether the subjects grabbed the siderail of the ramp, either to steady themselves after unlocking the brakes or to aid in propulsion (not permitted).
g. rollback: on the incline, while propelling forward, backward movement between forward propulsions.

RESULTS

The results are shown in Table 1. Those in the HP group were more likely, when propelling forward up an incline, to deviate to the hemiparetic side, to use more propulsive cycles per unit distance, to need support from a spotter to maintain position, to use a siderail and to roll back between cycles. When stopping while moving backward on the level or incline, they were more likely to deviate to the unaffected side. Foot slippage was common in the HP group, particularly during backward propulsion. Only subjects in the THP group demonstrated wheel slippage.

DISCUSSION

Many, but not all, of the hypotheses were corroborated. There were a few unexpected results: those in the HP group were as successful as those in the THP group at propelling and stopping in a straight line forward on the level and in propelling backward on the level or incline. This may have been because the feet of those in the HP group served well in their steering capacity and because both groups experienced some difficulty in backing up straight. Also, some of the HP subjects deviated to the N rather than the H side when wheeling backward on the level. This may have been due to the tendency of subjects to turn the upper body in the wheelchait in order to see where they were going.

This study had some limitations, notably that only short distances were studied, the failure to study subjects as they negotiated obstacles (e.g. soft surfaces, level changes, and doors), the small number of subjects and the homogeneous ability level of the persons with hemiplegia (all were capable of performing the tasks). Also, the observations were qualitative; many of them could be evaluated in a more quantitative fashion, as they should be in future studies.

Nevertheless, it is clear that those in the HP group were likely to have expended more energy, to be less effective in getting to destinations and in positioning themselves correctly once there, and to be at increased danger (e.g. of deviating into a hot stove or off the edge of a ramp). These findings have implications for wheelchair training, prescription and design.

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Table 1: Forward and backward propulsion and stopping (n = 9 in each group)

Parameter		Level		5° Incline	
		HP	THP	HP	THP
Forward propulsion and stopping					
Deviation during propulsion, deviation (N/H)		1 (0/1)	0	5 (0/5)	0
Deviation while stopping, direction (N/H)		1 (1/0)*	1	NA	NA
Slippage	foot	4	NA	2	NA
	wheel	0	5	0	0
Propulsive cycles per distance (mean)		3.8	3.4	9.5	4.4
Support when locks off		NA	NA	4	0
Grabbed side rail		NA	NA	5	0
Rollback		NA	NA	4	0
Backward propulsion and stopping					
Deviation during propulsion, direction (N/H)		3 (3/0)	2	3 (3/0)	2
Deviation while stopping, direction (N/H)		4(4/0)	0	8 (7/1)	1
Slippage	foot	8	NA	9	NA
	wheel	0	1	0	0

HP = hemiplegic pattern group; THP = two-hands-propulsion group; N/H = deviation to the normal/hemiplegic sides; * n = 8, because the stop was out of the videorecorder's field of view; NA = not applicable

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BILATERAL ANALYSIS OF MANUAL WHEELCHAIR PROPULSION ON VARIOUS SURFACES

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ABSTRACT

The purpose of this paper was to determine the peak tangential force and work per unit distance required to transverse specific surfaces in a wheelchair. The work per unit distance parameter was then used to compare the surface/speed conditions and the left and right sides. Significant differences were found between surfaces. The carpet at a medium speed (16.92 ± 5.17 J/m) and the flat tile at a slow speed (6.34 ± 1.24 J/m) were the left side extrema, while the sloped tile at a slow speed (13.35 ± 2.54 J/m) and the flat tile at a slow speed (3.00 ± 1.24 J/m) were the right side extrema. The parameters for all the conditions were larger on the left side than the right side. Bilateral analysis of wheelchair propulsion using the peak tangential force (14.40 ± 6.19 N to 66.46 ± 16.89 N), the maximum peak tangential force (27.38 ± 6.90 N to 90.93 ± 16.08 N) and the work per unit distance (3.00 ± 1.24 J/m to 16.92 ± 5.17 J/m) will aid clinicians in assessing the appropriateness of a manual wheelchair for an individual.

BACKGROUND

The ability to determine the amount of work and peak tangential forces that are required to transverse specific surfaces is important in assessing the ability of an individual to use a manual wheelchair for mobility purposes. This will primarily depend on the environmental conditions the individual will encounter. Forces and moments, as well as the amount of work required to propel a wheelchair over surfaces with a resistance similar to that provided by an ergometer, dynamometer, or treadmill have been determined. [1,2,3]. Previously, the only way to make all of these measurements was through a system which was restrained to the laboratory setting. The SMART^{Wheel} [4], which is fully transportable outside the laboratory setting, allows for the direct measurement of the 3-D forces and moments an individual imparts on the handrim, as well as the position of the wheel over time. The incorporation of two SMART^{Wheel}s on an individual's wheelchair allows, for the first time, the bilateral measurement of 3-D forces and moments in almost any setting.

The purpose of this paper was to determine the peak tangential forces and work per unit distance required to transverse specific surfaces. Then compare the work per unit distance from one surface to the next as well as from the left side to the right side. Clinicians could use this data in conjunction with equipment they already possess (free weights, cybex ergometer, dynamometer, and/or instrumented wheelchair such as the SMART^{Wheel}), to determine if a manual wheelchair should be incorporated in an individuals mobility plans.

METHOD

The forces and moments applied to the pushrim as well as the wheel's angular position were obtained using two SMART^{Wheel}s. The axles were positioned in the rear most position (manufacturer's default) on a Quickie 1 wheelchair. A single subject familiar with wheelchair use, but not a daily wheelchair user, was selected for the trials.

Two portable computers recorded the SMART^{Wheel} data and six 6V batteries powered the SMART^{Wheel}. The laptops and batteries were mounted to a trailing wheelchair. The data were synchronized by sending a single voltage through a coaxial cable to the parallel port of each portable computer. The sampling rate of each SMART^{Wheel} was 240 Hz.

Each trial consisted of propelling the wheelchair for 20 seconds or until the end of the selected surface. The subject was instructed to start from a stopped position on the specified surface, and was to stop prior to the end of the specified surface. The four surfaces tested are a bumpy tile floor with no incline, a smooth tile floor with no incline, a smooth tile floor with a 1% incline, and carpet. Data were collected at a slow speed (slow as possible without stopping forward motion), a medium speed (cruising speed), and a fast speed (fast as possible). Four trials were conducted at each surface/speed condition.

The forces along the x, y, and z axes, respectively, the moments about the three axes, respectively and the angular position of the wheel were measured using the SMART^{Wheel} [4]. The individual strokes were determined using the methods described by DiGiovine, et. al. [5].

The work for each stroke is defined as, $W = \int Mz \cdot dr$, where W is the work performed

during the complete stroke, Mz is the moment about the wheel axle and r is the angular position of the wheel. The integration was performed using trapezoidal numerical integration. For comparison purposes (stroke to stroke and trial to trial) the work performed per unit distance was calculated.

RESULTS

Following a preliminary analysis to insure the integrity of the data, some of the trials had to be removed from consideration. The trials used in the final analysis consisted of four slow speed trials and two medium speed trials. The average speeds for the slow speed trials and medium speed trials were 0.39 ± 0.09 m/s and 0.69 ± 0.08 m/s, respectively. For each different surface/speed condition, there were at least two trials ranging from four to twelve strokes per trial. The strokes used in the analysis were strokes at steady state, therefore, the initial stroke for each trial and strokes used to straighten the chair were discarded. Upon removal of the non-steady-state strokes, the steady-state strokes per trial ranged from three to eleven.

The mean and standard deviation of the work per unit distance performed during a complete stroke over all strokes are shown in Table 1. The mean and standard deviation of the peak tangential force (F_t) during a complete stroke over all strokes are shown in Table 2. Also, the maximum peak tangential force ($F_{t\ max}$) over all the strokes for each trial was isolated, and the mean and standard deviation of these values were determined for each surface, Table 2.

Table 1. The mean ± s.d. of the work per unit distance (J/m) for each surface/speed combination.

Surface	N	Left Side	Right Side
A Bumpy Tile (S)*	9	6.99±1.55	3.56±1.38
B Sloped Tile (S)*	19	15.16±2.74	13.35±2.54
C Flat Tile (S)*	23	6.34±1.24	3.00±1.24
D Carpet (S)*	16	15.99±3.03	6.03±2.02
E Bumpy Tile (M)	8	8.65±1.62	7.12±7.62
F Carpet (M)*	16	16.92±5.17	8.21±3.61

*denotes significant difference ($\alpha = 0.05$) between sides
S = Slow Speed Trial, M = Medium Speed Trial
N = number of complete strokes per condition

A one-way ANOVA (confidence interval = 95%, $\alpha = 0.05$) using Scheffé's Multiple-Comparisons Procedure was utilized in order to compare the means of the work per unit distance for four different surfaces at the slow speed. This was repeated for both the right side and the left side, respectively, Table 3.

A one-way ANOVA (confidence interval = 95%, $\alpha = 0.05$) using Scheffé's Multiple-Comparisons Procedure was utilized in order to compare the means of the work per unit distance for the bumpy tile at slow and medium speeds, and the carpet at slow and medium speeds. This was repeated for both the right side and the left side, respectively, Table 3.

Table 2. The mean ± s.d. of the peak tangential force (F_t) (N) and the maximum peak tangential force ($F_{t\ max.}$) (N) for each surface/speed condition.

		Left Side		Right Side	
	N	F_t	$F_{t\ max.}$	F_t	$F_{t\ max.}$
A	9	25.86 ±11.14	47.79 ±13.33	15.02 ±6.72	28.53 ±3.71
B	19	45.75 ±10.10	64.05 ±0.53	38.35 ±8.74	48.90 ±17.38
C	23	23.88 ±7.01	37.10 ±6.83	14.40 ±6.19	27.38 ±6.90
D	16	44.51 ±8.89	60.10 ±4.39	21.22 ±9.71	37.44 ±1.88
E	8	44.15 ±11.37	54.16 ±5.14	35.48 ±7.89	40.95 ±9.23
F	16	66.46 ±16.89	90.93 ±16.08	40.25 ±12.86	59.04 ±14.16

N = number of complete strokes per condition

Table 3. Comparison of surface/speed conditions ($\alpha = 0.05$). The form is Left/Right.

	A	B	C	D	E
B	Y/Y				
C	N/N	Y/Y			
D	Y/Y	N/Y	Y/Y		
E	N/Y	N/A	N/A	Y/N	
F	Y/Y	N/A	N/A	N/Y	Y/N

Y=significant, N=not significant, N/A=not applicable.

An unpaired t-test assuming equal variance (confidence interval = 95%, α=0.05) was utilized in order to compare the work per unit distance for the left and right sides. This was repeated for all six surface/speed conditions, Table 2.

DISCUSSION

The work required by an individual using a manual wheelchair to travel across a specific surface can be stated in the form of work per unit distance. This parameter is normalized based on the distance traveled and is independent of time, therefore, a clinician can investigate whether an

individual should be able to transverse a surface, regardless of time requirements. If the distance to be traveled on a specific surface is known, a prediction as to the amount of work which would be required can be made. The independence on time is a potential deficiency of this parameter. It may be feasible for an individual to transverse the surface based on the work per unit distance, but it may require an excessive amount of time, therefore, making it impractical (and frustrating) for the individual to transverse the surface.

Another factor which is important in determining whether an individual should be able to travel over a specific surface is the peak tangential forces (F_t) requirement. If the required peak tangential forces, for the individual, are not attained then motion may not be initiated on a specific surface, or maintained at a practical speed.

In the comparison of the surfaces at slow speeds, significant differences were found for bumpy tile vs. sloped tile, bumpy tile vs. carpet, and flat tile vs. sloped tile for the right side and left side, Table 3. These results are reasonable because one would expect the bumpy and flat tile surface to be different than a sloped tile surface with a 1% grade and a carpet surface. Mixed results were found for carpet vs. sloped tile. No significant differences were found between the bumpy tile and the flat tile for the right side and left side, as would be expected.

In the comparison of the surfaces at medium speeds and the corresponding surfaces at slow speeds, significant differences were found for bumpy tile at a slow speed vs. carpet at a slow speed once again, and bumpy tile at a slow speed vs. carpet at a medium speed for the right side and left side, Table 3. These are reasonable results because work per unit distance is independent of speed (time). Mixed results were found for the remainder of the comparisons. The comparison of the left side data appears valid in which there is no significant difference for bumpy tile at a slow speed vs. bumpy tile at a medium speed, and carpet at a slow speed vs. carpet at a medium speed, whereas there is a significant difference for carpet at a slow speed vs. bumpy tile at a medium speed and bumpy tile at a medium speed vs. carpet at a medium speed, Table 3. Once again, these are reasonable results because work per unit distance is independent of speed (time).

In the comparison of the left side to the right side at six surface/speed conditions, significant differences were found for all the conditions except for the bumpy tile surface at a medium speed, Table 2. The work per unit distance, peak tangential force (F_t), and maximum peak tangential force ($F_{t\ max.}$) were always larger on the left side than the right side. This was probably a result of the asymmetries in the subject's stroke (dominant left hand), the wheelchair (consistently pulled left), and/or the surface itself.

The relevance of the methods devised and the data collected from a clinical standpoint are that the peak tangential forces (F_t) across all complete strokes could be correlated to a weight an individual should be able to lift (benchpress, curl, tricep-curl, etc.) a number of times in order to transverse a surface of a given length in a set amount of time. The maximum peak tangential forces ($F_{t\ max.}$) could be correlated to a weight an individual should be able to lift (benchpress, curl, tricep-curl, etc.) once. Also, a reference table of surfaces and the work per unit distance required to transverse that surface could be created, allowing a clinician with an instrumented wheel similar to the SMART^{Wheel} to determine if a specific manual wheelchair is appropriate for an individual, and on what surfaces the individual will most likely be able to successfully navigate.

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DYNAMIC WHEELCHAIR STABILITY: RELIABILITY OF AN ORDINAL SCALE

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ABSTRACT

Dynamic wheelchair instability is a common cause of injury. Twenty-one users of manual wheelchairs were videotaped twice as they performed 6 tasks intended to induce dynamic rear instability. The test-retest, intra-rater and inter-rater reliability of a 5-point ordinal scale of dynamic stability revealed complete agreement in 85, 94 and 94% of each of 126 comparisons. Although the reliabilities were very good to excellent, opportunities to improve these values were identified, principally by enhancement of the videorecording techniques.

BACKGROUND

There have been a number of reports published of serious injuries and deaths due to wheelchair-related accidents (1,2), with wheelchair instability a factor in ~75% of such incidents. The International Standards Organization (ISO), in association with its national counterparts, has developed standards for the determination of static stability (ISO, 7176-1)(3). Unlike for static stability, there is no well standardized method for quantifying the dynamic stability of manually propelled wheelchairs. One method is the use of an ordinal scale to score dynamic stability as subjects in wheelchairs undertake standardized tasks (4-8). The ISO standard on the determination of the dynamic stability of electric wheelchairs(9) is under revision (10) and includes the following scale:

4: "no tip" (at least one uphill wheel remains on the test plane)
3: "transient tip" (all uphill wheels lift, then drop back onto the test plane, and the antitip devices do not contact the test plane)
2: "transient antitipper-limited tip" (all uphill wheels lift, then drop back onto the test plane, and one or more antitip devices contact the test plane)
1: "stuck on antitip device" (all uphill wheels lift off, the wheelchair antitip device[s] contact the test plane, and the wheelchair remains on the antitip device[s])
0: "full tip" (the wheelchair tips completely over with the wheelchair coming to rest at least 90° from its original orientation [unless caught by a restraining device or testing personnel for test purposes]).

RESEARCH QUESTION

Any method of quantitating dynamic wheelchair stability should have good measurement properties. The object of the present study was to evaluate one such property of the proposed ISO dynamic-stability scale, specifically the reliability as users of manually propelled wheelchairs perform a set of tasks likely to induce rear instability.

METHODS

Subjects and wheelchairs. We studied 21 wheelchair users with their informed consent, 14 men and 7 women with a mean age of 43.3 (range 15-69) years. The reasons for wheelchair use were paraplegia/quadriplegia (traumatic, myelitis or meningomyelocele) in 9, amputation of lower extremity in 5, central nervous system disorders (stroke, head injury, tumor) in 3, peripheral neuropathy in 2 and musculoskeletal problems in 2. All subjects used rear-wheel-drive manually propelled wheelchairs, products of 5 different manufacturers, 16 of which were of a folding type and 16 of which were equipped with rear antitip devices.

Procedure. Three tasks (reaching backward, accelerating forward and decelerating while moving backward), each on the level and on a 5° incline, were used to induce rear

instability. After the six tasks had been completed, they were immediately repeated. All tasks were videotaped from the left lateral perspective.

Data analysis. By reviewing the videotapes, a set of scoring instructions were generated to assist raters in using the ordinal scale. The videotapes were then reviewed by the raters, at full speed and in slow motion. Test-retest reliability, reflecting the consistency of the wheelchair users, was evaluated by comparing the scores of rater 1 from the first and second trials. Intra-rater reliability was evaluated by comparing the scores of rater 1 on trial 1 with the same trial scored at least two weeks later. Inter-rater reliability was evaluated by comparing the scores of raters 1 and 2.

RESULTS

Test-Retest Reliability. Of the 126 comparisons (6 tasks x 21 subjects), there was perfect agreement in 107 (85%). Where there was disagreement, the two scores disagreed by only a single level in 17/19. On one occasion, a subject had a score of 4 on the first trial and 0 on the second due to the subject reaching further in the second trial. On the other occasion, during the deceleration-while-moving-backward task, a subject had a score of 2 on the first trial and 0 on the second. Where there was disagreement, the first score was higher in 10 and the second higher in 9.

Intra-Rater Reliability. Of the 126 comparisons, there was perfect agreement in 118 (94%). Where there was disagreement, the two scores disagreed by only a single level in all, the first being higher in 7 and the second higher in 1.

Inter-Rater Reliability. Of the 126 comparisons, there was perfect agreement in 118 (94%). Where there was disagreement, the two scores disagreed by only a single level in all, the first being higher in 6 and the second higher in 2.

DISCUSSION

The test-retest results were very good. The variability between trials (in excess of what can be attributed to limitations in intra-rater reliability) probably reflects performance inconsistency and/or a learning effect. The intra- and inter-rater reliabilities were excellent, with perfect agreement in 94% of tests.

However, improvements in the data-collection technique should permit even better reliability. For instance, the spotter should be trained to always allow the extent of instability to become clear before intervening to prevent a full tip. If the subject tips back onto the antitippers, the spotter should ask the subject to restore the chair to the original position without moving the buttocks, but should not tell him or her how to do it. Also, two videocameras would be preferable to one, to avoid periods when uphill wheels or antitip devices move out of view. Backlighting is helpful in detecting brief instances of wheel liftoff or antitipper contact.

Although the study was limited in scope (studying a limited number of tasks, in a relatively homogeneous population of users, in manual wheelchairs only and only in the rear-stability direction) and there is room for improvement in how such tests are administered and scored, the ordinal scale under consideration by the ISO appears to be a reliable tool with excellent promise in both the clinical and research areas.

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A STUDY OF THE POWER WHEELCHAIR OPERATIONAL STATUS OF TWENTY FOUR DRIVERS AT A LONG-TERM CARE FACILITY

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ABSTRACT

The power wheelchairs of twenty-four drivers at a long-term care facility were checked for operational status. The equipment was examined on nineteen occasions over a period of two months. The power wheelchairs were found to be operational 94% of the time. The chairs controlled by joystick were 98% operational, while those controlled by multiswitches were operational only 89% of the time. Data from a wider sampling could be the basis for general usage performance criteria for power wheelchairs. Further study should examine power wheelchairs used in other environments, and the specific causes of non-operational status.

BACKGROUND

In evaluating power wheelchairs (PWC's), users and powered mobility professionals have identified durability and reliability as top priorities. (Brienza et al., 1995) Despite much anecdotal reporting from PWC consumers and their caregivers, little documentation of this type of functional equipment performance was found in published literature. Ongoing laboratory comparative testing of PWC structural durability is being performed for the development of standards, but how standards relate to general usage performance at the consumer level has not been established. PWC quality must not only be defined from and engineering perspective, but from a user and clinical one as well. (Cooper et al., 1996) Indeed, improvements in PWC design or the true functional reliability of any PWC, cannot be adequately assessed without basic usage performance measurements. This study describes a simple model of measuring the general functional status of PWC's over time.

RESEARCH QUESTIONS

Related to the PWC's of clients at a long-term care facility for persons with severe developmental disabilities, this study sought to answer the following two questions:

How regularly are the PWC's in functional, working condition?

Does the functional reliability of joystick-controlled PWC's differ from those activated by multiswitches?

METHOD

Sample

Twenty-four PWC users, residents of a long-term care facility for persons with severe developmental disabilities, participated in this study. This facility has an in-house Rehabilitation Technology department chiefly responsible for the maintenance and repair of the PWC's. Fourteen of the drivers were joystick-users, and ten used multiswitch access. All participants were generally seated in their PWC's for the entire day, except for one who drives for only a few hours a day.

Procedure

On nineteen weekdays over the course of two months, the PWC's of twenty-four users were each checked for their functional operating condition. On a test day, each PWC was simply graded as "operational" or "non-operational". "Unavailable" was used to describe a PWC which was not found at the time of survey. The survey was performed at supper, to which all residents gather. Data collection for most subjects was simplified by merely witnessing the resident's arrival (via PWC) to the meal. Clients who were not observed driving or not seated in their PWC's were interviewed as to their PWC's functional status. If the user was unsure of the operational status of their PWC, the surveyor located the chair and tested it.

In all, 24 responses were collected on 19 days, for a total of 456 pieces of data.

RESULTS

From the 456 occurrences, 26 instances (5.7%) of "non-operational" PWC's

and 34 instances (7.5%) of "unavailable" PWC's were found. Twelve (50%) of the PWC's were operational at every survey; only two of these were multiswitch-controlled PWC's. Operational status of the twenty-four participant PWC's ranged from 50% to 100%. Two PWC's accounted for half of the "non-operational" occurrences. These 13 occurrences resulted in the two lowest individual operational status performances; 50% and 76%. Both of these PWC's were multiswitch-controlled.

From the available PWC's surveyed, the mean of those which were found operational was 94%. There was greater incidence of non-operational status amongst PWC's controlled via multiswitches. Multiswitch-controlled PWC's were operational only 89% of the time, compared to 98% for joystick-operated PWC's. An examination of the raw data of these two groups suggested that the assumptions for t-test comparison of means would not be met. A Mann-Whitney U-test found a significant difference between the joystick and multiswitch groups in the mean percentage of days the PWC was operational. ($U=30.50$, $p<.05$).

DISCUSSION

The results of this study can be seen as significant in three ways, but are limited by its scope and uncontrolled variables. At this residence, baseline functional performance values were established for: 1)each individual PWC, 2)joystick-PWC's and multiswitch-PWC's each as a group, and 3)the PWC's in general. To increase the validity of these quantitative results, this population would need to be sampled again. It is unclear whether these performance values have significance beyond this particular facility. Equivalent surveys would need to be performed at facilities with similar consumer and equipment maintenance characteristics, as well as those dissimilar to the studied residence.

This study did not in any way account for the age of the PWC, or track how lightly or heavily a particular PWC was used by any particular user on any given day. The study did not collect detailed data on the cause(s) of a non-operational PWC. Thus all "down-time" was considered equivalent; whether caregiver-related (i.e. inadequate battery charging), usage-related (i.e. van transport shaking components loose), or design-related (i.e. fatigued frame weld crack).

The mean functional status of the multiswitch-controlled PWC's was 9% lower than their joystick-controlled counterparts. It is theorized that the increased complexity of the multiswitch inputs and the fact that they are not integrated by design into a standard PWC, increases their vulnerability to mishandling and breakage. This result indicates the need for improved multiswitch design for PWC application, but further study may reveal other factors specific to multiswitch-controlled PWC's or their usage which account for the dissimilar performance.

At the facility where this study was performed, some of the therapeutic and care giving goals relate to maximizing independence through the provision and use of adaptive equipment. This objective measure can be used to indirectly assess the outcomes of the therapeutic and equipment-maintenance programs. Each resident's PWC now has a baseline performance value to compare to the overall community mean, as well as to the mean of their access sub-group (joystick-PWC or multiswitch-PWC).

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A COMPOUND SENSOR FOR BIOMECHANICAL ANALYSIS OF LOAD-BEARING SOFT TISSUE

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ABSTRACT

The development and evaluation of a compound sensor for use in a Computer Automated Seating System (CASS) are described. An 11 by 12 array of support elements constitutes an adjustable seat support surface. A pressure transducer is fixed in the center of a swiveling head on top of each support element. four 7.5 MHz ultrasonic transducers are evenly distributed around the pressure transducer in 9 support element heads, which form a 3 by 3 array. A novel, composite ultrasonic transducer using an 1-3 ceramic-polymer structure is used in the design. Compared with conventional PZT ultrasonic transducers, this transducer has higher sensitivity, signal-to-noise ratio and resolution. The sensor measures pressure from 0 to 10 psi with ±0.15% linearity and identifies subcutaneous soft tissue characteristics 5 to 50 mm below the skin surface with 0.3 mm axial resolution.

BACKGROUND

Pressure ulcers are a common and costly clinical problem, especially in the elderly and spinal cord injury populations. According to the National Pressure Ulcer Advisory Panel, pressure ulcer prevalence in U.S. hospital settings ranges from 3.5% to 29% (1). In addition, it has been estimated that between 50% and 80% of persons with spinal cord injury will develop a pressure ulcer (2). The total cost of pressure ulcer treatment in the US exceeds 1.3 Billion dollars (1). These estimates indicate that pressure ulcers are a significant health care problem.

A unique ultrasound-seating system for soft tissue characterization is being developed based on the computer-automated seating system developed by Brienza et al (3, 4). It combines ultrasonic detection with the closed-loop, dynamically controlled shape and pressure sensing system. It allows quantification of the complex relationships among shape, tissue deformation and interface pressure under controlled loading conditions. Such knowledge could lead to an improved understanding of mechanical factors leading to pressure ulcer formation.

STATEMENT of the PROBLEM

A compound sensor is one of the keys to developing the ultrasound system. This sensor will allow interface pressure and tissue distortion information to be measured simultaneously. However, the sensor must overcome limits due to the geometrical structure, especially the ultrasonic transducers. It was determined that the diameter of the ultrasonic transducer must be less than 3 mm, a long cable is required to connect to the existing seating system, and it must have good acoustic and electric characteristics. For example, the transducer needs to meet acoustic impedance match as well as electric impedance match. The sensor needs to have high sensitivity, a broad frequency bandwidth, narrow pulse width, good axial resolution and low noise. Among these are two contradictions, that is, the contradiction between small size and high sensitivity, and the contradiction between high emitting frequency with a long cable and low noise.

DESIGN/DEVELOPMENT

The compound sensor is shown in Fig. 1. A pressure transducer is fixed in the center of a swiveling head on top of a support element. Four ultrasonic transducers are evenly distributed around the pressure transducer. The overall size of the sensor is 33.7 mm in diameter by 7.2 mm high. Each ultrasonic transducer has as 3 mm diameter and is a height of 7.2 mm. The sensor can detect pressure from 0 to 10 psi with ±0.15% linearity and an ultrasonic echo from 5 to 50 mm depth. The axial resolution exceeds 0.5 mm. Specifications determined for the ultrasonic transducer included a central frequency of 7.5MHz, a frequency bandwidth more than 60%, pulse width less than 0.2 μs and a

sensitivity more than -22 dB. In addition, the coupling materials needed between the sensor and body soft tissue must be compatible with the pressure transducer.

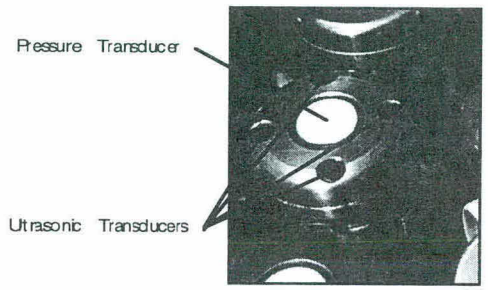


Fig. 1 The structure of a prototype sensor

EVALUATION

Sensor Performance Evaluation

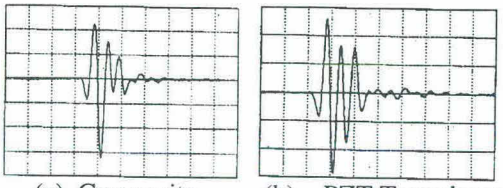
The acoustic field measurement system consisted of the AIMS-01 (beam scan) and the UTA-4 (echoes scan) ultrasound measurement system. The ultrasound soft tissue characterization system was developed in our laboratories and used to detect the axial resolution of the transducer (3). The measurements were done in a standard water tank. The sensor performance results are summarized in Table 1.

Table 1. Sensor performance results

Parameters	Composite FS960046	PZT 1 #951069	PZT 2 #960102
Sensitivity	-22 dB	-31 dB	-35 dB
Bandwidth (-3 dB)	81.71%	42.72 %	34.04 %
(-6 dB)	98.7 %	53.3 %	43.9 %
Central Frequency	7.506 MHz	7.157 MHz	8.136 MHz
Pulse width	0.165 μs	0.23 μs	0.295 μs
Axial Resolution	0.3 mm	0.6 mm	0.6 mm
Cable Length	3 m	2 m	2 m

Echo waveform in time-dimension

The echo waveform of the composite transducer is shown in Fig. 2(a). The third positive voltage peak at 34.1 % is the maximum positive peak voltage, and the third negative voltage peak at 22 % is the maximum negative peak voltage. The echo waveform of the PZT transducer is shown in Fig. 2(b). Here, the third positive voltage peak at 70 % is the maximum positive peak voltage and the third negative voltage peak at 97.7 % is the maximum negative peak voltage. These results demonstrate the better damping capabilities of the composite transducer over the PZT transducer.



(a) Composite Transducer (b) PZT Transducer

Fig. 2 Waveform in Time Dimension
(X axis: Time, 0.2 μs/division.
Y axis: Output Voltage, 0.05V/division.)

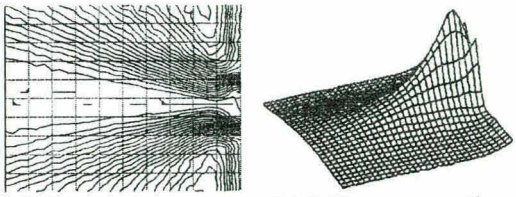
Ultrasound Field Scan

The scanning receiver was a 0.2 mm hydrophone, placed 40 mm from the center of ultrasound transducer. The scanning size was 75 $\times$12 mm and the incremental area was 1 mm^2 when the sound beam was scanned. Fig. 3 (a) shows a 2-D planar scan-contour plot of the ultrasound field of the composite transducer with a beam waist near 0.4 mm in diameter. When the ultrasound field energy attenuates 3 dB, the beam width is 1.0 mm in diameter at the maximum energy position and is 5.4 mm in diameter for a detecting distance of 54.5 mm. The 3-D plot of the ultrasound field characteristics is shown in Fig. 3.(b) and represents the ultrasound field intensity and the distribution of the transducer in water.

Ultrasound Coupling Material Compatibility

The influence of the ultrasound coupling material on the interface pressure measurements was investigated. Pressure measurements were made using a pressure calibration device and method as described in Brienza et al (4). Different coupling materials, including ultrasound gel, nylon, machine oil and starch, were tested. The test showed ultrasound gel

produces the most stable and reproducible results with an error less than 8 % over the entire range of applied pressure and standard deviation less than 5×10^{-3} psi.



(a) 2-D contour map (b) 3-D representation
Fig. 3 The ultrasound characteristics of the composite transducer

DISCUSSION

The composite ultrasonic transducer, using the 1-3 ceramic-polymer structure, has many desirable characteristics. As shown in Table 1, it's sensitivity is 9-13 dB higher than the piezoelectric transducer and it's bandwidth is wider by 39-47.7 %. The axial resolution was improved to 0.3 mm. Although the cable of the composite transducer was lengthened to 3 m, it's performances was much better than that of the conventional PZT transducers.

The non-homogeneous nature of tissue may result in larger variations in energy transmission. In seating design, the weight-bearing pelvis presses down onto the buttocks and onto the associated tissues of muscle, fascia, fat and skin. Thus, the multiple reflections between tissue and transducer, non-linear behavior of tissue, beam scattering and sound velocity in non-homogeneous tissue needs to be investigated further.

CONCLUSION

A novel composite ultrasound transducer using 1-3 structure has been developed and was only recently commercialized. The novel composite transducer was used to design a compound sensor with ultrasonic and pressure transducers. The test results showed that the performance of the composite transducer was much better than the PZT transducer. It's higher sensitivity improves the design of a small transducer. The transducer's broad bandwidth and high axial resolution improve the ability to identify tissue characteristics. It's high signal-to-noise ratio with the longer cable meets the requirement of the CASS system. In additions, the use of ultrasound coupling gel is compatible with pressure measurement. In summary, the compound sensor can be used to investigate the biomechanical characterization of the load-bearing buttock's soft tissue.

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SMART^{ACCELEROMETER}: A DEVICE TO MEASURE THREE-AXIS ACCELERATION FOR THE PURPOSE OF EVALUATING WHEELCHAIR RIDER COMFORT

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ABSTRACT

A method is presented to measure an individual's vibration exposure for a normal day of wheelchair use. A subject's own wheelchair was fitted with a three-axis accelerometer and a microcontroller based circuit board. The Fast Fourier Transform (FFT) was performed continuously on the acceleration data which was sampled at 200 Hz. The signal power was then estimated and summed over periods of 1 hour throughout a 4 hour period. The results were then compared to the International Organization for Standards standard ISO-2631. Longitudinal acceleration (fore-aft), exceeded the ISO-2631 *reduced comfort boundary* based on 16 hours of exposure.

BACKGROUND

A wheelchair rider's comfort is related to the whole-body vibration he/she experiences. Although there is much research regarding whole-body vibration, there is little information available on the characteristics and tolerance for whole-body vibration among wheelchairs users [1,2]. ISO-2631 [3,4] (International Organization for Standards) can be used as a starting point for the measurement of the wheelchair rider's exposure to vibration. ISO-2631 describes methods which are acceptable for accumulating vibration test data and defines vibration tolerance limits for an individual in the seated position. A wheelchair's frame, tire, cushion, and suspension can transmit vibration from the road surface to the rider. By customizing the characteristics of these components to minimize vibration, a wheelchair could be made to be more comfortable.

The ISO-2631 standard defines exposure boundaries over the frequency range of 1 Hz to 80 Hz. The exposure boundaries are a function of the time of exposure and the frequency of vibration. Time of exposure is the sum of vibration exposure over a typical day with no allowance made for recovery periods between exposures within the same day. There are three vibration exposure boundaries defined by ISO-2631. These are, in increasing order of exposure, the *reduced comfort boundary*, the *fatigue-decreased performance boundary*, and the *exposure limit boundary*. The standard uses the *fatigue-decreased performance* boundary as a baseline and the other two boundaries are determined by scaling. The *exposure limit boundary* is defined to be 6 dB (2 x) greater in magnitude than the *fatigue-decreased performance boundary*, and the *reduced comfort boundary* is defined as 10 dB less. The frequencies where the lowest longitudinal vibration exposure is allowed are for the range from 4 Hz to 8 Hz. This range is commonly reported to be the resonant frequency of the human body in the seated position. The boundaries for transverse vibration (x,y-axes) are lowest in the range of 1 Hz to 2 Hz.

In accordance with ISO-2631, vibration is measured on the surface which contacts the body. In the case of a wheelchair, this is the seat. A separate standard, ISO 10325-1 [5], calls for the placement of a thin piece of metal or other stiff material between the individual (subject) and the seat surface. Since wheelchair users have an increased risk of pressure sores over the ischial tuberosities when seated on hard surfaces for long periods, this method cannot be implemented exactly as stated in the standard.

According to ISO-2631, the intensity of each frequency range is to be reported as a root mean square (RMS) value. The frequencies from 1 Hz to 80 Hz are divided into 20 third-octave ranges. The tolerance within each frequency may be treated separately (rating method), or the weighted sum of each third octave RMS value may be used to produce one cumulative value (weighting method). RMS is one estimate of the power of a signal over a frequency band. RMS is not the only method for signal power estimation. A method based on the Fast Fourier Transform (FFT) is often used in practice.

RESEARCH QUESTIONS

The research presented here attempts to answer two questions regarding wheelchair rider comfort. What are the dynamic accelerations exerted on a wheelchair and rider during normal use? Do these dynamic accelerations significantly affect the comfort of the wheelchair user?

METHODS

Instrumentation

The acceleration of the wheelchair was measured with three capacitive single-chip accelerometers (Analog Devices ADXL05) mounted in a three-axis configuration. The displacement of a micro-machined plate is offset by an electrostatic force-balance control loop. The control signal, which is proportional to the acceleration, is output as a voltage. The full-scale range of these accelerometers is ± 4 g's.

The voltage output of the accelerometers is measured and analyzed on a continuous basis by a microcontroller based circuit board designed especially for this task. This circuit board is based on an MC68HC11 microcontroller with 32 Kbytes of onboard memory. The digital operating voltage is 3.1 V and the current draw is 55 mA. This low power design allows for over 50 hours of operation

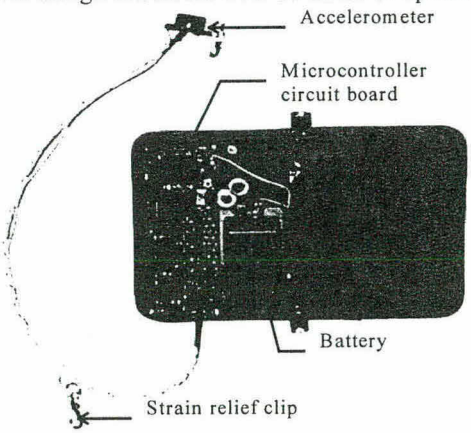

Figure 1 - SMART[ACCELEROMETER] System. The pack contains the microcontroller circuit board and a NiCad camcorder battery. The accelerometer is mounted to a wheelchair tube near the right rear axle. The clip provides strain relief.

on a camcorder battery (3000 mAh, 6 V, NiCad). Two ultra-low dropout voltage regulators from Texas Instruments were used (TPS7101Q) to isolate the digital section of the circuit from the analog section.

The microcontroller's eight-channel, eight-bit, analog to digital converter is used to sample the accelerometer's output voltage at 200 Hz. These values are stored in three 1024 byte ring buffers by a software interrupt routine. When 512 data points have been received, a Fast-Fourier-Transform routine is used to determine the frequency content of the acceleration signal. While the FFT routine is operating, the interrupt routine collects the next 512 data points. To accelerate the performance of the FFT routine, the first 256 bytes are treated as real input data and the next 256 bytes are treated as imaginary input data. Both data streams are added together as shown in Equation 1.

$$h(t) = f(t) + jg(t) \tag{1}$$

In Equations 2 and 3, the discrete Fourier transform $F(\omega)$ and $G(\omega)$ are separated from the discrete Fourier transform of the combination of the time domain data. ω_S refers to the sampling frequency.

$$F(\omega) = \frac{H(\omega) + H^*(\omega_s - \omega)}{2} \tag{2}$$

$$G(\omega) = \frac{H(\omega) - H^*(\omega_s - \omega)}{2j} \tag{3}$$

To further enhance the performance, the FFT software routine was written to process all three ring buffers simultaneously. This reduced the time necessary to calculate the indexes of the FFT routine by two-thirds.

The power of the input signal is estimated for each frequency by Equation 4 and summed over the period of one hour. In Equation 4, $P(\omega)$ is the signal power estimate, and N is the number of points in the FFT calculation (N = 256). The signal power of the signal for frequencies of 1 Hz to 19 Hz is stored individually, and the signal power of the signal from 20 Hz to 112 Hz is grouped into 4 Hz bins.

$$P(\omega) = \frac{1}{N}\sum_{t=0}^{T}\left(F(\omega,t) + G(\omega,t)\right)^2 \tag{4}$$

The program is written in C (Archimedes Software, Kirkland, WA) and compiled to a binary format. The program is loaded into the microcontroller's RAM through the serial port from an IBM-compatible PC. A small program, written in assembly, resides in the microcontroller's EEPROM for the purpose of performing the download operation. A subject operated switch attached to the circuit, signals the software program to suspend data collection when the subject is not in the wheelchair. The data collection proceeds from the spot where it was suspended upon reactivation of the switch by the subject.

Experimental Protocol

For the preliminary test, the subject's personal wheelchair was fitted with the SMART[ACCELEROMETER] system. The data logger was mounted on a

horizontal tube underneath the seat and the accelerometer was mounted to a frame tube near the rear wheel with the axes of measurement aligned with the wheelchair. Acceleration signal power was summed for one hour intervals over a four hour period while the subject performed normal office activities. After the test, the stored data was retrieved and the SMART^{ACCELEROMETER} removed. The data was then converted from a signal power scale to an amplitude scale (m/s^2) and compared to the ISO-2631 boundaries defined for 16 hours of exposure. Sixteen hours was chosen to represent a potential day of wheelchair use.

RESULTS AND DISCUSSION

The acceleration amplitudes for the transverse (side-to-side) and vertical directions did not exceed any of the ISO-2631 boundaries. The acceleration amplitude did exceed the *reduced comfort boundary* for the longitudinal direction (fore-aft). **Figure 2** is a graph of the results for the longitudinal acceleration over a frequency range of 1 to 19 Hz. The acceleration amplitude only exceeds the *reduced comfort boundary* between 1 Hz and 2 Hz. This result is probably due to self directed movement by the subject as he propelled the wheelchair. Self directed movement is not generally thought to cause a reduction of comfort or an onset of fatigue.

A device has been successfully constructed to both measure and analyze the vibration exposure of a wheelchair user. The data from the one subject indicates that if ride comfort is impacted by vibration, this probably does not occur when using a wheelchair indoors. Future tests will use this device to collect data for a 24 hour period from five subjects. Based on the preliminary results presented here, the protocol will be modified to record peak vibration exposure as well as the average exposure over one hour intervals. The ISO-2631 standard allows for greater exposure over short time intervals, but activities such as dropping off a curb, or traversing a gravel driveway may exceed these higher limits.

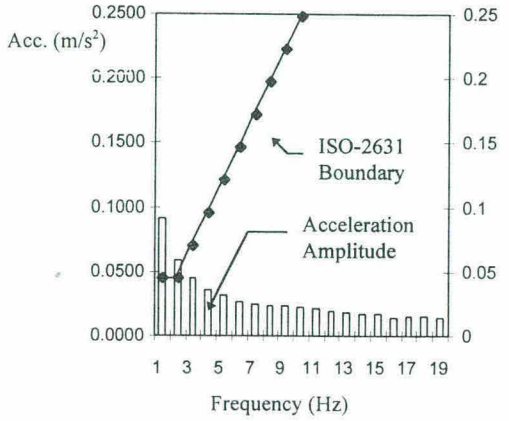

Figure 2 - Longitudinal accelerometer power distribution by frequency for the first hour of a four hour test. Line indicates the *reduced comfort boundary* as defined by ISO 2631.

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A METHOD TO DESCRIBE SHOULDER BIOMECHANICS DURING WHEELCHAIR PROPULSION: A LOCAL COORDINATE SYSTEM

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ABSTRACT
The shoulder is a very complex joint to analyze. Consequently, a limited amount of three-dimensional analyses exist. We have created a method to calculate shoulder angles during wheelchair propulsion in three-dimensions using a local coordinate system. A male subject with T-12 paraplegia was filmed using a three-dimensional kinematic system for five complete strokes. The right and left shoulder angles were compared for asymmetries during the propulsion phase. An unpaired t-test found significant differences in all maximum and minimum shoulder angles when compared between right and left sides with the exception of the maximum internal/external angle. The bilateral shoulder analysis will facilitate kinematic analyses of wheelchair propulsion, by further improving on techniques used to identify injury mechanisms.

BACKGROUND
Among manual wheelchair users, a high incidence of injury exists in the shoulder joint. Common injuries include rotator cuff tears and impingement problems [1,2]. Injuries to the shoulder can greatly hinder mobility, consequently, the mechanisms of these injuries should be thoroughly investigated.

The numerous degrees of freedom associated with the shoulder causes the analysis to be very complex. There have been few studies that have performed a shoulder analysis in three-dimensions. Often, these studies described the shoulder in a laboratory or global coordinate system [3,4]. The global system describes motion relative to an absolute space, but does not describe the shoulder movement relative to the body. In order to analyze the shoulder relative to the body, the shoulder must be placed into a local coordinate system, resulting in anatomic shoulder motions. The anatomic shoulder motions describe the motion of the humerus relative to the trunk.

The purpose of this study was to develop a new method to analyze wheelchair propulsion biomechanics in three-dimensions using a local coordinate system.

METHODS
A single male subject with T-12 paraplegia, volunteered for this study. Before the experimental trials, the subject was familiarized with the testing protocol, then gave informed consent. The subject propelled his own wheelchair, Quickie II, during the entire testing session. The wheelchair was fitted with a SMART^{Wheel} on both sides in order to determine when the subject was in propulsion or recovery. There were no adjustments made to the subject's wheelchair, with the exception of the fitting of the SMART^{Wheel}. The implementation of the SMART^{Wheel} on the subject's wheelchair did not change the camber or diameter of the subject's normal pushrim or tire size.

A bilateral motion analysis system, OPTOTRAK (Northern Digital Inc.), was utilized for this study. Two carbon fiber composite rigid bodies, composed of three markers each, were used to identify head and trunk motions. Each rigid body had three LED markers, creating an isosceles triangle (figure 1). Fourteen additional markers were used to identify anatomical landmarks. Markers were placed on the subject's right and left: acromion process (marker 3), lateral epicondyle (marker 2), olecranon process, ulnar (marker 1)and radial styloid, and second and fifth metacarpophalangeal joint (figure 1).

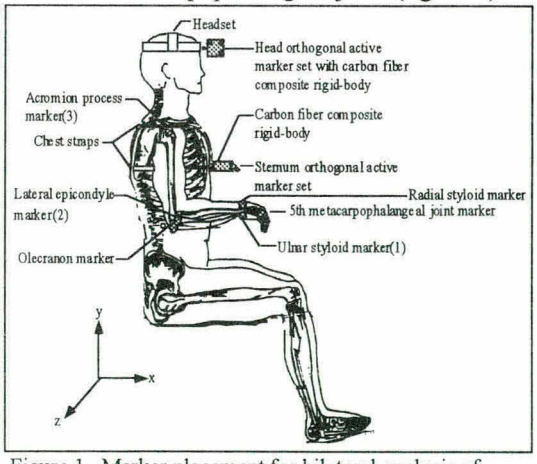

Figure 1. Marker placement for bilateral analysis of wheelchair propulsion.

In order to place the shoulder into a local coordinate system, a shoulder and trunk local coordinate systems must be defined. The shoulder coordinate system consist of three unit vectors; i_s, j_s, and k_s. The unit vector, j_s, lies along

the humerus of the subject. This is defined by:

$$j_s = \frac{v_{3-2}}{\|v_{3-2}\|}.$$

The unit vector, k_s, is defined as the vector perpendicular to the plane that is formed by the humerus and forearm. The unit vector, k_s, calculated by the cross-product of the unit vector, j_s, and a unit vector lying along the forearm segment. The final unit vector, i_s, is defined by the cross-product of j_s and k_s:

$$k_s = j_s \times \frac{v_{2-1}}{\|v_{2-1}\|}, \qquad i_s = j_s \times k_s.$$

The second local coordinate system defines the trunk segment. The markers creating a vertical vector on the trunk rigid body (markers 5 and 6), defines the first unit vector:

$$j_t = \frac{v_{6-5}}{\|v_{6-5}\|}.$$

The unit vector, k_t, is calculated by the cross-product of the unit vector j_t and the unit vector lying along the horizontal line on the trunk rigid body (marker 4 and 5). The last unit vector, i_t, is defined as the cross-product between j_t and k_t:

$$k_t = j_t \times \frac{v_{5-4}}{\|v_{5-4}\|}, \qquad i_t = j_t \times k_t.$$

Now since we have defined the two local coordinate systems:

$$R_{LS} = \begin{bmatrix} i_{s,x} & i_{s,y} & i_{s,z} \\ j_{s,x} & j_{s,y} & j_{s,z} \\ k_{s,x} & k_{s,y} & k_{s,z} \end{bmatrix}, \qquad R_{LT} = \begin{bmatrix} i_{t,x} & i_{t,y} & i_{t,z} \\ j_{t,x} & j_{t,y} & j_{t,z} \\ k_{t,x} & k_{t,y} & k_{t,z} \end{bmatrix}.$$

We can calculate shoulder anatomical flexion/extension, abduction/adduction, and horizontal flexion/extension angles by rotating the humerus, i_s, into the trunk coordinate system,

$$h_t = R_{LT} \times [i_s]^T = \begin{bmatrix} i_{t,x} & i_{t,y} & i_{t,z} \\ j_{t,x} & j_{t,y} & j_{t,z} \\ k_{t,x} & k_{t,y} & k_{t,z} \end{bmatrix} \begin{bmatrix} i_{s,x} \\ i_{s,y} \\ i_{s,z} \end{bmatrix}.$$

resulting in:

$$h_t = i_{s_LT} + j_{s_LT} + k_{s_LT}.$$

Shoulder flexion/extension is described by:

$$\theta = -a\tan 2(i_{s_LT}, j_{s_LT}).$$

while, shoulder abduction/adduction is defined as:

$$\phi = -a\tan 2(j_{s_LT}, k_{s_LT}).$$

The shoulder horizontal flexion/extension angle was also calculated. The angle is defined as:

$$\beta = a\tan 2(k_{s_LT}, -i_{s_LT}) + \pi.$$

The internal/external angle of the shoulder is described by rotating the humerus so that it is in alignment with the unit vector, k_t. This is done in two rotations.

First we must rotate the humerus parallel to the i_t and k_t plane by finding the angle: Θ

$$\Theta = -(a\tan 2(j_{s_LT}, i_{s_LT}) - \pi).$$

Using the rotation matrix, R_k,

$$R_k = \begin{bmatrix} c(\Theta) & -s(\Theta) & 0 \\ s(\Theta) & c(\Theta) & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

we then rotate the humerus by:

$$R_{i1} = [R_k][i_s]^T.$$

Then the angle, Φ, is calculated in order to rotate the humerus parallel to the j_t and k_t plane:

$$\Phi = -(a\tan 2(i_{s_LT}, k_{s_LT}) + \pi).$$

Using the rotation matrix, R_j,

$$R_j = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c(\Phi) & s(\Phi) \\ 0 & s(\Phi) & c(\Phi) \end{bmatrix},$$

we rotate the humerus once again by:

$$R_{i2} = [R_j][R_{i1}].$$

Finally, the rotated unit vector, k_s, is projected into the i_t and j_t components of the trunk coordinate system. This defines internal/external rotation:

$$\psi = -a\tan 2(jR_{i2}, iR_{i2}).$$

This technique transforms the three-dimensional motion that is involved with internal/external rotation into a two-dimensional motion. This method greatly simplifies the description of internal/external rotation.

RESULTS

Kinematic data for five strokes were analyzed for both upper extremities. An unpaired-t test was used to compare calculated angles for the right and left shoulder. The level of significance was set at 0.05.

Tables 1 and 2 provide mean maximum and minimum shoulder angles, respectively. The angles were calculated from the OPTOTRAK kinematic data using MatLab (MathWorks Inc.). Positive sagittal flexion/extension, abduction/adduction, internal/external rotation, and horizontal flexion/extension angles represent sagittal flexion, abduction, external rotation, and horizontal flexion, respectively, while negative angles represent sagittal extension, adduction, internal rotation, and horizontal extension, respectively.

Max. Angle (deg)	Flex/Ext Mean (± sd) *	Abd/Add Mean (± sd) *	Int/Ext Mean (± sd)	Hor. Flex/Ext Mean (± sd) *
Right	35.66 (1.34)	63.11 (1.07)	-33.90 (7.34)	12.78 (1.799)
Left	25.23 (1.40)	59.22 (1.28)	-26.84 (3.30)	-1.02 (2.19)

* denotes significant difference ($p<0.05$) between sides

Table 1. Mean maximum shoulder angles for subject's right and left side for 5 propulsion strokes.

Min. Angle (deg)	Flex/Ext Mean (± sd) *	Abd/Add Mean (± sd) *	Int/Ext Mean (± sd) *	Hor. Flex/Ext Mean (± sd) *
Right	-36.49 (0.73)	33.04 (0.86)	-90.89 (0.46)	-45.52 (0.79)
Left	-41.86 (1.81)	31.09 (0.79)	-73.67 (1.20)	-56.02 (1.72)

* denotes significant difference ($p<0.05$) between sides.

Table 2. Mean minimum shoulder angles for subject's right and left side for 5 propulsion strokes.

Significant differences ($p<0.05$) were found between the right and left shoulder flexion/extension, abduction/adduction, and horizontal flexion/extension angles when maximum angles were analyzed. All shoulder minimum angles showed significant differences when compared between the right and left shoulder.

Figure 2 illustrates the right and left arm angles during the propulsion phase for five strokes. From the graphs, it can be seen that the characteristics between shoulder angles during propulsion are similar.

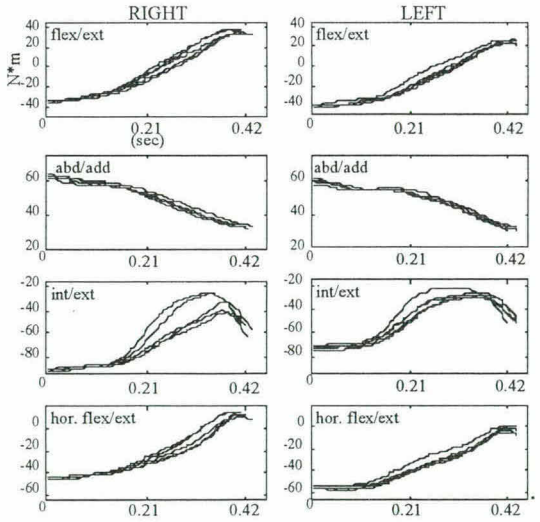

Figure 2. Shoulder angles for right and left arm during five propulsion phases.

DISCUSSION

The local system provides a more clinical representation of the shoulder motion because of its reference to the subject's trunk motion.

Our analysis showed significant differences between the shoulder angles from the right and left side. The asymmetry found between shoulder angles during wheelchair propulsion may contribute to potential injury. We hypothesize that the asymmetry between sides causes differential loading of the upper extremity joint structures, possibly causing injury. The asymmetry between sides also may be an indication that the individual has an existing injury and is modifying his/her stroke mechanics in order to detour or reduce the pain or discomfort while propelling the wheelchair.

Even though this study found asymmetries in the subject's shoulder angles, it can not be generalized across all wheelchair users. Currently, further studies are exploring this phenomenon in a larger group of subjects.

The new shoulder model using a local coordinate system will not only facilitate the analysis of upper extremity biomechanics during wheelchair propulsion, but will help to determine the mechanisms of injury among wheelchair users. The anatomical shoulder motions can further be used to provide information to the clinician regarding the range of motions which wheelchair users often experience during wheelchair propulsion. This ultimately aids the clinician with the proper information to modify seating positions and/or stroke mechanics to prevent further injury.

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AN IMPROVED METHOD FOR MEASURING POWER WHEELCHAIR VELOCITY AND ACCELERATION USING A TRAILING WHEEL DESIGN

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ABSTRACT

Power wheelchairs provide mobility for many people with disabilities. They must be designed for safety as well as meeting the needs of the user. It is important that parameters affecting safety such as velocity and acceleration can be accurately measured. A trailing wheel was designed to measure velocity and acceleration (according to ISO 7176-6) and compared with current methods of measurement. Significant reductions in experimental error were achieved using the trailing wheel, and additional useful data not supplied by current methods were collected.

BACKGROUND

Power wheelchairs must be designed for safety as well as performance. Kirby et al. (1) analyzed 651 injury records related to overall wheelchair use received by the FDA between 1975 and 1993. 77.4% of the records involved powered wheelchairs or scooters. Ummat and Kirby (2) evaluated 2,066 nonfatal accidents associated with wheelchairs. In 73.2% of incidents, tips or falls from the wheelchair were the cause of accidents.

High values of velocity and acceleration could lead to dynamic instability resulting in tips or falls. The ISO Standard 7176-6 (3) was developed to address methods of measuring wheelchair velocity, acceleration, retardation, and braking distances on varying slopes.

STATEMENT OF PROBLEM

Proper instrumentation is needed to accurately measure velocity and acceleration in accordance with ISO 7176-6. Current methods include the use of a stopwatch and speed trap to measure velocity, and accelerometers to measure acceleration. Variability of velocity data results from the test operator's inability to accurately determine wheelchair entry and departure from the speed trap. Acceleration data variability results from the high sensitivity of accelerometers to temperature and vibration. The trailing wheel was designed to reduce error associated with current methods of measurement, and disclose more accurate results to manufacturers and consumers.

DESIGN

Figure 1 shows the trailing wheel clamped to the backrest of a wheelchair. The design consists of a 0.65" diameter aluminum rod threaded at its ends to attach to a top caster fork and clamp, and to a second bottom caster fork and caster. The two forks were firmly tightened to prevent caster swivel. The clamp was made to allow contact to bars $\geq$ 0.75", accounting for the varying backrests of different wheelchairs.

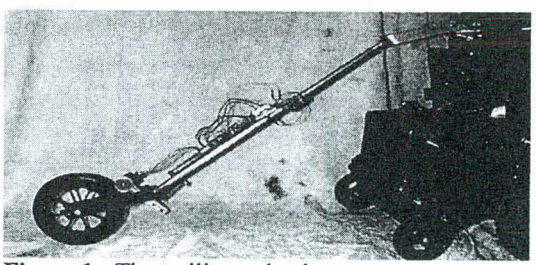

Figure 1 - The trailing wheel.

Figure 2 shows the lower portion of the trailing wheel. A small aluminum bar was mounted to the caster fork to which an optical encoder was connected at one end. A gear was placed on the optical encoder shaft and positioned to contact the center of the wheel.

At the other end of the bar, a spring was attached to ensure constant contact. The optical encoder sends a signal of position based upon shaft revolution. The signal is processed by a digital board mounted on the rod directly above the caster. A serial connector was mounted above the board which transmits the signal from the board to a computer where the data is saved. Battery clips were mounted to the rod for two 9 volt batteries used to power the board.

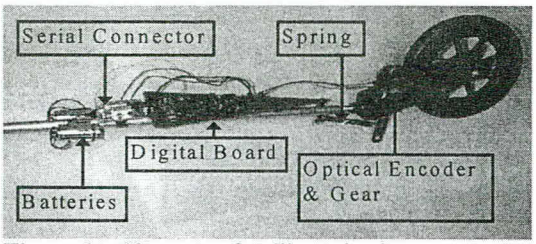

Figure 2 - Close-up of trailing wheel.

METHODOLOGY

Velocity and acceleration tests were conducted by the same operator and with the same wheelchair model. Wheelchair batteries were fully charged prior to testing. The trailing wheel weighed 2 kg (<1.3% of total weight) and was assumed to have negligible effects on velocity and acceleration.

In the first two experiments, velocity was measured using a stopwatch and a speed trap, and acceleration was measured using a uniaxial accelerometer. Velocity was measured by actuating the stop watch while traveling through the speed trap, and the caster was used as a visual reference for actuating the stop watch. The accelerometer was calibrated and acceleration was obtained by recording changes in voltage.

In the third experiment, velocity and acceleration were measured using the trailing wheel. The wheelchair was operated from rest to maximum speed for 5 seconds. Gear ratio was determined by measuring the gear (3.9 cm) and caster wheel (19.0 cm). The following equation converts optical encoder data, x (counts), to distance traveled, d (meters):

$$d = \frac{x \cdot 2\pi(radians/rev) \cdot 3.91(cm) \cdot 19.02/2(cm) \cdot 0.01(m/cm)}{500(counts/rev) \cdot 19.02(cm)}$$

Position data was collected at 240 Hz for a total of 1200 data points for each trial. Data were smoothed using a polynomial curve fit. Several curve fits were tested, and all converged varying less than 2% along the spline. The 10th order fit yielded highest convergence of data at the endpoints, providing the best approximation. The polynomial was differentiated once with respect to time for velocity and twice for acceleration.

RESULTS

Data collected using current methods of measurement are shown in Table 1. Table 2 illustrates the velocity and acceleration data for three trials using the trailing wheel.

Table 1- Data from 3 velocity trials with a speed trap and 3 acceleration trials with accelerometers.

Velocity (m/s)		Acceleration (m/s^2)	
Trial 1	2.41	Trial 4	1.74
Trial 2	2.77	Trial 5	1.80
Trial 3	2.50	Trial 6	1.91
Mean ± Std. Dev.	2.56 ± 0.19	Mean ± Std. Dev.	1.82 ± 0.09

Table 2- Data from 3 velocity and acceleration trials using the trailing wheel.

Velocity (m/s)		Acceleration (m/s^2)
Trial 1	2.62	1.52
Trial 2	2.62	1.55
Trial 3	2.61	1.55
Mean ± Std. Dev.	2.61 ± 0.006	1.54 ± 0.02

Velocity and acceleration for the three trials were obtained by differentiation and plotted. Figures 1-3 show plots of position, velocity, and acceleration for Trial 1.

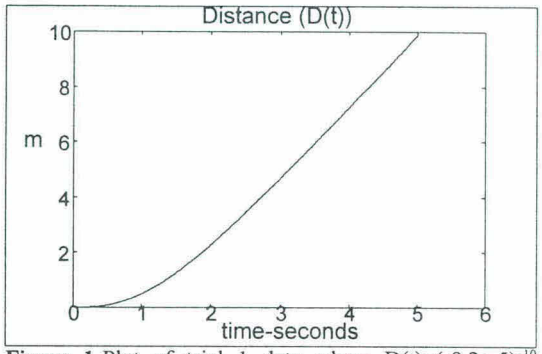

Figure 1-Plot of trial 1 data where $D(t)=(-9.2e-5)t^{10}+2.0e-4t^{9}-0.0017t^{8}+0.0083t^{7}-0.029t^{6}+0.11t^{5}-0.39t^{4}+0.74t^{3}+0.041t^{2}+0.0051t+5.4e-5$

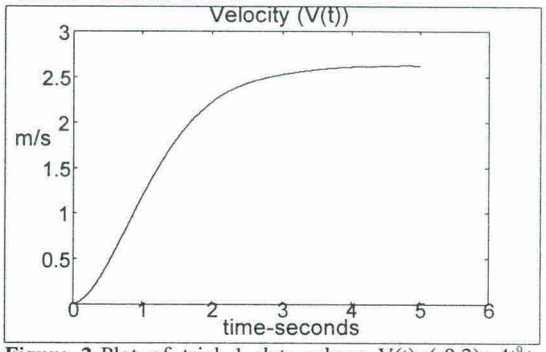

Figure 2-Plot of trial 1 data where $V(t)=(-9.2)e-4t^{9}+0.0018t^{8}-0.014t^{7}+0.058t^{6}-0.17t^{5}+0.54t^{4}-1.5t^{3}+2.2t^{2}+0.082t+0.0051$

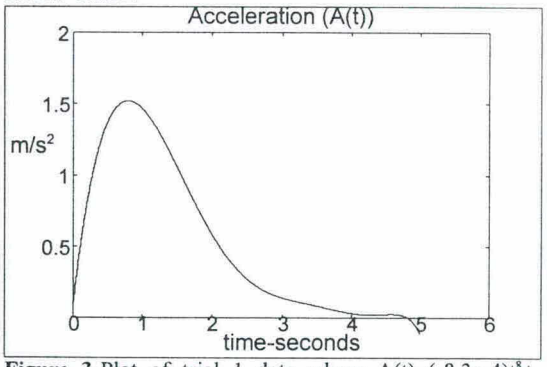

Figure 3-Plot of trial 1 data where $A(t)=(-8.3e-4)t^{8}+0.014t^{7}-0.098t^{6}+0.35t^{5}-0.86t^{4}+2.2t^{3}-4.6t^{2}+4.4t^{2}+0.082$

DISCUSSION/CONCLUSION

The trailing wheel has several advantages over current data collection methods. From Table 2, standard deviations are much less than those in Table 1. This indicates using the trailing wheel is more repeatable.

In addition to accuracy, the curve fitting method of the trailing wheel provides more information. The plots in Figures 2 and 3 show not only maximum values, but characterize the velocity and acceleration over the entire 5 second interval. In addition, the trailing wheel is capable of measuring braking distance, and velocity and acceleration on slopes.

Finally, the trailing wheel reduces experiment time. Half as many trials were needed to collect velocity and acceleration data. Experimental set up time was reduced and no modifications were needed between trials, unlike experiments in which accelerometers required time for zeroing between each trial.

The trailing wheel will be used in the future to provide more accurate data to manufacturers and consumers. Hopefully this increase in accuracy will instill more confidence and reliability in data regarding power wheelchairs and lead to safer designs.

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BIOMECHANICAL WRIST ANALYSIS DURING WHEELCHAIR PROPULSION: A LOCAL COORDINATE SYSTEM

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ABSTRACT

The incidence of carpal tunnel syndrome (CTS) among wheelchair users is high. This high incidence has been attributed to high force exertions, repetitious motions, and awkward postures. The purpose of this study was to evaluate a model used to describe wrist kinematics and kinetics during wheelchair propulsion.

An experienced wheelchair user, pushing a Quickie II wheelchair fitted with a SMART^{Wheel}, was digitized in real-time at two different speeds with a three-dimensional motion analysis system for 6 complete strokes.

Wrist motion, forces, and moments were described utilizing an anatomically based wrist coordinate system. Significant differences were found in all wrist force and moment measures when compared between the two speeds of propulsion. The measurement of the kinematic and kinetic components that occur at the wrist during wheelchair propulsion stroke can provide insight into the cause and prevention of wrist injuries in manual wheelchair users.

INTRODUCTION

Carpal tunnel syndrome (CTS) has been reported to be as high a 63% in manual wheelchair users [1]. It has been hypothesized that exposing the wrist joint to large repetitious forces and awkward postures may, in part, be a cause of injury [2]. When injury occurs to the wrist, the wheelchair user's independence is jeopardized. Hence, mechanisms contributing to CTS should be thoroughly investigated in manual wheelchair users.

The repetitious nature of wheelchair propulsion can not be avoided, although, the forces and wrist postures associated with propelling the wheelchair may be altered through wheelchair fit and stroke training.

The purpose of this study was to develop a method to describe wrist joint kinematics and kinetics during wheelchair propulsion using a local coordinate system. The local coordinate system provides angle, force, and moment measures relative to the wrist's anatomical position.

METHODS

A single male experienced wheelchair user with a T-4 spinal cord injury, volunteered and gave informed consent for the study. The subject pushed his own Quickie II wheelchair, fitted with a SMART^{Wheel} [3], while secured to a wheelchair dynamometer. No adjustments were made to the subject's wheelchair for the fitting of the SMART^{Wheel}. The SMART^{Wheel} was used to measure three-dimensional pushrim force and moment data about the wheel hub. The subject pushed the wheelchair at two speeds (2 and 4 mph) for three minutes per trial, after an acclimation period. A 60 Hz, three-dimensional camera system (OPTOTRAK, Northern Digital Inc.) was utilized to collect kinematic data, when the subject reached a steady state. A synchronization pulse generated by the OPTOTRAK system was utilized to ensure that the SMART^{Wheel} data collection were synchronous. LED markers, used for kinematic analysis, identified the following anatomical landmarks: acromion process, lateral epicondyle of the humerus, olecranon process, radial and ulnar styloid process, and the 2nd and the 5th metacarpophalangeal joint on each extremity.

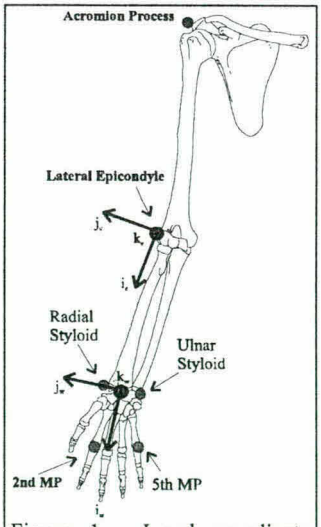

Figure 1. Local coordinate system for elbow and wrist using OPTOTRAK marker system

A local coordinate system was created in order to describe anatomic wrist motions. The three-dimensional local coordinate system consisted of the three axes, i_W, j_W, and k_W. The i_W axis originates from the midpoint between the radial and ulnar styloids, projecting towards the third metacarpophalangeal joint. The k_W axis originates between the styloids, projecting perpendicular to the plane formed by the hand. The last axis, j_W, is orthogonal to the i_W and k_W axes (see figure 1). The wrist local coordinate system moves with the hand.

A second local coordinate system was created at the elbow in order to measure supination and pronation angles (see figure 1). The first axis, i_e, ran along the length of the ulna. The second axis, j_e, is perpendicular to the plane formed by the ulna and humerus. The final axis, k_e, is orthogonal to the i_e and j_e axes. The origin of this system lies at the lateral epicondyle.

Flexion/extension angles, θ, are calculated by the projection of the ulna, i_e axis, into the i_W-k_W plane:

$$\theta = -\text{atan2}(i_{e_w}(z), i_{e_w}(x)).$$

Radial/ulnar deviation, ϕ, is calculated by projection of the ulna into the i_W-j_W plane:

$$\phi = \text{atan2}(i_{e_w}(x), i_{e_w}(y)) - \pi.$$

The supination/pronation angle, ψ, is calculated by the projection of the jw axis into the j_e-k_e plane of the elbow:

$$\psi = \pi - \text{atan2}(j_{w_e}(z), j_{w_e}(y)).$$

The triple, x,y,z, represent the projected vector coordinates, from the origin of the specified local coordinate system. The forces and moments measured from the SMART^{Wheel} (laboratory coordinate system) are transformed into anatomically referenced measures by rotating them into the wrist coordinate system.

The external forces in the i_W, j_W, and k_W, represent compressive/distractive, radial/ulnar directed shear, and palmar/dorsal directed shear forces, respectively. The external moments about the i_W, j_W, and k_W axes represent moments that tend to supinate/pronate, flex/extend, and radial/ulnar deviate the wrist about a point between the radial and ulnar styloids.

Joint angles and the anatomically based external forces and moments in three-dimensions were analyzed for 6 propulsion strokes at 2 and 4 mph.

To determine which parameters were reliable across repeated strokes and speeds, a two-step approach was used. First, the interstroke reliability was evaluated by intraclass R correlation coefficients. These factors were computed separately for each testing speed. A parameter was considered reliable and stable if intraclass R was > 0.60. Second, for parameters that met the preceding criteria, Cronbach's coefficient alpha was computed to determine the measurement precision or increased reliability of creating aggregated scores across the repeated strokes. The summed score was considered to have good reliability if coefficient alpha was > 0.80 at both speeds. A paired t-test was used to compare reliable wrist angles, forces, and moments measures between speeds. A p value of less than 0.05 was considered statistically significant.

Max Angle (deg)	Flex Mean (± sd)	Ext Mean (± sd)	Rad Dev Mean (± sd)	Uln Dev * + Mean (± sd)	Sup * + Mean (± sd)	Pro * + Mean (± sd)
2 mph	12.09 (0.61)	23.70 (1.42)	49.47 (1.42)	-15.98 (1.16)	-24.02 (5.46)	46.31 (1.63)
4 mph	12.67 (0.75)	21.09 (1.59)	49.27 (1.51)	-13.64 (0.81)	-17.86 (2.60)	41.97 (2.43)

* denotes significant difference between speeds ($p<0.05$)
\+ denotes reliable parameter

Table 1. Mean maximum wrist angles for 6 consecutive strokes. Negative ulnar deviation and supination represent positive radial deviation and pronation angles, respectively.

Max Force (N)	Comp * + Mean (± sd)	Distr * + Mean (± sd)	R-U * + Mean (± sd)	U-R * + Mean (± sd)	P-D * + Mean (± sd)	D-P * + Mean (± sd)
2 mph	70.45 (4.68)	2.12 (1.86)	60.06 (6.04)	3.65 (1.68)	14.49 (4.58)	4.79 (1.43)
4 mph	99.85 (7.99)	8.21 (0.73)	89.45 (10.42)	22.77 (5.02)	21.74 (4.13)	12.66 (5.91)

* denotes significant difference between speeds ($p<0.05$)
\+ denotes reliable parameter

Table 2. Mean maximum forces for 6 consecutive strokes. R-U and P-D represent radial to ulnar and palmar to dorsal directed forces, respectively. The opposite applies to the U-R and D-P measures, respectively.

RESULTS

The primary objective of this paper was to evaluate a new model for describing biomechanical wrist measures. A single subject was used in this study to initially evaluate the reliability of the current model. Tables 1-3 show mean angles, forces, and moments, respectively, for 6 strokes during the 2 and 4 mph speeds.

Significant differences ($p<0.05$) were found in ulnar deviation, supination, and pronation values when compared between speeds. All force and moment values showed significant differences ($p<0.05$) between speeds.

Max Moment (N•m)	Flex * + Mean (± sd)	Ext * + Mean (± sd)	Rad Dev * + Mean (± sd)	Uln Dev * + Mean (± sd)	Sup * + Mean (± sd)	Pro * + Mean (± sd)
2 mph	1.51 (0.34)	23.21 (1.53)	0.62 (0.67)	17.88 (0.98)	11.97 (2.46)	1.93 (0.87)
4 mph	3.30 (0.58)	35.09 (2.39)	4.97 (1.19)	26.33 (3.37)	19.94 (1.77)	9.36 (1.54)

* denotes significant difference between speeds ($p<0.05$)
\+ denotes reliable parameter

Table 3. Mean maximum moments about a point between the radial and ulnar styloids for 6 consecutive strokes. The anatomically referenced moments are the external moments that tend to move the wrist in the labeled direction.

DISCUSSION

The current wrist model has been used to successfully describe the kinematics and kinetics of the wrist. This data can be further used as a comparison to industrial based motions and forces that are known to contribute to CTS. The magnitudes of force and angular data are similar or higher than measures reported in industrial measures[2]. Consequently, the higher forces and more awkward postures is hypothesized to contribute to the higher incidence of CTS in manual wheelchair users.

The ultimate goal of our biomechanics research is to reduce the incidence of injury in manual wheelchair users. This is one of the first steps in creating a robust methodology which will enable us to characterize the motion, forces, and moments occurring at the wrist during wheelchair propulsion.

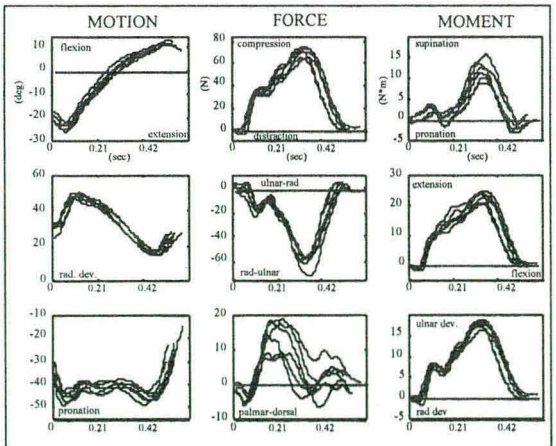

Figure 2 illustrates motion, force, and moment data for 6 propulsion strokes during the 2 mph trial.

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KINEMATIC ANALYSIS OF ANTHROPOMETRIC TEST DUMMY DURING POWER WHEELCHAIR BRAKING

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ABSTRACT

There are approximately 36,000 serious wheelchair-related injuries every year. The majority of which are due to the user falling out of the chair. The purpose of this paper was to determine the effects of using seatbelts and footrests on the occurrence of falls by investigating the kinematics of an anthropometric test dummy. This research concluded that there is a significant difference in head displacement measurements and trunk angle displacements under hard braking conditions, such as cutting power with the kill switch. The significance means the reduction of wheelchair accidents involving falls through user awareness and by equipping chairs with safety devices such as seatbelts and properly adjusted footrests.

BACKGROUND

Most power wheelchair users have paraplegia, quadriplegia, or cerebral palsy. Because of this, it is difficult to maintain the body in an upright seated position, especially when the upper body is subjected to braking forces. Data collected by Calder, et al. report that there are about 36,000 serious wheelchair accidents annually. Between 1973 and 1987, 770 wheelchair related deaths were reported to the United States Consumer Product Safety Commission (USCPSC), 68.5% of which were attributed to falls and tips. Of the 2,066 nonfatal accidents reported between 1986 and 1990 to the USCPSC, falls and tips were the cause 73.2% of the time [1 & 2]. It is important that these numbers are reduced and power wheelchairs are made safer. To do this, the exact cause of the falls must be known. Many safety devices such as seatbelts and footrests go unused. Many power wheelchairs are manufactured without seatbelts and it is also common for users to remove the footrests for a tighter turning radius. This study correlated the risks of injury due to falls with the use of said safety devices.

METHODS

For this study, a fiftieth percentile anthropometric crash test dummy (ATD) was used to simulate the occupant of a power wheelchair. The test dummy was outfitted with black clothing and reflective markers in nine anatomical positions (refer to figure 1): 1) back of the ear, 2) acromion process, 3) lateral epicondyle, 4) between the ulnar and radial styloids, 5) second metacarpophalangeal joint, 6) greater trochanter, 7) fibular head, 8) lateral malleolus and 9) second metatarsal (all on the left side). Hot glue was used to secure the markers to the dummy.

Each power wheelchair tested was outfitted with black cloth, tape and/or paper to cover the highly reflective areas (chrome and nuts/bolts). A reflective marker was placed on six areas of the left side of each wheelchair: 10) top corner of the backrest, 11) corner of the backrest and seat frame, 12) front end of the seat corner, 13) rear wheel hub, 14) rear wheel sidewall, and the 15) hub of the front caster. When the footrest was used, there was a reflective marker placed on the left side in the 16) center of the footrest edge. The left armrest was removed for filming in order to expose the anatomical markers on the test dummy. All wheelchair batteries were fully charged before testing.

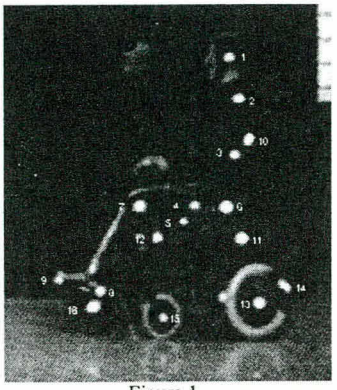

Figure 1

Black curtains were used as a back screen where the filming was conducted to insure a high contrast between the reflective markers and the environment. The filming was performed in two locations: the test laboratory hallway and a recreational room. The surface of the floor was the same in both areas. The two chairs tested in this study were the Everest & Jennings Tempest and the Quickie Designs P200. The P200 was tested in the recreation room because more space was needed to capture the longer braking distance on video. The camera was 18 and 25 feet from the line of action during the hallway and the recreation room testing, respectively. A halogen spot light was used to illuminate the testing areas. A Panasonic Digital 5100 camera and a Panasonic AG-7400 VCR were used to film the testing of the wheelchairs. Data were collected at 30 frames per second with a shutter speed of 1/500 second. The film was digitized using a Peak Performance analysis system at 60 images per second and conditioned with a low-pass butterworth filter with a 6 Hz cutoff frequency.

Test protocol included three braking conditions: kill switch activation, joystick release, and full reverse of the joystick. There were four wheelchair conditions tested: seatbelt and footrest, seatbelt and no footrest, no seatbelt with the footrest, and no seatbelt and no footrest. One tester, dressed in all black clothing, drove the wheelchair from the right side without obscuring the markers. A twenty foot run-up area before the filming area was used to achieve maximum speed of the wheelchair. There was a markered line on the floor where the tester initiated the braking condition when the front caster crossed that line. Trials were repeated until adequate data was collected for three trials. Adequate data was described as where the markers were visible for digitization through the entire range of motion of the wheelchair and the test dummy.

RESULTS

Head displacement and angular displacement of the trunk were used as the measure of the degree to which the dummy falls from the chair. Due to the length of this paper, only the most significant factors will be reported. The average speeds of the Tempest and P200 at the point of braking were 2.03 $\pm$ .067 m/s and 3.15 $\pm$ .114 m/s, respectively. Table 1 displays braking characteristics of the chairs.

Braking Times and Distances								
Braking Condition	Tempest				P200			
	time (s)		dis. (m)		time (s)		dis. (m)	
	avg	Sd	avg	Sd	avg	Sd	avg	Sd
Kill Switch	.88	.132	.91	.112	1.12	.082	1.86	.161
Joystick Release	1.61	.078	1.63	.117	1.66	.230	2.48	.170
Full Reverse	1.25	.085	1.35	.145	1.12	.098	1.92	.262

Table 1

Head displacement is defined as the change in distance between the ear and the top of the backrest. Table 2 shows the maximum head displacement during each trial.

Head Displacement (m)						
Braking and Wheelchair Conditions	Tempest			P200		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
joystick release: seatbelt & footrest	.31	.38	.59	.50	.51	.27
joystick release: no seatbelt & no footrest	.53	.44	.68	.64	.93	.58
kill switch: seatbelt & footrest	.41	.46	.32	.52	.30	.21
kill switch: no seatbelt & no footrest	.58	.63	.70	1.19*	1.11*	1.48*

* denotes trials in which ATD fell from wheelchair.

Table 2

ANOVA tests within each chair showed that the kill switch, no seatbelt & no footrest combination on the P200 was significantly different ($p<.05$) from the other conditions.

The trunk angle is the angle generated between the fibular head, greater trocanter, and acromion process. The largest difference in the trunk angle is displayed below in Table 3.

Trunk Angular Displacement (deg.)						
Braking and Wheelchair Conditions	Tempest			P200		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
joystick release: seatbelt & footrest	32.0	49.9	69.2	51.8	52.6	37.1
joystick release: no seatbelt & no footrest	61.2	50.7	90.2	53.0	52.5	56.7
kill switch: seatbelt & footrest	52.2	52.0	38.1	51.2	28.5	30.1
kill switch: no seatbelt & no footrest	69.4	79.0	87.4	75.8*	76.1*	87.5*

* denotes trials in which ATD fell from the wheelchair.

Table 3

ANOVA tests showed a significant difference ($P<.05$) between the kill switch, no seatbelt & no footrest conditions on the P200 and all other conditions. To help illustrate differences in trials, data are displayed visually in the form of a stick plot. Figure 2 is a stick plot showing trials from the P200 and Tempest in which the kill switch is used as the braking condition with no seatbelt and no footrests on either chair.

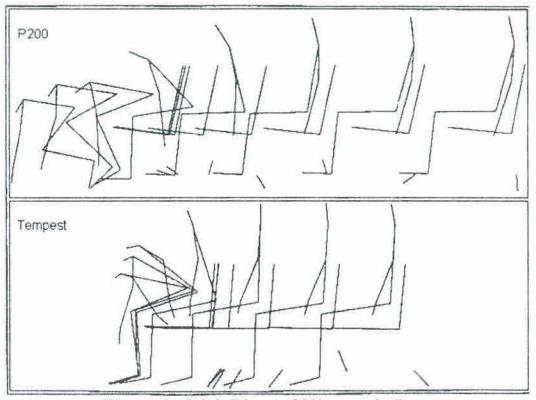

Figure 2 Stick Plots of Kinematic Data

DISCUSSION

The wheelchair condition had no significant effect on the dummy kinematics for the joystick release braking condition. This is due to the smaller average decelerations of that particular braking condition and possibly the stiffer limbs of the ATD. Both head displacement and angular trunk displacement were significantly different when the seatbelt and footrests were used versus when they were not during kill switch braking. It is during this kind of braking that the significance of using properly adjusted legrests and seatbelt is apparent. This study shows that the set-up of the wheelchair, and the braking condition influence driver safety. Since many people remove their wheelchair legrests to increase maneuverability within their homes, schools, or offices; it is important to fully understand the potential risk. Risk can be minimized by using a seatbelt, and placing the on/off so that it cannot be mistakenly activated.

Possible limitations are as follows: removal of the left arm rest for filming purposes, obstruction of fall by joystick, comparably less flexibility of ATD than its human counterpart, possible larger mass in lower extremities of dummy than in a quadriplegic. These limitations, in most cases, reduce the motion of the dummy.

This paper proves that falls can and do occur and successfully recreates this event in the testing environment. At the same time it demonstrates that these falls can be prevented by using simple restraining and positioning devices. The ultimate goal is to reduce the incidence of injury to power wheelchair users. This can be partly accomplished by operating the devices while using a footrests and a seatbelt.

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SIG-10
Electrical Stimulation

JOINT MOTION SENSORS FOR FES: The Gyro-goniometer

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ABSTRACT

The relative angles between two articulating body segments can be determined by integrating the difference between the outputs of rate gyroscopes positioned on the segments. Inclinations can also be obtained by attaching an accelerometer with dc response to one segment.

Using the Murata ENC05EA gyroscope in a motion simulating the movement of the knee during standing up (range 90 - 180 degrees) the Gyrogoniometer closely approximated the angle to better that 0.7° root mean square error when compared with a Penny & Giles Ltd. model M180 flexible goniometer.

INTRODUCTION

Joint angles are often required for closed loop control of FES systems. Usually these are laboratory studies where commercially available electrogoniometers such as the Penny and Giles flexible goniometer (Penny and Giles Ltd. 1996) are used. These devices require attachment across the joint and are difficult to maintain in position for joints such as the hip. In addition, they cannot readily be worn underneath clothing and are too fragile for everyday use with our hybrid FES orthosis comprising floor reaction type ankle foot orthoses and multichannal FES (Andrews et al. 1989). Closed-loop control of sit-stand-sit and transfer maneuvers have been demonstrated in the laboratory using Penny and Giles goniometers positioned over the knee and hip joints (Andrews 1990). In order to use this FES system outside the laboratory a robust, low cost and reliable sensor system is required to give joint angles, and perhaps limb inclination.

Micromachined silicon transducers such as accelerometers and miniature rate gyroscopes have recently been developed by a number of companies and a variety of low cost, robust surface micromachined silicon devices including multi-axial accelerometers and rate gyroscopes are anticipated in the near future.

A simple sensor system comprising one rate gyroscope per limb segment and a single dc accelerometer on one of the segments is described. The system is shown schematically in Figure 1.

The knee angle at any time t following reset is determined by integrating the difference between the two rate gyroscopes i.e.

$$\beta = \int_0^t (\omega_2 - \omega_3).dt$$

The inclination of the leg is given by

$$\theta = \theta_0 + \int_0^t \omega_3 \ .dt$$

Where: $\theta_0 = cos^{-1}(V_a / g)$ is the initial inclination of the leg, and V_a the sampled output of the accelerometer, at $t = 0$ and g the gravity constant. Similarly, the inclination of the thigh is given by $\psi = \theta + \beta$ and the pelvis by $\xi = \psi + \alpha$.

where $\alpha = \int (\omega_1 - \omega_2).dt$

Typically, FES sit -stand-sit transitions last 3-6 seconds, so the effects of drift must be negligible over this period. Usually the intention to stand-up or sit-down is signaled by the patient operating a push-button just prior to the maneuver. At this time the leg is usually stationary so the initial inclination can be calculated, and the integrators reset.

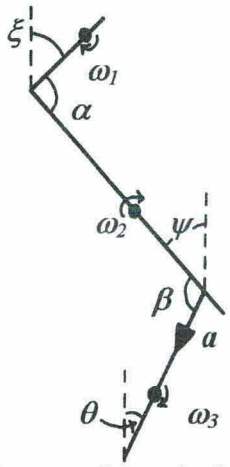

Figure 1. Schematic diagram of three articulating links representing the saggital view of the lower limb and pelvis during sit-stand-sit maneuvers.

METHODS

Devices The above scheme was implemented using the ADLX05JH accelerometer (Analog Devices 1996) and the Gyrostar model ENC05EA piezoelectric rate gyroscope (Murata 1996).

Calculating the relative joint angle Two gyroscopes were mounted on two uniaxially hinged plastic rods at a distance approximately 15 cm from the joint axis. A Penny and Giles M180 flexible goniometer was also positioned across the joint. The amplified signals from the two rate gyro's and the flexible goniometer were input to a 12 bit A/D converter and a computer program was used to calculate the integral of the difference between the rate gyro signals using Euler's formulae. The gyroscope signals were sampled at 200Hz. At the start of the motion a reset button was pressed and the integration commenced. The plastic rod was then rotated to approximate the knee joint motion. A typical data sample is shown in Figure 2. showing the joint angle estimated using the rate gyro's superimposed on that measured by the Penny and Giles device.

RESULTS

The difference was found to be less than 0.7 degrees rms.

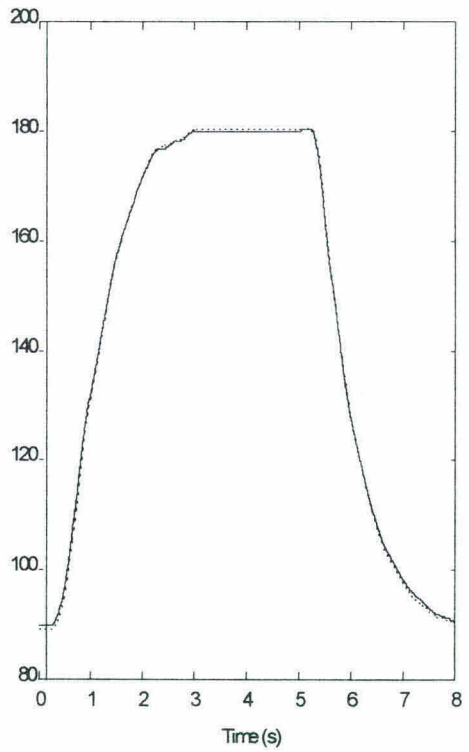

Figure 2. Comparison of relative joint angle computed from the gyroscope signals (solid) versus the Penny and Giles flexible goniometer output (dashed).

DISCUSSION

This method of measuring angles provides a low cost solution for FES control of the sit-stand-sit maneuver. The devices are small, lightweight and can be readily attached using adhesive tape or elastic straps. The method, in principle, may be extended to 3-D which will be facilitated by multiaxial versions of similar rate gyroscopes and accelerometers. The method may also be useful for low cost clinical movement analysis and virtual reality applications. To monitor motions over prolonged periods the effects of thermal drift must be considered e.g. for cyclical movements it may be possible to ocassionally reset the integration at fixed points in the cycle.

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AVAILABILITY OF FUNCTIONAL ELECTRICAL STIMULATION (FES) TREATMENT OPTIONS - IDENTIFICATION AND DISSEMINATION

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ABSTRACT

Functional Electrical Stimulation (FES) is a treatment option that can enhance the health and independence of individuals with spinal cord dysfunction. A survey was conducted of clinicians and researchers providing services to the spinal cord injury and multiple sclerosis (MS) communities. The survey assessed the specific FES treatment modality being provided, including indications and contraindications for the treatment. The survey responses were incorporated as a referral dataset into a publication called the FES Resource Guide for dissemination to persons with spinal cord injury, their family members, and service providers. The Guide included a tutorial on FES, a glossary, and pointers to additional resources.

BACKGROUND

Although individuals with spinal cord dysfunction may benefit from functional electrical stimulation interventions, there are few resources that can help identify and assess FES treatment options. The goal of this project was to support individuals with spinal cord dysfunction in reaching their maximum health potential through the use of an educational resource guide on functional electrical stimulation. Specific objectives for readers of the resource guide were to 1) increase the knowledge base on the use of FES, 2) increase access to FES providers, and 3) increase decision making ability regarding the appropriateness of FES interventions.

OBJECTIVE

This paper addresses the second project objective: increasing access of the target audience to FES providers. Specific objectives were to identify clinicians and researchers providing FES services to individuals with spinal cord dysfunction, to describe the services being provided in a standard format, to disseminate the information for use by individuals with spinal cord injury and MS, and to assess the utility of the dissemination method.

METHOD / APPROACH

Eighteen different applications of FES in spinal cord dysfunction were identified from a review of the literature (1,2,3). A survey was developed to solicit the following information from FES providers: facility description, type of electrical stimulation treatment offered (Table 1), status of the treatment (clinical service/ experimental research), typical course of treatment, candidate selection criteria, candidate restrictions/ contraindications, history of the application at the facility, typical cost, third party reimbursement, and equipment used.

The survey was mailed to approximately 3,600 clinics around the world. 105 surveys were returned with usable, self-reported data. The results were compiled in a specialized database and a report format was developed to profile each FES program entry for inclusion in the FES Resource Guide publication.

Table 1. FES Applications

1. Cardiovascular exercise
2. Breathing assistance
3. Cough assistance
4. Grasping and reaching
5. Bladder and bowel control
6. Transfers and standing
7. Stepping and walking
8. Erection and electroejaculation
9. Improving circulation
10. Preventing pressure sores
11. Treating pressure sores
12. Controlling spasticity
13. Preventing or treating contractures
14. Preventing or treating osteoporosis
15. Treating weak, atrophied muscles
16. Controlling tremor
17. Restoring sensation
18. Regaining voluntary function/ Improving movement control

Individuals with spinal cord dysfunction who were members of the National Spinal Cord Injury Association participated in an evaluation of the Guide by mail survey. The evaluation consisted of a baseline assessment of FES knowledge (n=120) and following distribution of the Guide, an assessment of the impact of the book on FES knowledge and access (n=25). Survey details are available but will not be described here.

RESULTS

Table 2 summarizes results obtained from the survey of FES providers. Regarding the evaluation of the FES Resource Guide by individuals with spinal cord dysfunction, 96% of respondents to the evaluation survey reported an increase in their knowledge of FES after using the Resource Guide that was significant at the .05 level (t=44.651). 74% of respondents demonstrated an increase in knowledge of where to go to get FES thereby increasing their access to FES providers. Finally, more individuals (24% increase) were able to determine if they were a candidate for FES after reviewing the Resource Guide, thereby increasing their decision making ability regarding the appropriateness of an FES intervention.

DISCUSSION

A significant outcome of this project is that this data sample provides a practical description, including availability and status, of the current state of the art of FES for individuals with spinal cord dysfunction. As such, this study raises important issues regarding the general acceptance and availability of FES modalities.

Although FES is generally considered to be experimental by most consumers and rehabilitation professionals, this data show that most FES offerings are not reported to be experimental. FES providers should investigate the effectiveness of their current techniques for disseminating information to the rehabilitation and disability communities.

Clinician training in FES modalities and a facility's acceptance of the techniques are important factors that influence availability. Although the technology investment is small and clinician training is minimal, "therapeutic" FES applications that can be used to treat secondary complications of spinal cord dysfunction and involve traditional neuromuscular stimulation techniques were offered at only 20% of the reporting facilities.

Finally, this data set has utility in analyzing the supply and demand characteristics of the FES service delivery market. For example, the data show a supply side emphasis on FES programs for lower limb movement. As one relevant measure on the demand side, this is the most requested topic by clients of the FES Information Center, a public educational resource on electrical stimulation. One could

conclude that there is a good match, in this case, between consumer demand and market supply.

Payment for FES is an important factor influencing availability that deserves additional study. The responses indicate a reluctance on the part of providers to report cost-related data.

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Table 2. Summary of FES Services

Location of FES Providers:	
56%	USA (22 states)
44%	outside USA (19 countries)
Types of FES Applications:	
27%	lower limb
19%	neuromuscular
13%	upper limb
9%	cardiovascular
9%	sexual functioning
7%	bladder control
5%	respiratory
5%	circulatory / skin
3%	bowel control
2%	sensory aid
1%	orthopaedic
Status of FES Applications:	
52%	clinical service
48%	experimental
Disability Requirements: *	
78%	SCI
22%	MS
66%	paraplegia
71%	tetraplegia
24%	hemiplegia
4%	other spinal disorder
Time after injury for FES participation:	
24%	6 mos. to 1 year
22%	after 1 year
16%	anytime
13%	3 mos. to 6 mos.
12%	injury onset to 1 mo.
10%	1 mo. to 3 mos.
3%	after 2 years
Cost of FES:	
21%	$1000 to $5000
16%	less than $1000
15%	more than $20000
12%	$5000 to $10000
11%	$10000 to $20000
25%	no answer

* More than one choice allowed

HOME USE OF AN IMPLANTED UPPER EXTREMITY FUNCTIONAL ELECTRICAL STIMULATION SYSTEM BY FIVE ADOLESCENTS WITH TETRAPLEGIA

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ABSTRACT

This investigation reports the results of a usage survey administered to five adolescents with C5 or C5/6 tetraplegia with an implanted functional electrical stimulation (FES) system for grasp and release in the home environment. A longitudinal prospective design was implemented over a 10 month period to gather data on frequency of use, exercise patterns and performance of activities of daily living (ADL). Results of the study indicated that FES was used in the home for both exercise and ADL performance. Because data indicated varying degrees of use across subjects in this small sample, further inquiry is warranted on reasons for use, obstacles to use and user satisfaction of the device for everyday activities.

BACKGROUND

FES for upper extremity function has demonstrated utility in the clinical setting (1, 2, 3). Application of FES systems has become easier to use and more precise for isolated muscle contraction due to technological advancement toward implantable systems for grasp and release.

The Freehand system is an eight channel implanted functional electrical stimulator examined for home use in this investigation. This system provides movement through coordinated stimulation of the flexor and extensor muscles of the hand. With voluntary movement of the contralateral shoulder, the user controls opening and closing of the hand in as graded manner. This movement is communicated through a battery-powered external control unit which monitors shoulder position and relays the appropriate response signals to the implanted stimulator by radio frequency control. This system provides lateral and palmer grasp and has been shown to be an effective method of providing grasp (2, 4, 5).

Clinical outcomes of the Freehand system with adolescents has indicated its efficacy for improved ability to grasp and release objects and increased independence in ADL (2, 6). However, little investigational work has focused towards home use of the device. The impact of this technology in real life situations is relevant to determine if the present state of implanted FES is perceived useful to persons able to benefit from it and to support justification of third party reimbursement through evidence of increased independence. This study proposes to examine and report home use of the Freehand system among five adolescents with tetraplegia.

METHOD

Sample

Following implantation, reconstructive surgeries, rehabilitation and evaluation to determine that the hand grasp system was effective for functional application (2), subjects returned home with the FES hand system for personal use during daily activity. These five adolescents with C5 or C5/6 level spinal cord injury voluntarily participated in this study. Each was between 17 and 20 years old at the onset of data collection. Written and informed consent was obtained from each

adolescent or legal guardian, prior to participation and included provision for subsequent home use investigation. All subjects clinically demonstrated functional abilities beyond typical performance associated with their level of spinal injury using the Freehand system (2, 5, 6, 7). Four subjects demonstrated independent splint free performance of eating with utensils, drinking from a mug, and writing with an ink pen (2). Several, in addition were able to insert and remove a floppy disc, shave with a standard razor and brush their teeth independently after set-up (2, 6). Subjects were free of shoulder or other pain and spasticity was managed in all cases as to not impair functional ability.

Procedure

A longitudinal prospective research design gathered information through telephone interview. A survey was administered weekly within the subjects home environment over a 10 month period. The survey was specifically designed to collect data on frequency of system use, determine what ADL were performed and to identify common factors which were barriers to use. The survey was composed of forced choice questions for system use and ADL performance and open-ended questions to identify factors affecting use. Administration was carried out by an occupational therapist trained in rehabilitation with the Freehand system. Each subject was implemented with the device sequentially and the home use survey was conducted following clinical participation of the fifth and final subject. Three of the subjects were discontinued from the study following medical intervention that altered their upper extremity functional abilities and prevented the full ten month participation.

Each weekly survey asked whether use and exercise were performed in the past week. A "yes" answer was indicated when the system was used at all, regardless of number of occurrences and a "no" answer was recorded when FES was not used in any way within that period. ADL responses identified if a particular activity had been performed in the past week and the method of performance. A large set of ADL activities were presented in the survey which typify those that can be performed by a person with mid-cervical tetraplegia to gain perspective on overall functional ability and level of independence in the home environment.

RESULTS

The survey collected two types of data. The first was frequency of use and exercise, the other was descriptive account of methods of ADL performance and reasons for non-use. Data was analyzed descriptively to identify trends in type of use within each subject.

Frequency of use data across the five subjects for ADL performance ranged from 0 to 53% of the weeks surveyed. For exercise, use ranged from 1% to 63% of weeks surveyed across subjects. The relationship between use and exercise was variable among subjects.

Four of the five adolescents indicated using Freehand to perform ADL. The most frequently cited activity was eating using utensils. This was indicated on 24 surveys of the total 126 surveys of the four subjects. Brushing teeth was next frequently cited on 22 surveys of the total number. Other ADL in which FES was used, but less frequently included: grooming, moving objects, shaving and writing. All FES activities performed at home had been included in rehabilitation training prior to discharge.

Reasons for non-use were organized into two main themes. Additional caregiver assistance was indicated as a limiting factor to independent use throughout the day. This generally occurred due to the dislodging of the controller or antenna following transfers. In addition, the perception of inadequate time or privacy limited prompt reattachment, although physical assistance may be

available. The other theme was dissatisfaction with the interface of the external components on the body. Tape used to attach the controller and antenna was perceived as ineffective or uncomfortable. Other reasons expressed, such as: allocation of caregiver time, no perceived use, and not choosing to don system on a specific day, may suggest underlying psychosocial factors that require further inquiry.

DISCUSSION

The five adolescents surveyed each used the system within the parameters of their individual lifestyle factors. Clinically demonstrated level of independence for all five adolescent participants was similar to their functional abilities, yet performance varied in the home environment according to survey results. Usage patterns may have also reflected personal motivation to use the system within a daily routine of activities. All subjects had parental or caregivers available to assist them with system set-up and maintenance as well as accessible living environments.

Descriptive data proposes that FES was used by adolescents when the physical and social environment was conducive to use. This occurred more often when caregiver support encouraged use over other methods, or in social situations when benefitting from the ability to use their hands independently.

Overall, lifestyle and psychosocial issues may be recognized as contributing factors towards use and non-use of the Freehand system. These factors are supported by frequency of use data and suggest that these adolescents may not have identified how independence afforded through using an FES hand system can fully impact their functional potential. Results of this investigation suggest that improvements are needed in the interface between the Freehand system and its user which has the potential to impact home use through promoting independence in a greater number of activities and better user acceptance among adolescents

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CIRCULATORY RESPONSES TO ELECRICAL STIMULATION OF LOWER LIMB MUSCLES OF HEALTHY SUBJECTS

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ABSTRACT

Twenty legs of ten healthy volunteers were tested in this study. The effects of voluntary and FES-induced static and continous lower extremity muscle contractions on the lower leg hemodynamics were evaluated using an Air Plethysmograph. FES-induced single muscle contraction of the lower extremity produced up to 47% Ejection Fraction and 40% Ejected Volume compared to voluntary contraction (VC). Residual Volume (RV) following repeated FES-induced contraction was higher than VC. Considering normal venous filling index in all the subjects, high RV during continuos FES-induced contraction could be an indication of an increase in arterial muscle blood flow. Based on this results, periodic static FES-induced contractions could be used as a preventive treatment to reduce venous stasis in the lower extremity and continuos FES-induced contraction may be used to increase arterial blood flow to the lower extremity

BACKGROUND

Recently more attention is being focused on the use of Functional Electrical Stimulation (FES) - induced contraction in the lower extremity blood flow. The use of FES is specially important when active muscle contraction is not possible due to loss of muscle function (i.e., paralysis). Electrical stimulation (ES) has been shown to increase the blood flow to the muscles receiving artificial stimulation (1,2). Muscle contractions produced by electrical current increases the metabolism of the muscle being stimulated, resulting in increased blood flow to the muscle. Maximum blood flow to a canine muscle resulted from continuous active ES (3). These studies show that different magnetite and frequency of FES - induced contractions could be used to either increase the blood flow in the region or decrease the blood volume in the limb. Impaired function of the calf muscle pump is responsible for venous hypertension, leading to excessive accumulation of fluid and fibrinogen in the subcutaneous tissue, and results in swelling lipodermatosclerosis, and finally ulceration. This is especially important in patients who lose their muscle function either due to paralysis or disuse. Static and periodic FES-induced muscle contractions could be used to activate the physiologic muscle pump and move the venous blood from the lower extremity and reduce stasis (4). This combined and continuing controversy about the mechanism of the effect of FES-induced lower extremity muscle contractions has created a need for a non-invasive quantitative assessment of calf muscle pump function and limb hemodynamics during these exercises/contractions. The aim of this study was to evaluate and compare the effects of static and continuos FES-induced and voluntary calf muscle contractions on the lower limb hemodynamics.

Material and Methods:

Subjects:

Ten subjects (four male, six female) participated in this study. The mean $\pm$ SE for age were 26 ± 2 years, height 171.08 ± 3 cm, and weight 69.41 ± 3.88 kg. All the subjects reported to be in good health and free of any detectable arterial or venous diseases . After signing an approved informed consent form , the subjects wore loose fitting gym shorts and lay in a supine position on a semi soft exam table.

Equipment

Air Plethysmograph: The APG-1000 (air plethysmograph) is a calibrated pneumatic

volume plethysmograph. Specifics of this system have been published elsewhere (6,7).

Neuromuscular Stimulator: The Respond Select Neuromuscular Stimulator, Empi Inc.) was used for FES-induced contractions. The stimulator has adjustments for stimulation intensity and stimulation timing. Carbonized rubber skin surface electrodes (Medtronic Inc.) were placed over motor points of the calf (gastrocnemius-soleus, and tibialis anterior). Two electrodes were placed over each muscle and the ES intensity was set to produce maximum plantar flexion without discomfort.

Procedure

Venous Volume (VV), Ejection Fraction (EF), and Ejected Volume (EV) following a voluntary and FES-induced single tip-toe contraction were measured. Venous Filling Index (VFI) and Residual Volume (RV) following ten voluntary and FES-induced tip-toe contractions were measured. On two different days subjects were randomly evaluated for either VC or FES contractions. VFI indicates the degree of valvular insufficiency. Rapid volume change of the rested extremity placed in a pendent position indicates reflux. In subjects with normal VFI it will take longer to fill the veins. An increase in RV in the presence of normal VFI could be an indication of increases in blood volume other than venous reflux.

The EF is a measure of calf muscle pump function. It is reported as a percentage (%) of functional calf volume. Effective muscle contraction of normal extremities results in ejection of a high percentage (50-60%) of their VV with each tip-toe maneuver.

Results:

Data were statistically analyzed using SAS programming system (5). Descriptive statistics and the treatment means were compared . Student *t*-test were performed. Significance were set at $p < 0.05$.

The measurements of EV, EF, RV and VFI are shown in figures 1-3. The results show that both voluntary and FES-induced contractions caused significant increases in EV and EF. When comparing the EF and EV between voluntary and FES, FES-induced single contractions produce up to 47% and 40% of values for EF and EV achieved by VC. The RV following ten tip-toe was significantly higher for FES than voluntary exercise. VFI was within normal limits for both groups (0.85 and 0.77 for voluntary and FES respectively).

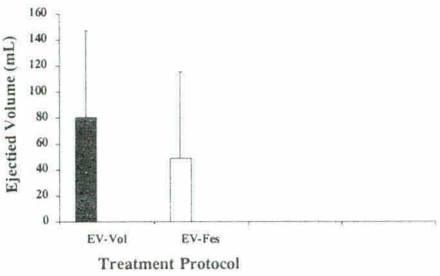

Fig.1. Ejected volume following FES-induced and voluntary static tip-toe contraction.

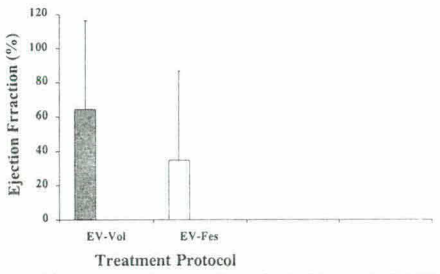

Fig.2. Ejection fraction following FES-induced and voluntary static tip-toe contraction.

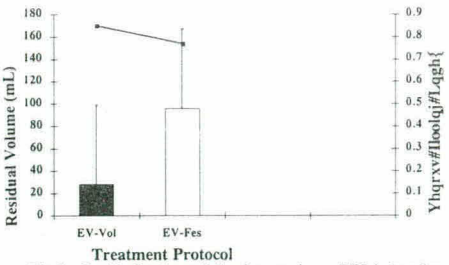

Fig.3. Residual volume following continous FES-induced and voluntary tip-toe contraction in relation to venous filling index.

Discussion

Single FES-induced contraction in our study produced an EF of up to 47% of VC. This

caused a significantly large volume of venous blood to be removed from the calf area by FES-induced contraction. Therefore FES could be used to activate the physiologic muscle pump. This issue is specially important for patients who have lost their muscle pump function (during anesthesia, or in paralysis). Although FES-induced contraction did not produce the same amount of EF and EV as VC, studies have shown that EF and EV of up to 50%-60% could significantly reduce the blood flow stasis and skin ulceration in patients with venous insufficiency (6).

Repeated FES-induced contraction produced a significantly higher RV when compared with VC. RV is the amount of blood in the lower leg after ten repeated contraction. In patients who have venous insufficiency or abnormal VFI the increase in the RV is an indication of venous insufficiency. However, in subjects with normal VFI (our subjects), the increase in RV could be an indication of increase in the lower limb blood volume, but not specifically of venous blood. Continuos and repeated FES contraction may cause an increase in arterial circulation to the exercising muscles (3,8). Gastrocnemios muscle is composed of fast glycolytic fibers and its metabolism is primarily anaerobic. Multiple contraction in our FES group may cause a large oxygen debt in this muscle, resulting in post FES hyperemia which was indicated by high RV.

Conclusion

FES-induced contraction could be used to facilitate both venous and arterial circulation. The timing and frequency of stimulation could be adjusted based on the symptom and the type of patients. More studies are necessary to evaluate the long term effects of FES in the limb blood flow.

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A CLINICAL PERSPECTIVE OF A HYBRID ORTHOTIC SYSTEM

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ABSTRACT

The case study of a T7 paraplegic subject with a right girdlestone arthroplasty who received a hybrid orthotic system is reported. The subject was implanted with 16 percutaneous electrodes and fitted with a reciprocal gait orthosis. After several months of training, the subject became proficient enough to use the system independently in his home. Functional outcome measures were utilized to determine his level of independence and if use of the system in the community was safe and efficacious. The subject was able to perform sit-to-stand, walking and stand-to-sit functions in a stable and repeatable manner and meet established criteria for limited community use. The HOS showed considerable potential to provide safe, independent, functional walking while allowing the performance of standing and light upright work activities for this subject.

BACKGROUND

Researchers have attempted to develop functional electrical stimulation (FES) systems for restoring lower extremity function in persons with paraplegia for many years. FES can provide propulsive forces for standing, walking, and upright mobility by exciting and contracting otherwise paralyzed muscles. Chronic stimulation can lead to rapid fatigue and stabilizing complex joints such as the hip require many active muscles.

Reciprocal gait orthoses (RGO) are generally used by children with spina bifida and similar disabilities along with individuals of all ages having lower level spinal cord injuries (SCI). The device stabilizes both the trunk and lower extremities and through mechanical linkages permits reciprocal gait. Individuals with obesity, high level SCI or skeletal deformities are typically excluded from this treatment.

Hybrid orthotic systems (HOS) combine the stability and antigravity support of an orthotic such as an RGO with the ease of mobility provided by FES.

This case study describes assessment of a HOS in a subject with significant orthopedic abnormalities. Functional outcome measures were applied and timed walking trials were performed to determine the systems effectiveness. This case report provides clinicians with a realistic look at a current HOS and offers insight into its possible functional use for other patients with spinal cord injury.

METHODS

The subject was a 34 year old male who sustained a T7 complete SCI in a sledding accident at the age of 15. In 1987, he fractured both hips in separate traumatic events requiring open reduction and internal fixation. Although the left hip healed normally, complications arose in treatment of the right hip resulting in a girdlestone excisional arthroplasty and a 13cm. leg length shortening. Prior to acceptance in the project, the subject underwent 13 months of physical therapy for conventional brace walking using an Isocentric RGO@, and was able to walk up to 10 meters with close supervision using a standard walker.

PROCEDURES

After informed consent, percutaneous intramuscular electrodes were implanted in outpatient surgical procedures.[1] Muscles

implanted included: quadriceps, gluteus maximus, gluteus medius, tensor fasciae lata, the posterior portion of the adductor magnus, iliopsoas, sartorius and gracilis. In addition, bilateral surface erector spinae and the left hamstring were stimulated during walking.

An Isocentric RGO@ was used for the conventional brace training prior to entry into the project and continued to be used once admitted with modifications. The hips were refabricated to allow abduction for ease with donning/doffing and transfers and the left knee bale lock removed to allow knee flexion during walking and sit to stand.

The stimulation patterns were developed by utilizing an initial, generic pattern, observing the subject standing and walking, identifying deviations and adjusting accordingly. Typical adjustments consisted of fine-tuning the timing, intensity and coordination of muscle activity to optimize the desired movements.

Tri weekly training sessions began with standing and walking in the parallel bars. The subject progressed to a two wheeled walker and eventually to forearm crutches. Due to the right hip instability and insufficient quadriceps strength, the right knee remained locked.

The subjects level of independence was graded using the Functional Independence Measure (FIM) and the Borg Scale used to measure perceived exertion.[2,3] Distance and velocity were collected to determine the limits of home and community use of the system.

Data for the FIM and Borg Scale were collected in the Motion Study Laboratory during five separate test sessions. The subject was videotaped performing sit-to-stand from his wheelchair, ambulating 6 meters, returning to his chair and completing with a stand-to-sit maneuver. All trials were performed in the same brace with FES and without FES. The subject was asked to rate his exertion using the Borg Scale for each maneuver. Results were calculated using the Student T-test comparing walking with the brace alone and with the brace and FES.

Distance and velocity data were collected on separate days. On a given day the subject was asked to walk 30, 50, 100 or 300 meters and repeat the walk after a five minute rest as many times as possible. The speed for each leg and the total distance were recorded. A minimum of three sessions were completed at each of the four distances.

RESULTS

The subject had a FIM score of 6 (independent) with sit to stand and ambulation using a two wheeled walker and occasional contact assist (ave. score of 4.4) with crutches for the same activities. These results were consistent whether FES was used or not.

Results of the Borg Scale indicated the subject found sit to stand with FES or without to be in the "very light" exertion range. Walking was perceived to be significantly easier ($p=.05$) or "fairly light" with FES verses "somewhat hard" without FES.

Distance and velocity data show the subject was able to walk an average of 430m at 0.43m/s for 30m trials, 416m at 0.36m/s for 50m, 300m at 0.36m/s for 100m and 450m at 0.29m/s for the 300 meter trials.

DISCUSSION

Although not conclusive, the results of this study highlight what a HOS can offer a person with paraplegia and a significant skeletal deformity. Functionally, the subject became independent in his home with a two wheeled walker for exercise. Even though training did not include performance of light work tasks, the subject reported he used his HOS to change light bulbs and to scrape and paint window frames. These findings are significant considering the fact that he would not have been a candidate for RGO training without participation in this study.

The subject perceived walking with the HOS to be easier ($p=.05$) than walking with the

RGO alone. This result mirrors other studies which demonstrate that the addition of FES to bracing decreases upper extremity exertion and conserves energy expenditure.[4,6] This perception will play an important role in determining if the device will be abandoned.

A study performed in Los Angeles County attempting to establish community walking criteria found distances to access frequently used sites, i.e., stores, banks, offices etc. to be 330m with walking speeds of 1.3m/s required for such activities as crossing a street with the light.[5] Our subject's ability to walk 420 meters or more with occasional rest periods clearly indicated that some community walking can be achieved with HOSs. More frequent short walks with greater rest periods like those found in an office environment also fall well within the capabilities of the HOS. His maximum walk distance, without a rest, of 300m necessitates wheelchair use for some functions but preliminary results with the HOS are encouraging.

The subjects orthopedic anomalies did not prove to be a major hindrance when performing tasks. Locking of the right knee in extension because of his injury necessitated he vault and circumduct in order to swing the limb forward. This type of gait demands increased upper extremity use which consumes more energy.[6] Also, the gait is not as esthetically pleasing as walking with knee flexion during swing phase.

Though these findings are encouraging, drawbacks of the RGO still exist. The subject reports inability to function in his wheelchair with the brace on, i.e., retrieve objects from the floor, perform toileting or balance sufficiently to carry out many of the activities of daily living. Additionally, donning and doffing time, cosmesis and stimulator and electrode failure need addressing before HOSs see daily use.

CONCLUSION

This case study illustrates the potential usefulness of the system for walking and standing in the home or work environment. A brace which would allow the user comfortable, all day wearing time would make the HOS an appealing and highly functional adjunct to wheelchair use for persons with paraplegia. Continued efforts should be focused on creation of a functional, safe ambulation system with a final goal of an easy to use, energy efficient system providing mobility for ambulation and stability for standing tasks.

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GAIT PHASE ESTIMATION DURING PARAPLEGIC FES WALKING

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ABSTRACT

An important component of a proposed control system to improve walking with functional electrical stimulation (FES) is to determine the phase of gait in real time from sensor signals. The sensors chosen should be suited for each individual patient, in terms of cosmesis, cost and reliability. The number of sensors should be minimized to reduce the system's complexity. Several groups of sensors were tested for their effectiveness in estimating the phase of gait.

BACKGROUND

Functional electrical stimulation (FES) has been shown to be able to produce standing and limited mobility in complete paraplegic patients. One limitation of existing lower extremity FES systems is their inability to compensate for changes. When the command to walk is issued, the stimulator sends a pre-stored stimulation pattern to the muscles.

A feedback control system is under development to enhance the performance of the FES walking by changing the stimulation depending upon the quality of the walking. Sensors that provide information about the gait are processed to assess the quality of the gait over the past steps. If anomalies in the gait are detected or measurements are not within specified limits, the muscle stimulation for the next gait cycle is modified.

This type of cycle to cycle control requires that the sensor measures be examined within the context of the gait cycle. Certain measures (e.g. forces, angles, accelerations, etc.) can only be examined relative to *when* during the gait cycle they occurred. Along with measures pertaining to the quality of gait, the beginning of each gait cycle and timing of certain phases must be extracted from the sensor signals.

Flexibility in sensor choice is desirable. The specific sensors may vary among patients depending upon their characteristics. The number of sensors used should be minimized, since processing fewer sensors reduces the computational burden for real time operation. Sensors choices should take into account cosmesis, ease of donning, and calibration requirements.

Several groups of sensors were evaluated for their effectiveness in estimating the phase of gait for paraplegics walking with FES.

METHODS

Sensor and video data were collected from two patients walking with FES. Their gaits were qualitatively different: patient DN wore a reciprocating brace with one knee locked, the other free to flex and used crutches; patient DC wore ankle-foot orthoses which allowed free plantar-dorsi flexion and used a rolling walker. Both patients controlled the FES manually, hitting a button to proceed with each step.

The phase of gait for each leg was estimated separately. The gait phases were *weight acceptance, midstance, terminal stance, early swing* and *late swing*. The events that defined the transitions between phases were *heel strike, foot flat, heel off, toe off* and *knee at maximum flexion* (2). The video frame at which each of these events occurred was determined. This provided the basis for training the gait

phase estimation rule bases and for assessing performance.

In order to estimate the gait phase, a fuzzy logic rule base was extracted using the fuzzy system identification methods described in (1), using a knowledge of gait event times (i.e. video frames) and the corresponding sensor signals. A different set of rules was obtained for each walking trial that involved the same leg and sensor subgroup. Then, each rule set was applied to the data for all the trials. The performance of a sensor subgroup (i.e. their accuracy in recognizing gait phases) was examined. To quantify performance, the median percent error over all trials that used different trials for training and estimation was used. The percent error was computed from the samples when the estimated phase did not agree with the phase determined from video.

The number of sensors in groups was reduced through an iterative process of removing a sensor from the group, and comparing the performance of the larger and smaller groups.

The performance of different groups of sensors to estimate the gait phase was assessed by comparing their median percent error. The percent error is the percent of samples in each trial when the estimated phase did not agree with the phase seen on video.

RESULTS

Patient DN was tested with triaxial accelerometers [Analog Devices, Inc.] mounted on the shanks of his brace and with insole mounted force sensitive resistors (FSRs) [Cleveland Medical Devices, Inc.]. The stimulator status was also recorded.

The first group of sensors examined consisted of two FSR signals, their derivatives and the stimulator status. A typical trial of the estimated and actual phases for the left leg is shown in **Figure 1**. The errors that are not early or late transitions between phases are usually brief fluctuations.

Additional processing to determine the phase transition times was used as a means of filtering out fluctuations and examining the estimated gait events. The difference between the estimated transition times and the event times on video was computed and plotted against an average gait cycle in **Figure 2**. The median estimated transition times(dashed line) are drawn relative to the average gait cycle. The shaded area is the extent of the middle two quartiles. The narrow band at the transition from late swing to weight acceptance demonstrates a good estimation of heel strike.

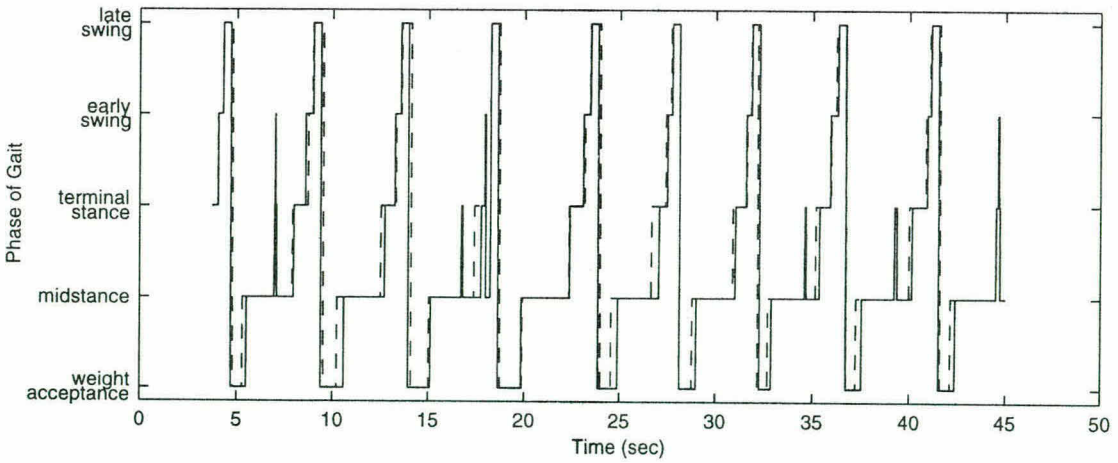

Figure 1 - Estimated (solid line) **and Actual** (dashed line) **Phase of Gait**

The wider band at the transition from midstance to terminal stance shows an increase in the variability of detecting heel off, and that it is usually detected slightly late.

The other group of sensors tested with DN consisted of three accelerometer signals (from a single triaxial accelerometer), their derivatives and the stimulator status. For the left leg, the percent error was larger using accelerometers than FSRs even though the plots of the transition time differences were not appreciably different. For the right leg, there was no statistically significant difference using accelerometers or FSRs.

Patient DC was tested with joint angle sensors at the hip, knee [Penny & Giles, Inc.] and ankle [resistive potentiometer] and with insole FSRs [Interlink Electronics]. The gait phase could be estimated using either the knee and ankle angles along with their derivatives or using two FSRs with their derivatives to similar degrees of accuracy. The addition of the hip angle and its derivative to the other joint angles did not decrease the percent error.

DISCUSSION

Several independent groups of sensors can effectively estimate the phase of gait during paraplegic FES walking. The two paraplegic patients examined wore different amounts of bracing and walked with qualitatively different gaits. However, the insole mounted force sensitive resistors, combined with stimulator information, could adequately estimate the phase of gait for both patients. Joint angles for one patient and accelerometers for the other were found to estimate the gait phase with accuracy equivalent to the insole FSRs.

Within each of the sensor groups, all of the original set was not needed. Each FSR insole has four sensors. Only two of these sensors were required, one at the heel and one under the forefoot. Two triaxial accelerometers on the lower leg of DN were originally tested, one near the knee the other by the ankle. Only

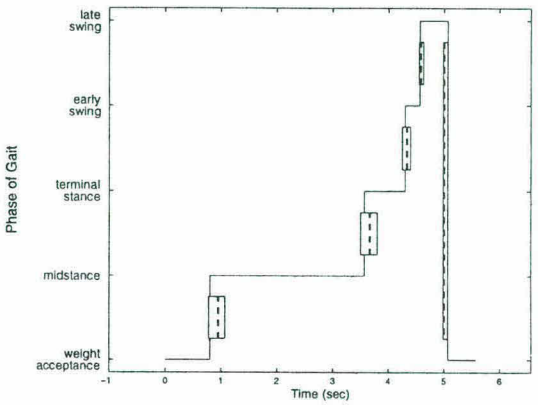

Figure 2 - Estimated Gait Events Relative to the Average Gait Cycle

the signals from the lower one were required to determine the transitions between the phases with accuracy similar to the FSRs. The most difficult joint angle sensor for DC to don was the hip sensor, but the knee and ankle angles could estimate the phase of gait just as well without this sensor.

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INTEGRATED HAND/WRIST CONTROL IN A NEUROPROSTHESIS FOR INDIVIDUALS WITH TETRAPLEGIA

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ABSTRACT

A feedforward controller was designed to reduce the interaction between hand grasp and wrist movement in a hand grasp neuroprosthesis. Simulations with a biomechanical model of the hand and arm revealed that the feedforward controller could maintain a constant wrist flexion/extension angle during changes in grasp position and force, as well as mimic tenodesis grasp (i.e. grasp closure with wrist extension) with minimal error.

BACKGROUND

Functional neuromuscular stimulation can restore hand function to individuals with a spinal cord injury at the C5/C6 levels [1]. Similarly, wrist extension can be provided through a combination of tendon transfer and electrical stimulation [2]. However, due to the crossing of the extrinsic hand muscles about the wrist, stimulation of the extrinsic hand muscles will change wrist position. Similarly, changing wrist position will change the length of the hand extrinsic muscles, affecting grasp position and grasp force. The interaction between hand grasp and wrist movement limits wrist extension, and results in neuroprosthesis users wearing a wrist splint in order to provide wrist stability.

RESEARCH QUESTION

Since the extrinsic hand grasp muscles are controlled by the hand grasp neuroprosthesis, the effect their activation has on wrist position is somewhat predictable. Thus, a feedforward controller might be able to model the interaction between hand grasp and wrist position. In this instance, the activation levels of the hand and wrist muscles can be set in a neuroprosthesis by the feedforward controller so that changes in grasp force or position will not have a significant effect on wrist position and visa versa. This will reduce the interaction between hand grasp and wrist movement.

METHODS

Design of Feedforward Controller

The feedforward controller is divided into two stages: a coordination network and an interaction network (Fig 1). The function of the

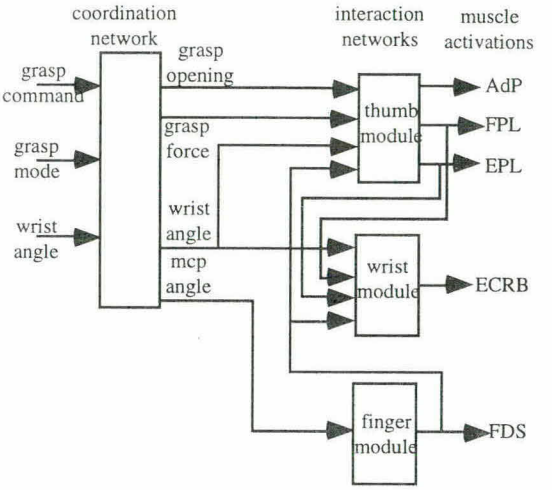

Fig.1 Design of Feedforward Controller.

the coordination network is to set the grasp and wrist posture based on subject input. The inputs from the subject are grasp mode (palmar or lateral grasp), grasp command, and wrist position. The relationship between grasp command and grasp force and position were implemented analytically by defining a grasp template based on those designed for neuroprosthesis users. Wrist position was defined as being either constant as grasp command increased, or change in parallel with hand grasp to mimic tenodesis grasp.

The function of the interaction networks is to select the activation levels of the hand extrinsic muscles and a wrist extensor to produce the desired combination of grasp and wrist angle; thus taking their interactions into account. The interaction networks were divided into three modules, where each individual module is responsible for controlling the wrist, thumb, and index finger. The inputs to each module are the primary element that module is controlling, and the secondary elements that will

have an effect on the primary element. For example, the primary input to the wrist module is wrist angle. However, the wrist module also has activation levels of the flexor digitorum superficialis (FDS), flexor pollis longus (FPL), and extensor pollis longus (EPL) as secondary inputs, since the activation of the hand extrinsic muscles will affect wrist angle. The output of the modules will be the activation level of the muscle controlling the primary element. Again using the wrist module as an example, the output is the activation level of the extensor carpi radialis brevis (ECRB) needed to reach the desired wrist angle.

The interaction networks were implemented with radial basis artificial neural networks (ANN). ANN were chosen since they can model nonlinear, smooth systems, the analytical relationship between the input and output does not need to be known, and they can generalize to inputs not part of the training set.

Training of Interaction Networks

Training data for the interaction networks were obtained with computer simulations with a biomechanical model of the hand and arm [3], [4]. For training the wrist module, the wrist angle was calculated for various activation levels of the ECRB, FDS, FPL, and EPL. For training the thumb module, wrist angle, grasp position and grasp force were calculated for various activation levels of the FPL, adductor pollus (AdP) (activated in parallel with FPL), and EPL. For training the finger module, the metacarpopalangeal (MCP) angle was calculated for different levels of FDS activation. Radial basis artificial neural networks were trained for each module with the MATLAB© neural network toolbox.

Evaluation of Feedforward Controller

The feedforward controller was also evaluated with the biomechanical model of the arm. Lateral grasp templates for the coordination network were designed for two cases: (1) a wrist angle constant at 15° extension as grasp position and grasp force changed linearly from 0 % to 100 % grasp command, and (2) wrist extension from 0° to 40° extension as grasp position and grasp force changed linearly from 0% to 100 % grasp command. The arm was in the neutral position (e.g. gravity acting in the ulnar direction), and no external disturbances (e.g. mass present in grasp) were present. The desired grasp force, grasp position, and wrist angle from the grasp templates served as inputs to radial basis neural networks designed in MATLAB that model the interaction networks. The output activation levels of the interaction networks (ECRB, FPL, EPL, AdP, FDS) then served as input to the biomechanical model of the arm. The actual MCP angle, grasp position, grasp force, and wrist angle were calculated, along with the rms error between the desired and actual values.

RESULTS

Figure 2 displays the desired and actual grasp templates for case (1) (linear increase in grasp command and grasp force as wrist angle remains at 15° extension) along with the muscle activation map. The rms errors between the actual and desired values were: 0.58° for wrist angle, 0.04 N for grasp force, 0.04 cm for grasp opening (from 0-50 %, before contact is made), and 2.1° for MCP angle. For the muscle activation levels, the wrist module increased ECRB in parallel with FPL and AdP activation in order to keep the wrist angle at 15° extension. Similarly, the thumb module changed the activation level of the EPL, FPL and AdP based on the desired grasp opening and force, and FDS activation.

Figure 3 displays the desired and actual grasp templates for case (2) (tenodesis grasp) along with the muscle activation map. The rms errors between the actual and desired values were: 2.2° for wrist angle, 0.04 N for grasp force, 0.06 cm for grasp opening (from 0-50 %, before contact is made), and 2.2° for MCP angle. The reason for the higher rms error in wrist angle for case (2) compared to case (1) is that EPL activation extends the wrist beyond the desired angle at 0 % and 5 % grasp command. In order to reach the desired wrist angle, a wrist flexor would also have to be stimulated. Also, the ECRB must be activated at higher levels in order to overcome wrist flexion and mimic tenodesis compared to when a constant wrist angle is required.

DISCUSSION

The feedforward controller was successful in learning the predictable interaction between hand grasp and wrist movement. Grasping tasks, however, will introduce unpredictable disturbances to the neuroprosthesis such as forearm orientation in

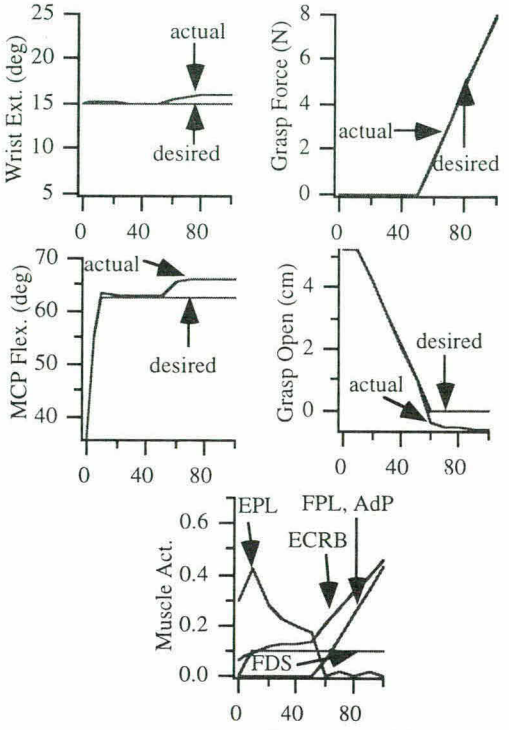

Fig 2. Input/Output Properties for Constant Wrist Angle during Grasp.

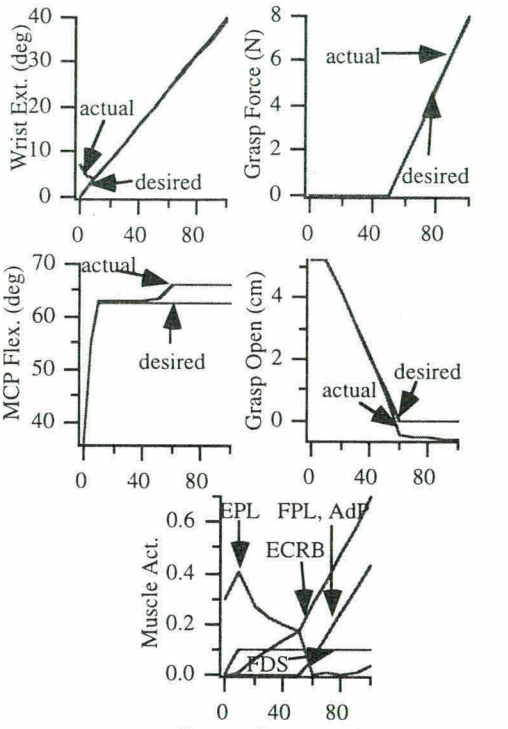

Fig.3 Input/Output Properties for Tenodesis Grasp.

the gravitational field, and the presence of an object in grasp. Voluntary effort, and the addition of arm orientation or feedback control to the feedforward control scheme should decrease grasp and wrist errors due to these type of disturbances. With these additions, integrated wrist and hand control should be possible in the neuroprosthesis, resulting in a more functional grasp for tetraplegics.

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FINGER JOINT MOMENT MEASUREMENTS IN NEUROPROSTHESIS USERS

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ABSTRACT
Hand grasp can be restored to persons with quadriplegia using functional electrical stimulation. Several approaches are used to measure the change of impairment, disability, and handicap provided by the neuroprosthesis. One measurement of impairment is the finger joint moments. A device has been developed and built which can record the finger joint moments generated with electrical stimulation of the muscles. These moments have then been recorded in six neuroprosthesis users. The overall goal is to use this information to improve the generated grasp patterns, as well as record muscle changes over time and compare muscle strength in neuroprosthesis users to able bodied subjects.

BACKGROUND
Functional electrical stimulation (FES) has been shown to provide controlled hand function to those individuals who have sustained a spinal cord injury at the C5 or C6 level. Electrodes are implanted in seven to ten selected muscles, allowing for a graded electrical stimulus to be specifically applied. A preprogrammed grasp template controls the order and magnitude to which the muscles are activated. Overall control of the system is maintained by the user through an external sensor which converts remaining voluntary movement into a proportional command-control signal to control grasp opening and closing. Logic signals, also generated by user controlled movements, turn the system on and off, change grasp patterns, and lock and unlock the system.

The current implantable system allows the user to select one of two possible grasp patterns, palmar prehension (three-jaw chuck grip) or lateral prehension (key grip). The generation of these grasp templates is accomplished using software specifically written for use with the implanted system. The grasp provided by the software is a first approximation to the desired grasp pattern. Further modification is based upon visual observation by an occupational therapist or a rehabilitation engineer. Therefore, the final grasp pattern becomes dependent upon the experience of the person. It has been demonstrated that the grasp pattern generated can be improved through accurate measurement of finger joint moments.[2] Also, the measurement of the finger joint moments, when tracked over time, is anticipated to provide useful insight to muscle changes that occur with electrical stimulation and what specific modifications would be required to provide the best grasp possible.

RESEARCH QUESTION
The aim of this study was to provide quantitative information on the functioning of the individual hand muscles in neuroprosthesis users. Measurements were also made on new neuroprosthesis recipients so that muscle function over time can be tracked. This information can then be used to provide the user with the most functional hand grasp possible.

METHODS
Subjects. These measurement were made on six neuroprosthesis users who ranged in age from 20 to 50 years. The subjects varied in the number of years that they had been using their neuroprostheses. The most experienced user had been using his system for ten years while the newest user had only been using his system a few months.

Finger Moment Transducer. A device was developed and built to measure the moments generated about the metacarpophalangeal and interphalangeal joints of the hand.[3] The design utilizes a parallelogram construction that allows the device to fit on different sizes of hands. Aluminum uprights, fitted with strain gages, were attached to each joint segment providing the measurement of isometric moments

generated about the joints of a single digit. Ball bearing joints between the upright beams and the parallel crossbars prevent hysteresis as well as provide a linear relationship between the value measured by the strain gages and the applied moment. Each joint of the finger can be positioned and locked at any angle throughout the range of motion of the joint. The repeatability of the moment measurements was less than 0.57 N-cm and the error was less than +/- 1.5% in the +/- 100 N-cm range, the maximum range allowable for this device.

Additional Hardware. Stimulation of the individual muscles was accomplished using the implanted neuroprosthesis. Electrical activation of the muscles was controlled using the clinical interface software that is used to program the external control unit. Data collection was accomplished through a program written in LabVIEW running on a Macintosh IIfx computer. The analysis of the data was accomplished through the use of Microsoft Excel on the Macintosh.

Experimental Protocol. The subject was seated comfortably with the hand implemented with the neuroprosthesis resting on a raised platform. Each of the muscles to be studied were then stimulated to determine the threshold level and the maximum stimulus level possible. The hand was then placed into the finger moment transducer and locked into an anatomically neutral position, or as close as possible depending upon the amount of flexibility that existed in the fingers. Using the profile information, the available range was broken down into a minimum of six levels of stimulation, evenly spaced throughout the available range. Each muscle was then stimulated at each level, and the moments across all the joints of the fingers were recorded. At least one minute of rest was given between each level of stimulation. The muscles studied were the extensor digitorum communis (EDC), the flexor digitorum profundus (FDP), the flexor digitorum superficialis (FDS), and the interossei of the fingers. Not all of these muscles were available in each user. This depended upon the extent of denervation which existed with the spinal cord injury, as well as the type of neuroprosthesis used (either the 8 channel or 10 channel implant).

RESULTS

Moments generated by the finger flexors and extensors. The moment measurements for the EDC and the FDS on the long finger are shown in Figure 1. The subjects are presented in the order in which they were studied. Negative moments indicate extension while positive moments indicate extension. Subject 1 does not have stimulatable finger extension. Instead, finger extension is achieved through a Zancolli lasso procedure which allows the FDS muscle to provide for interphalangeal joint extension. Extension of the metacarpophalangeal joint is provided through tenodesis to allow wrist flexion to generate extension at that joint.

Subjects 5 and 6 were the first subjects in which it was possible to record the finger joint moments over a period of time, starting from the time the neuroprosthesis was first used. The initial measurements are from one week after the casts on the arms are removed, while the second measurement is at least one month later. Subject 5 shows definite improvement in the muscles moment generating capabilities, between 25 and 200%. Subject 6 only shows minor improvement in muscle strength, but definite improvement in muscle action. Further measurements on these subject are planned to observe stability of the muscles over time.

Moments generated by the interosseous muscle of the hand. The moments recorded for the second dorsal interosseous are shown in Figure 2. The measurements presented for Subject 1 were made during an initial study on the actions of the intrinsic muscles.[4] The moments measured in the neuroprosthesis users are shown in comparison to the moments recorded from able bodied subjects using electrical stimulation. Subject 1 was capable of generating moments that were only 9 to 13% of those generated by able bodied subjects. This is because the muscles in Subject 1 were deconditioned as a result of his paralysis. In comparison, Subjects 5 and 6 were capable of generating moments that were 50 to 90% of those generated by able bodied subjects.

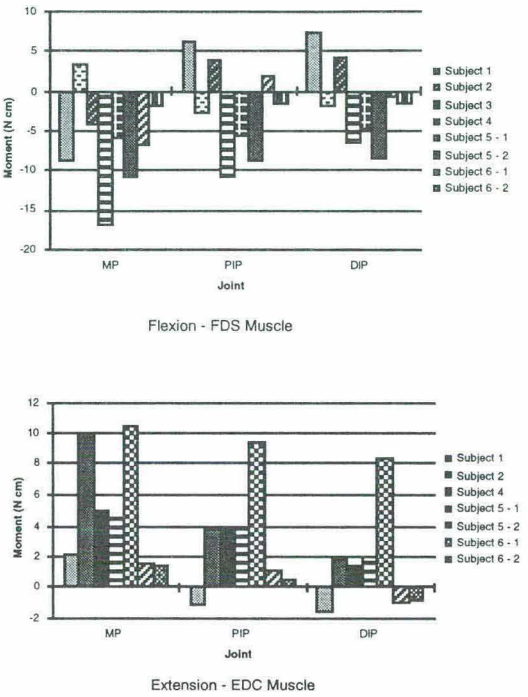

Fig.1 - Finger Flexor and Extensor Moments

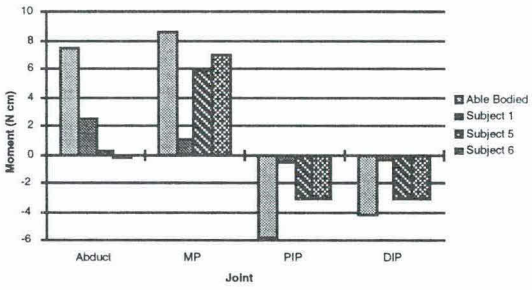

Fig. 2 - Second Dorsal Interosseous Moments

DISCUSSION

The study presented here provides direct measurements of the moment generating capabilities of electrically stimulated muscles in the neuroprosthesis users. These direct measurements have allowed us to monitor the effect of electrical stimulation on muscle strength over time. This will allow for modification and adaptation of the grasp patterns as the muscles strengthen and change with use. In addition to following the effects on muscle strength over time, this data also allows for a comparison of the electrically conditioned paralyzed muscle to the healthy muscle. This will provide us with some measure of how much function a person using a neuroprosthesis can regain.

The measurement of joint moments provides the basis for automated synthesis of hand movement. For example, hand grasp can be optimized by the computer to set up the movement template so that the need for judgment and experience is reduced. In addition, the joint moment data, when analyzed for all the fingers of the hand, provides insight into how strongly the muscle acts on each finger, thus providing insight into any possible deficiencies in the electrically induced grasp. This means that a better grasp template can be derived so that the neuroprosthesis user can get the most functionality out of their hand that is possible.

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CHARACTERIZING THE PASSIVE MOMENT OF THE METACARPOPHALANGEAL JOINT

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ABSTRACT

The passive moments at the index MP joints of six normal controls and two patients with tetraplegia due to SCI were measured and compared. Measurements were made while rotating the joint through its range with the wrist fixed at two positions. Changes in PROM, rest position, and four derived measures of joint stiffness were noted as the wrist position changed. These parameters were also compared across subjects. In both wrist positions the SCI subjects averaged greater stiffness parameters, lesser PROM, and a more flexed rest position than the normal controls. The stiffness parameters and PROM of SCI subjects also changed more for a given wrist rotation than did those parameters for the normal controls. This suggests that the passive moments of finger joints in SCI patients are more dependent on wrist position than the passive moments of the finger joints in able-bodied people.

BACKGROUND

Neuroprostheses using functional electrical stimulation have been successful in providing grasp function for C5 and C6 level spinal cord injured individuals. For some individuals, the ideal grasp patterns cannot be achieved due to the passive properties of the paralyzed hand. Frequently, paralyzed individuals develop a "claw hand" posture, in which the metacarpophalangeal (MP) joints are hyperextended and the proximal interphalangeal (PIP) joints are flexed. This is a poor posture for grasp. If the passive properties could be changed, we anticipate that grasp function could be improved. Therefore, we have initiated a study to characterize the difference between the passive properties of normal and paralyzed hands. The specific purpose of this study was to measure the passive moment of the MP joint of the index finger as a function of wrist angle changes.

METHOD

Subjects

Eight subjects have participated in this study to date. Two subjects had a C5/C6 level spinal cord injury. The age range for all subjects is 20 to 38.

Procedure

Passive moment measurements are made by rotating the index MP joint while simultaneously measuring the joint angle and the resistance to rotation. The apparatus is a modified version of the one described by Esteki & Mansour (1996). The index finger is inserted into a splint that holds the interphalangeal joints straight. A rod extending from the splint inserts into a vertically oriented cantilevered beam that is mounted with strain gages and serves as the force transducer. This beam is attached at one end to a rotating horizontal arm controlled by a torque motor. Limit switches are set in place by the investigator to keep the joint rotation within a range that elicits passive moments less than 40 N·cm. The motor is set to rotate the joint at a constant rate of 50 degrees per second. The hand and forearm are splinted to fix the wrist angle at two positions (0° and 60° extension).

Before measuring the passive moment, the joint is rotated at least five times through its range to stretch the tendons, allowing the joint to "warm-up" and the passive moment per rotation to stabilize. Three complete cycles are then sampled at 100 Hz for each wrist position.

Analysis

The data are analyzed in the form of moment-angle curves (MACs). These are plots of the passive moment measured versus the position of the MP joint as it rotates through its range. In order to make quantitative comparisons between MACs, certain characteristics of the MACs are parameterized. This is accomplished by first fitting the MAC data to the function, $M = a(e^{b(\emptyset-\emptyset r)} - e^{c(\emptyset-\emptyset r)})$. This fit yields four parameters for each MAC: a, b, c, and Ør. The Ør parameter is the joint angle at which the curve fit crosses the abscissa (where the passive moment is zero). Ør, therefore, is a measure of the angle at which the MP joint rests for the given wrist position. We refer to Ør as

the "rest position" of the joint.

From the curve fit parameters, five parameters that can be compared across MACs are computed. Four of these derived parameters are slopes of line segments connecting specific points on the fitted curve as shown in Figure 1. These four slopes, designated as Ext(0-20), Flx(0-20), Ext(20-30), and Flx(20-30), are indications of the stiffness of the joint at various locations along its range of motion. They have units of N·cm/radian. The final parameter computed is the passive range of motion (PROM) which is defined in this study as the joint rotation range between the bounds of -20 and 20 N·cm. PROM is also shown in the figure below.

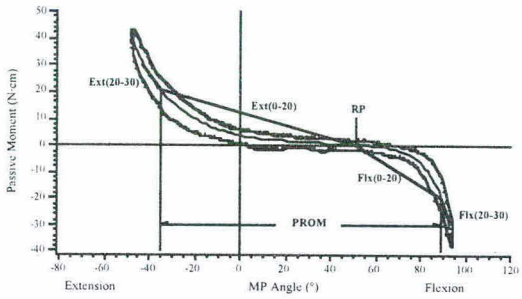

Figure 1. Example MAC with curve fit showing six parameters for curve comparisons: Ext(0-20), Flx(0-20), Ext(20-30), Flx(20-30), Rest Position, and PROM.

RESULTS

Stiffness Measures

For all subjects in both wrist positions, the stiffness values were greater in the flexion region of the MAC than the corresponding values in the extension region, as shown in Table 1. The difference was accentuated when the wrist was extended.

Table 1. Average MAC Parameter Values

Wrist = 0°	Ext(0-20)	Flx(0-20)	Ext(20-30)	Flx(20-30)	Ør(°)	PROM(°)
Paralyzed	18.0	24.2	83.2	113.0	44.8	111.6
Normal	14.8	20.7	66.0	93.2	30.6	138.4
Wrist = -60°	Ext(0-20)	Flx(0-20)	Ext(20-30)	Flx(20-30)	Ør(°)	PROM(°)
Paralyzed	20.8	41.8	68.4	143.7	71.8	83.1
Normal	15.0	23.0	65.9	102.7	52.0	132.5

* N=2 for Paralyzed Hands; N=6 for Normal Hands
The stiffness measures, Ext(0-20), Flx(0-20), Ext(20-30), and Flx(20-30), are in N·cm/rad.

Table 1 also shows that, on average, the stiffness parameters are greater for the tetraplegic population than for the normal population, but more subjects need to be tested before this result can be conclusive.

Figure 2 shows the *change* in each stiffness parameter for all subjects as the wrist was extended from 0° to 60°. Table 2 shows that the average stiffness parameters of the SCI subjects' joints changed more than those of the normal controls as the wrist was extended.

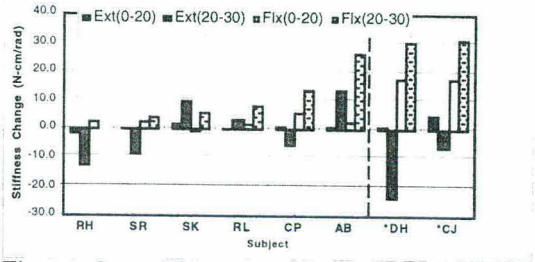

Figure 2. The change in each stiffness parameter for each subject as the wrist extends from 0° to 60°. The two subjects to the right of the dashed line have paralyzed hands.

Table 2. Average Change in MAC Parameters with Wrist Extension

	Ext(0-20)	Flx(0-20)	Ext(20-30)	Flx(20-30)	Ør(°)	PROM(°)
Δ (Paralyzed)	2.8	17.6	-14.9	30.7	27.1	-28.5
Δ Normal	0.2	2.3	-0.1	9.5	21.5	-5.9

* N=2 for Paralyzed Hands; N=6 for Normal Hands
The stiffness measures, Ext(0-20), Flx(0-20), Ext(20-30), and Flx(20-30), are in N·cm/rad.

PROM and Rest Position

On average, the PROM for the SCI subjects was less than that for the normal controls at both wrist positions as shown in Table 1. Individual results showed that at both wrist positions the SCI subjects could not extend their MP as far as the normal controls, but the flexion range was equal for both groups. Additionally, the average rest position for the SCI subjects is more flexed than that of the normal controls.

Figure 3 shows the *change* in PROM and Ør for each subject as the wrist was extended from 0° to 60°. For all subjects, the rest position became more flexed as the wrist extended. For all but one subject, the PROM decreased as the wrist was extended. The PROM decreased much more for the SCI subjects than for the normal controls as the wrist extended from 0° to 60°. Individual results show that the loss in PROM is from the extension region of the MAC. There appears to be no significant difference between tetraplegic

and normal subjects in the amount that the rest position changes as the wrist is extended from 0° to 60°.

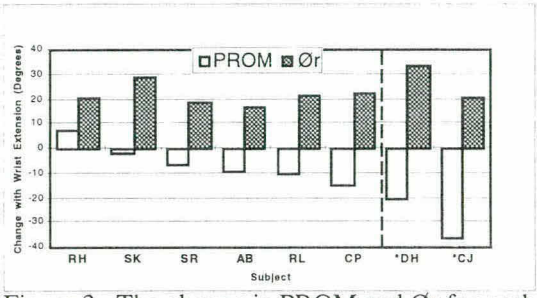

Figure 3. The change in PROM and Ør for each subject as the wrist extends 60°. The two subjects to the right of the dashed line have paralyzed hands.

DISCUSSION

The passive properties of the hand are an important component of grasp function. The alteration in the passive properties of paralyzed hands can result in poor hand posture and make it difficult to provide function through electrical stimulation. In this study, we have begun to characterize the differences in these passive properties, with the future goal of being able to suggest appropriate changes that will result in improved grasp function.

The passive properties of a single joint can be due to the properties of the joint itself (the tissues of the joint capsule, ligaments and bones) and also to the tightness of the tendons crossing the joint. Passive properties due to tendons will be affected by movement of any joint about with the muscle crosses. In this study we are able to analyze the contribution of these two components of the passive moments by changing the position of the wrist while measuring the changes in the passive moments at the MP joint. Wrist extension will tighten finger flexor tendons and loosen finger extensor tendons. Tightening the finger flexors should reduce MP joint extension. Loosening the finger extensors should allow greater MP flexion. Because the finger flexor tendons typically have greater moment arms at the wrist joint than the extensor tendons, it is expected that flexor tightening will occur to a greater degree than extensor loosening, resulting in a decrease in PROM with wrist extension. The results are consistent with this hypothesis for seven of eight subjects. The one subject whose PROM increased when the wrist was extended gained that extra range of motion in the flexion region of the MAC, indicating that the loosening of the extensors had a greater effect than tightening the flexors.

All subjects demonstrated lower stiffness parameters in the extension region of their MAC. This is presumably because the stretched finger flexors are the predominant factors in limiting MP joint extension. The flexion region shows a higher stiffness, and this may be because the joint range is limited by ligaments or bony contact. It is expected that when the wrist is flexed, the stiffness in the two regions will be nearly equal because the extensor tendons are more likely to be the predominant factor limiting flexion. This hypothesis will be evaluated in future studies.

The preliminary results of this study suggest that the passive properties of a paralyzed MP joint are different from that of a normal joint. Specifically, we have found that, for the paralyzed joint: the stiffness is higher regardless of wrist position, MP extension is reduced, total passive range is reduced, the rest position is more flexed and the passive properties are more dependent on tendon length. Obviously more subjects must be studied to verify these preliminary findings.

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A QUANTITATIVE ANALYSIS OF SHOULDER MOTION USED FOR CONTROLLING FES SYSTEMS IN ADOLESCENTS WITH C4 LEVEL SCI

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ABSTRACT

This study examined the ability of individuals with C4 level SCI to produce shoulder motions capable of controlling a FES system in comparison to individuals with C5 level SCI and able-bodied persons. On average, the subject populations largest motions occured during elevation and had the following magnitudes: able-bodied=23°, C5=14° and C4=9°. No significant difference was found between the three subject populations in either the accuracy of reaching discrete shoulder positions with visual feedback or in the stability of holding a discrete shoulder position without visual feedback (α = 0.95). With no pre-defined minimum range of motion the results suggest that within their limited range, individuals with C4 level SCI have sufficient position control to command a FES system.

BACKGROUND

FES systems designed for individuals with C4 level SCI attempt to compensate for the total loss of arm function with a very limited number of user interface sites. Researchers have investigated and developed voice command [1] and sip & puff [2] interfaces to control FES systems. Inspired by the results of a pilot study [3], the focus of this study is the investigation of the shoulder as a possible FES system control interface for individuals with C4 level SCI.

To be able to control stimulated movement, the shoulder interface must be able to extract adequate information from the user's shoulder motion.[4] Specifically, the motion must have a range large enough such that the sensor's noise does not mask the shoulder motion discrimination. Furthermore, the user should be able to move to discrete positions within his or her range. Finally the user should be able to hold his or her shoulder at a particular position indicating intact proprioception thus allowing the shoulder interface as a site for controlling stimulation to potentially benefit from extended physiological proprioception (EPP).

OBJECTIVE

The objective of this study was to quantify shoulder motions typically used in controlling a FES system of individuals with C4 level SCI in comparison to those of individuals with C5 level SCI as well as able-bodied persons.

METHODS

Of the 13 subjects included in the study a total of 17 shoulders were examined: 5 able-bodied, 6 C5 and 6 C4. A dual-axis angular displacement transducer developed at Case Western Reserve University [4] was placed on the subject such that angular deflections measured both elevation/depression (ϕ) and pro/re-traction (θ). The signal from the transducer was sampled through a NIDAQ 12 bit A/D board at 50 Hz and stored and later processed on a Pentium PC.

Each subject was asked to complete a range of motion, incremental stepping and incremental holding experimental section. The range of motion section (ROM) consisted of four motion sets (elevation, depression, protraction and retraction) with each set having five trials were the subject was instructed to move maximally.

In the incremental stepping section each subject was instructed to perform five motion sets (elevation, depression, protraction, retraction, combination). Each motion set consisted of instructing the subject to move the computer generated visual representation of his or her shoulder to a series of discrete target positions. Each target position appeared one "step" away from the previous position at 10 second intervals

until the target reached the end of the subject's range.

Finally, the incremental holding section consisted of five motion sets (elevation, depression, protraction, retraction and combination). During a motion set, when a subject's shoulder reached one of the desired target positions (mid/end-range) visual feedback was removed and the subject was instructed to hold his or her shoulder for 30 seconds (blind period).

DATA ANALYSIS

A Kruskal-Wallis nonparametric statistical test (α=0.95) was performed on all group data. Previous work done with C5 subjects [4] indicated that the shoulder motions of individuals with C4 (and C5) level SCI would most likely be a coupling of elevation and retraction. To determine the maximum range of motion, angles of elevation/depression (ϕ) and pro/re-traction (θ) were used to calculate a normalized magnitude (β) and direction (α) of relative motion. Where the magnitude (β) is described by:

$$\beta = 2\arcsin\left[\frac{\sqrt{2}}{2}\left(1 - \cos\phi\cos\theta\right)\right]$$

and the direction (α) is described by:

$$\alpha = \arctan\left[\tan\phi\sec\theta\right]$$

RESULTS

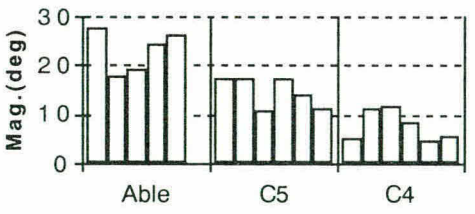

Figure 1. Mean magnitude (β) for all subjects averaged over 5 trials during the elevation motion set of the range of motion section.

The groups had the following mean magnitudes during the elevation set: able-bodied=23°, C5=15° and C4=9°. No significant difference was found between the C5 and C4 groups for any of the four motions sets. However, the C4 group's mean magnitudes were consistently lower than the C5 group in all motion directions.

In the incremental stepping section, the accuracy in reaching a target was evaluated by the absolute steady state error (Ess) and the time in tolerance (Ttol). For a given subject, the absolute steady state error was calculated by averaging absolute error over the last 5 seconds of each "step" as steady state, then averaging over all steps for a given motion. The time in tolerance refers to the percentage of the time that the subject was within the (±20% of step) tolerance range, starting from when the subject first reached minimum tolerance.

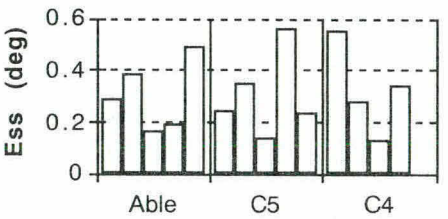

Figure 2. Mean Steady State Error (Ess) for all subjects during the elevation motion set of the incremental stepping section.

No statistically significant difference was found between the groups for either the time in tolerance or the absolute steady state error for any of the motion sets.(figure 2)

Finally in the incremental holding section, the stability of holding the target shoulder position was established by breaking the blind period error into quartiles. The absolute error was averaged in each quartile and no statistically significant difference was detected between any of the quartiles for any given subject during all five motions sets. Furthermore no statistically significant difference was found between any of the groups for all quartile errors for all motion sets.

The total absolute steady state error for both the mid and end range target positions was

calculated by averaging the absolute error over the entire 30 second blind period.

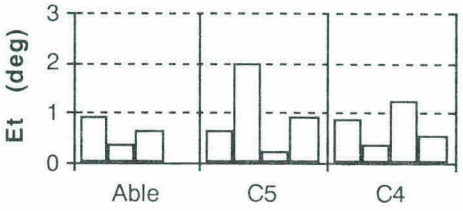

Figure 3. Average Total Errors of mid range target positions for all subjects during the elevation motion set of the incremental holding section.

Again no significant difference was found between the three groups for either mid/end-range total errors.

DISCUSSION

The results from the range of motion section suggest the limited range of motion in C4 level SCI is increased if the motion is not exclusively elevation or retraction but rather the magnitude of the relative motion (elevation ϕ=6.5°, magnitude β=9.0°).

The results from the incremental stepping section suggest that with the aid of visual feedback persons with C4 level SCI persons have the ability to move to discrete positions within their range of motion.

The results from the incremental holding section suggest that there is no significant difference between C4, C5 and able-bodied subjects in their ability to hold a static shoulder position for an extended period of time. These results also imply that C4 subjects must have some form of functional proprioception at the shoulder.

The results of the study indicate that within the limited range of motion (≈9°) individuals with C4 level SCI may have sufficient shoulder control to regulate a FES system.

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FUNCTIONAL EVALUATION OF ELECTRICALLY STIMULATED ELBOW EXTENSION

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ABSTRACT

Two individuals with a C6 spinal cord injury have been provided with elbow extension through functional electrical stimulation (FES) of the triceps. A tilt sensor placed on the individual's upper arm activates the triceps stimulation. The individuals also have an external switch to activate triceps stimulation regardless of proximal arm position. As part of a pilot study, each individual performed a set of functional tasks that require elbow extension (such as acquiring an object from a shelf, making a call from a wall phone, turning on a light switch). A test was developed to quantify functional performance. Initial results indicate that stimulated elbow extension allows these individuals to perform reaching tasks with greater independence and ease.

BACKGROUND

An upper extremity neuroprosthesis has been developed by researchers at Case Western Reserve University to provide the ability to grasp and release objects to individuals with C5 or C6 tetraplegia [1]. The neuroprosthesis stimulates paralyzed muscles in the hand and forearm via implanted electrodes to provide lateral and palmar prehension. Typically, the user operates hand opening and closing through voluntary movements at the wrist or shoulder which are detected by an externally mounted controller. This signal is processed by an external microprocessor unit and transmitted to the implanted stimulator via an external transmitting coil. To date, over fifty individuals have received this neuroprosthesis from 13 centers as part of a multi-center clinical trial.

It has been our experience that those injured at the C5/C6 level desire the ability to extend their elbow in addition to having a functional hand grasp. Until now, the only methods of providing elbow extension to these individuals has been through a tendon transfer of the posterior deltoid to triceps [2] or through the use of an elbow-extension orthosis [3]. The tendon transfer requires the individual to have a strong posterior deltoid muscle and requires longer immobilization than the implanted triceps electrode. In some individuals, this transfer can stretch over time, reducing its strength and effectiveness. The orthoses tend to have poor cosmesis and are difficult to don/doff.

RESEARCH QUESTION

How does stimulated elbow extension affect performance in activities of daily living vs. absent triceps function or a transfer of the posterior deltoid to triceps?

METHOD

Selection Criteria: In addition to the selection criteria for the hand grasp neuroprosthesis [1], candidates for stimulated elbow extension must fit the following criteria: 1) intact lower motor neurons innervating elbow extension muscles, 2) minimal to no upper extremity contractures and 3) voluntary controlled biceps (grade 4).

Implementation: Two research participants were provided with stimulated triceps for elbow extension; one with an implanted intramuscular electrode [4] and the other with percutaneous electrodes [1]. After the initial immobilization period of three weeks, exercise and functional use of the triceps begins. The stimulation level is set to obtain at least grade 4 elbow extension or stronger without causing stimulation of adjacent muscles. Stimulated elbow extension was controlled through an accelerometer (IC Sensors, model 3145-002) placed on the individual's upper arm. The accelerometer sensed the tilt of the upper arm relative to the gravitational field. Abducting the upper arm caused the sensor angle to pass a pre-set threshold value which made the triceps stimulation ramp up to the maximum value. The individuals could attain intermediate elbow flexion angles by flexing their biceps.

Functional Training and Evaluation: A pilot study was undertaken in which the participants were asked to complete a series of functional tasks in the lab that required some extent of reaching. The individual received training in the activity prior to testing. Activities were tested in the lab using a simulated set-up.

Each activity that was tested had its own module, which was placed at specified heights depending on the task. Each module was fixed to a pegboard wall via hooks and Velcro™ to allow for flexibility in placement. The heights / positions were determined by the average height of that activity in a functional environment. (i.e. the height of the wall switches was determined from measurements taken in a functional environment). The participants were asked to attempt each activity from an established position or approach. The activities included: using a wall phone, turning on lights (standard toggle switch, horizontal toggle, round dimmer, slide dimmer, rocker switch) acquiring a book or other object from a shelf, and hanging up a garment.

The participants were tested with the triceps stimulation on vs. with the triceps stimulation off. They could choose to use or not use the FES hand grasp depending on its usefulness in the task. One aim in developing this test was to minimize or eliminate any difficulties in task performance due to limitations in hand grasp.

Evaluating Performance: Task performance was assessed by measuring physical ability to perform the task, the quality of performance, the ease of performance, and the person's preference to use triceps stimulation or not (see Table 1). Physical ability was judged by whether or not the person needed to use compensation techniques for elbow extension, whether they needed to approach the task in a modified way, and whether or not any adaptive equipment was used.

RESULTS

Each participant was tested in eight functional reaching tasks. Results (Table 1) indicate that that there was some improvement in each participant's task performance as judged by each of the four measures. Participant #1 showed improvement in at least one of these four performance areas in eight out of eight tasks tested. Participant #2 showed improvement in at least one of these four performance areas in six out of eight tasks tested.

Table 1.Tasks Improved with Stimulated Elbow Extension

	Ability		Quality		Ease		Prefer.	
Subject	1	2	1	2	1	2	1	2
Slide dimmer	+	0	+	0	+	0	+	0
Round dimmer	+	0	0	+	0	0	0	0
Toggle switch	+	0	0	0	0	0	0	0
Horiz. toggle	+	0	0	+	0	0	0	0
Rocker switch	+	0	+	+	+	0	+	0
Book on shelf	+	+	0	0	+	+	+	+
Garment/hanger	0	+	0	+	+	+	+	+
Wall phone	+	+	+	+	+	+	+	+
# improved / # tested	7 / 8	3 / 8	3 / 8	5 / 8	5 / 8	3 / 8	5 / 8	3 / 8

+ = improved with triceps stimulation
0 = no difference

Results varied between the two participants. Participant #1 showed that stimulated elbow extension improved his ability to perform 7 of the 8 tasks tested. Participant #2's ability improved in only 3 of the 8 tasks tested. However the quality of performance improved in 5 of the 8 tasks tested for participant #2, compared to participant #1 who had better quality in only 3 of the 8 tasks tested. There was no apparent correlation between improvement in ability and improvement in quality of performance. Neither ability nor quality was worse in any of the tasks with stimulated elbow extension.

Of the tasks where the participants physical ability improved with stimulated elbow extension, the participants more frequently reported the task to be easier and preferred to use the stimulated triceps to perform the task (seven out of ten tasks). In all tasks where the participants reported performance to be easier with the stimulated elbow extension, they also preferred the use of stimulated elbow extension. Reported reasons for preferring the stimulated elbow extension include: "It's easier", "I have more control", "It's more powerful of a motion" and "My arm is more stable".

Of the tasks where there was no change in the participant's physical ability to perform the task, ease and preference were reported to be

neutral in all but one task (where the participant reported the task to be easier with and preferred to use stimulated elbow extension).

Fatigue of the voluntary shoulder muscles was observed in both participants when they were not using stimulated elbow extension. This was exhibited by many unsuccessful reaching attempts during a trial. Usually a rest break of 2-10 minutes was necessary before the participant could continue. Fewer and shorter rest breaks between trials were needed with stimulated elbow extension.

In addition to the activities tested in the lab, the participants reported that the stimulated elbow extension assisted them in the following activities performed at home or in the community: brushing hair, acquiring product from shelf while shopping, inserting a floppy disk into a computer, and pushing on/off switches for computer peripherals.

DISCUSSION

The improvement in ability differed greatly between the two participants. Why participant #1 showed greater improvement in ability with stimulated elbow extension compared to participant #2 may be explained by a number of factors. Participant #2 had a tendon transfer of the posterior deltoid to the triceps to provide elbow extension. Participant #1 did not have this transfer.

Anthropometric factors are also believed to have contributed. Participant #2 has a greater arm and torso length, and sits higher in his wheelchair than participant #1. The height difference was eight inches. This provided participant #2 with an advantage, especially in tasks where the task set up was not altered as a result of the person's height. For these tasks (i.e. wall phone and light switches) standard heights that were found in homes and the community were tested. For other tasks (such as reaching a book from a shelf, or hanging up a garment) there was more flexibility to adjust height due to the variability of the heights of the tasks at home or in the community.

Despite the tendency of the participants to report a task to be easier to perform and their preference to use stimulated elbow extension when there was an improvement in ability, there were three tasks in which this varied. In each of the three tasks, the participant needed to compensate or change his approach to the set up of the task in order to complete the task. The result of this was to make the task equally as easy with the stimulated elbow extension vs. without stimulated elbow extension.

Overall, the stimulated elbow extension provided many benefits to the participants. Fatigue of the voluntary shoulder muscles was less of a problem with stimulated elbow extension. Additionally, the participants performed better with stimulated elbow extension for tasks that required the participant to maintain a steady elbow extension, such as dialing the wall phone. One of the most important benefits is the flexibility that stimulated elbow extension provides in activities. There are many situations at home and in the community where environmental barriers limit or prevent a person from using compensation techniques or from approaching a task in the way that they need. The stimulated elbow extension allows the person to more easily adapt to a situation without having to adapt the environment.

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A MULTICHANNEL IMPLANTABLE SYSTEM FOR NEURAL CONTROL

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ABSTRACT

A neuroprothesis, composed of an implanted stimulator-telemeter device, multiple implanted stimulating electrodes, an implanted joint angle sensor, and an external power and control unit, has been developed. The initial application of this neuroprosthetic system is to restore function in the hand and arm of individuals who have sustained cervical spinal cord injury. It provides enhanced functions beyond current implantable systems used for restoration of hand grasp function.

BACKGROUND

Individuals who have sustained spinal cord injury at the cervical level lose upper extremity function. With the loss of function comes dependency on assistance for activities of daily living and limited employment opportunities. Various adaptive aids and orthotic devices have been developed to increase these individuals independence. A system utilizing functional neuromuscular stimulation (FNS) has been used to provide basic hand grasp and release function (1). An external sensor is used to measure joint angle from some remaining voluntary function such as shoulder or wrist movement. This transduced position is used as a continuous command input to an external controller. The external controller processes the command information and controls multiple channels of electrical stimulation that are applied to various muscles of the hand and forearm providing coordinated movement.

STATEMENT of the PROBLEM

The current implantable FNS system, which provides restoration of hand grasp, has eight channels of stimulus output and uses an externally mounted joint angle transducer for monitoring user commands. The FNS system described here provides enhanced restorative function through:

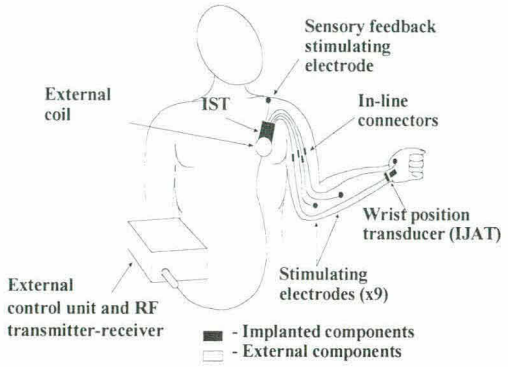
- Increased available stimulus channels to enhance hand-arm function.
- An implantable joint angle sensor to eliminate cable and mounting issues.
- Implant device power supply status for minimizing system power consumption.

RATIONALE

Spinal cord injury affects over 180,000 individuals in the United States and it is estimated that there are another 10,000 new cases each year. Restoration of lost function increases the individual's independence thus decreasing their reliance on assistance in both the home and workplace. This independence also increases the viable employment opportunities easing the reliance on other forms of financial support.

DESIGN

The neuroprosthetic system, as configured for restoration of upper extremity function, is shown in the figure below.



FNS System for Restoration of Upper Extremity Function

This configuration restores hand grasp and release function through a command derived from wrist position for a 'powered' tenodesis similar to a flexor driven hinge splint. As the user flexes her/his wrist, the stimulus levels to the finger flexors are increased.

The implanted components of the system consist of the implantable stimulator-telemeter device (IST), the ten stimulating electrodes, and the implantable joint angle transducer (IJAT). In-line connectors are used to connect the electrodes and IJAT to the IST.

The external portions of the system consist of the external control unit (ECU) and the external coil. The ECU provides power and control to the implanted IST and recovers data and status from the IST through the external coil.

DEVELOPMENT

The IST device provides several functions (2). It receives power through an inductive link that can best be described as an air coupled transformer, 'primary winding' being the external coil and the 'secondary winding' being part of the IST. This powering scheme is used so as not to limit the lifetime of the device due to its power source. This link has been optimized for a coaxial alignment of the internal and external coils with a separation of approximately one inch. Commands for control of stimulus output, transducer powering, and data collection are transmitted to the IST across the same inductive link. Finally, data from the transducer and IST system status are transmitted back to the ECU across the inductive link as well (3). The IST hybrid circuit is enclosed in a titanium package. The IST device has been transferred to Biocontrol Technology Inc. (Indiana, PA.) for manufacturing.

Two types of electrodes are utilized with the IST device. Epimysial electrodes are sewn on the surface of the muscle. Intramuscular electrodes are placed inside the muscle using a hypodermic needle insertion tool. The ten implantable electrodes can be any combination of these two styles of electrodes. Epimysial electrodes are typically placed on the more superficial muscles, where there is good exposure of the muscle belly. Intramuscular electrodes are used in small muscles or in deeper muscles where access to the muscle surface is difficult.

The IJAT is based upon an array of linear Hall effect sensors implanted in one side of the joint and a magnet implanted in the other side (4). The sensor array measures the magnetic field which changes as the joint angle, magnet, moves. Both the sensor array and magnet are contained in titanium packages.

PRECLINICAL TRIALS

An animal model was developed to evaluate the system in vivo. One animal, with an earlier IJAT package design and the IST device, was tested for 18 months. There are currently three animals being evaluated: one with an IJAT only and two with complete IJAT/IST systems.

CLINICAL IMPLEMENTATION

The 10-channel IST/IJAT system will initially be implanted in two stages in order to

minimize the surgery time. In the first stage, the IST device and ten stimulating electrodes will be placed. The six leads necessary for the IJAT will be capped with silastic plugs and placed subcutaneously in the upper arm. In the second stage, the IJAT will be placed in the wrist and the leads tunneled up the arm and connected to the existing connector site on the arm. By implementing a two stage procedure, we minimize the risk of a prolonged surgery during the initial implantation of the IJAT into a human wrist.

At present the IST device has been implanted in two individuals (CMJ and DMH). Both individuals have undergone stage I of the procedure. In addition to seven electrodes for grasp function, both subjects were provided with two electrodes in the finger intrinsic muscles. These electrodes provide improved finger extension and positioning for the palmar grasp pattern. Subject CMJ also received an electrode on the triceps muscle for elbow extension. Subject DMH was provided with an electrode on the pronator quadratus for forearm pronation. Both subjects currently use an externally mounted wrist transducer to control grasp opening and closing and have exhibited the ability to perform many activities including eating, grooming and office tasks. Both subjects have expressed satisfaction with the grasp patterns and with the added elbow extension or forearm pronation that they obtain with the system. Both subjects are now using their device regularly at home. They will return in the spring of 1997 to complete the second stage of the installation.

SUMMARY

A multichannel implantable system for neural control has been developed.. In its first application for restoration of hand/arm function, this system provides 10 channels of stimulus output. It also derives commands from wrist joint angle position using an implanted joint angle transducer. This system has been tested in vivo in several animals. The first stage of human implementation has been completed in two individuals who use it on a regular basis. This system is being transferred to an outside manufacturer.

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A CLINICAL PROGRAMMING SYSTEM FOR THERAPEUTIC ELECTRICAL STIMULATION BY INJECTABLE MICROSTIMULATORS

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ABSTRACT

A new class of electronic devices can be injected into muscles to exercise and strengthen them, following a stroke or arthroplastic surgery for example. We have designed user-interactive software that enables the clinician to test these devices, identify multiple implantation sites and set up an exercise program that the patient can then self-administer using a bedside controller (described in (1)). The Windows™ based software is user-friendly and maintains a record of treatment sessions administered while it is used in the bedside controller's stand-alone configuration.

BACKGROUND

Muscles made inactive by surgery or injury, such as in spinal cord injury and stroke, tend to atrophy. Reduction in the size and strength of atrophied muscle fibers can be reversed with therapeutic electrical stimulation (TES) (2,3). Traditional technology for TES has substantial shortcomings: skin-surface electrodes are difficult to don and may produce skin irritation and unpleasant sensations related to activation of cutaneous nerves. Percutaneous electrodes are unsightly and risk infection and breakage. Multichannel internal stimulators require major surgery to implant the electrodes, leads, and stimulator.

RATIONALE

BION™s (BIOnic Neurons) are small devices (2 mm diameter x 16 mm length) that can be injected directly into the desired muscles, minimizing intrusiveness and providing reproducible and well-controlled levels of stimulation to individual muscles (4, 5). The system that we have developed permits implantation and programming as an out-patient procedure, avoiding extensive surgery.

DESIGN

The power and data for one or more BIONs are transmitted by an amplitude-modulated RF carrier applied to a single external coil. The two main internal components of the BION are the tuned receiving coil and the integrated circuit chip, which converts the carrier to DC power, demodulates and interprets the data and generates the stimulus pulses (4). Up to 3000 commands per second can be transmitted, each of which causes one stimulation pulse with digitally controlled output current and pulse width to be generated by the one BION whose digital address matches that sent at the beginning of the communication string. Power for stimulation is stored between pulses by charging an electrolytic capacitor composed of the electrodes and intervening body fluids.

The complete clinical system consists of the clinician's fitting software on a personal computer, a bedside control box, a transmitting coil and power oscillator (configured like a heating pad), and a test-well (Figure 1A). During testing and fitting, the PC communicates with the microprocessor in the bedside controller via RS-232 port. For treatment, the bedside controller is operated in stand-alone mode by the patient or primary care-giver.

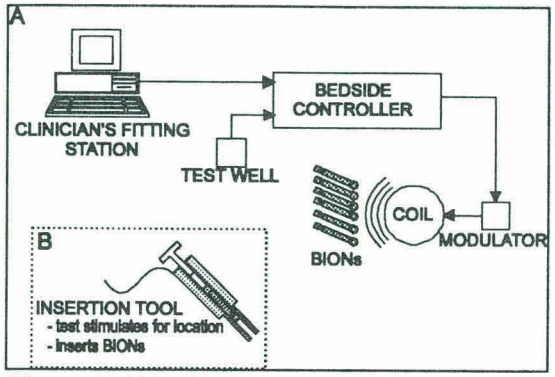

Figure 1: (A) Block diagram of the stimulation system, and (B) insertion tool.

Clinician's Fitting Software

The software described in this paper is used by the clinician to perform different tasks necessary for the proper fitting of a patient with BIONs: recording general patient information; testing and identifying the address of a device; recording and identifying BIONs injected in the patient; measuring and recording threshold for each BION; designing a stimulation program for a patient; and recording usage of the stimulation program from the counter in the bedside controller. The software is modular and consists of a series of dialog boxes that can be opened in parallel. To facilitate its use, the software indicates the next logical step to the clinician with the use of hint buttons that appear at different stages of the fitting procedure.

One of the important features of this software is that any modification or addition to the stimulation system of a patient is recorded as a dated entry in a database that is organized according to 'visits'. At each new visit, the clinician may inject more BIONs in the patient, define new thresholds for already inserted devices, and modify or create new stimulation programs for the patient.

Programs can generate interleaved pulses from up to eight BIONs. Many stimulation programs can be created for a patient and the software records each of the m with the date of creation and comments entered by the clinician. Stimulation programs are stored by patient database.

Clinical Procedures

Before injecting a BION in a patient, the device in its sterile package is placed in a test-well containing recording electrodes in order to test its function and identify its address. Information about the BION is entered into the database of the software: muscle, location in the muscle, address, and serial number. A 12-gauge modified angiocath is inserted into the target muscle (Figure 1B). Using electrical stimulation at the tip of the needle, the clinician can confirm location before inserting the BION.

The trochar is then removed and the BION pushed into the muscle through the plastic sleeve of the angiocath. A few days after the injection of one or more BIONs, the clinician determines the threshold stimulus parameters (pulse current and duration) that evoke a palpable twitch of the muscle. After the thresholds have been defined, the clinician uses a graphical user interface to develop an exercise program consisting of trains of electrical pulses at the various sites of implantation. The clinician can define the parameters for the stimulation program: cycle time; number of times the cycle is to be repeated; frequency and duration of each stimulus train; delay time for the start of the cycle; stimulus intensity for each BION; and ramp-up (Figure 2). For simplicity, stimulus intensity is usually specified by the clinician as a multiple of the currently applicable threshold for evoking a twitch at each site; direct control of pulse current and duration is also available. Up to four different exercise programs can be downloaded into the bedside controller so that the patient can self-administer various muscle exercises. At subsequent visits, the clinician can upload information about the usage of each program.

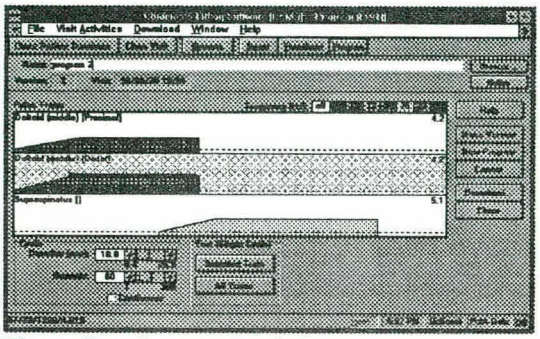

Figure 2: software stimulation program screen

STATUS

Biocompatibility testing in animal and in vitro has shown that BIONs are both reliable and safe, resulting in a benign and stable foreign body reaction in the muscles after chronic stimulation (5). The BION implant is being manufactured as an investigational medical device by Advanced Bionics Corporation of Sylmar, CA.

Our first clinical study will consist of implanting BIONs in the deltoid and supraspinatus muscles of post-stroke patients to prevent and treat shoulder subluxation. The patients will first use stimulation at the hospital and will continue this therapy at home after discharge for a total of 6 weeks. They will be compared to a control group regarding range of motion, muscle atrophy, radiographic shoulder posture, and various subjective indices.

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COMFORT: A CRITICAL ISSUE FOR SUCCESSFUL NEUROMUSCULAR ELECTRICAL STIMULATION

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ABSTRACT

Comfort is the key to the successful use of electrical stimulation [ES] for most patients. Researchers, manufacturers and clinicians often overlook the fact that almost all potential ES users have sensation. The focus of this paper is to review comfort issues in ES, as well as to report comfort ratings and associated muscle performance during open and closed-loop ES of the quadriceps with singlet and doublet pulse trains. The majority of 30 healthy subjects, especially those with a fast-fatigue profile, preferred singlet ES. Contrary to previous reports, doublet ES resulted in lower peak moments and more rapid fatigue. These findings have clinical application for the management of patients and athletes.

BACKGROUND

There are a number of reasons why electrical stimulation [ES] may not be effectively used in patient management, including inappropriate candidate selection, lack of [or inappropriate] goals, and disregard for stimulus selection to minimize fatigue and optimize exercise performance. Comfort, however, is the "bottom-line" for success in neuromuscular ES. Only a tiny percentage of potential ES candidates are anesthetic. Most patients have sensation and whether the goal of treatment is to gain range of motion, improve strength or endurance, prevent deep venous thrombosis, enhance timing of recruitment or control muscles for walking or grasping, stimulation will be ineffective if it hurts. Despite this fact, many clinicians, manufacturers and researchers have not considered the user's comfort in stimulator design, waveform selection and protocol design.

Bowman and Baker clearly demonstrated that a 300 uS balanced pulse was preferred over other waveforms and pulses of shorter duration [300-50 uS], and 50 uS was the least preferred duration a blind, controlled study of ES knee extension [1]. We know from experience in our own laboratory that ramping of intensity by pulse amplitude is more comfortable than ramping by pulse duration [2]. When skin electrodes are employed, electrode placement is critical to avoid excessive bombardment of cutaneous receptors [3], and the distribution of the current flow under the skin electrode is extremely important. Although stimulation requirements vary with the goal of treatment and the anatomical geometry of the target muscles, the quality of the electrode current distribution may make the difference between successful use of ES or a patient complaint of excessive burning. Current distribution under skin electrodes can be easily measured and visualized in graphic format [4].

The use of paired, or multiple, pulses has been shown to increase twitch force [5,6], and it is known that motor units may discharge together normally, especially in ballistic movement [7]. Karu, et al, [8] demonstrated greater peak knee extension [KE] moment and fatigue resistance during a closed-loop tracking trial in a sample of normal and SCI patients.

RESEARCH QUESTION(S)

The purpose of this presentation is to report the comfort ratings and associated muscle performance during singlet and doublet stimulation of the quadriceps during open-loop,

isokinetic and closed-loop, isometric KE exercise. The study was designed to determine if there were differences in muscle performance [ie force generation, work performance and fatigue resistance] and comfort between singlet and doublet stimulation.

METHOD

30 healthy subjects [27.4± 4.1 years] participated in the open loop isokinetic exercise trials, and 17 of these same subjects continued to participate in the closed-loop protocol.

Instrumentation: Cutaneous electrodes [3.4 in, Axelgaard Mfg, Fallbrook, CA] were used [2 channels of 250 uS, balanced biphasic]. ES was provided by a modular stimulator, plug-in board in an IBM PC/AT. KE exercise was controlled by a LidoActive dynamometer [Loredan Biomedical, Davis, CA]. Analog signals from the LidoActive system were sampled by the IBM for angular position, velocity and moment. Calibration, gravity compensation and data acquisition were performed by the IBM system. Stimulation was programmed for a 1.5 sec pulse train with a 1.5 sec off time, so the timing of ES was the same in isokinetic [60 Deg/S] and isometric trials. Electromyography was performed with disposable, monopolar needles and a Cadwell 5200A [Kennewick, WA]. **Procedure:** During each test session, a recruitment curve [RC] was performed to document the maximum comfortable ES amplitude and resultant KE moment. An electrode placement map assured similar placement on subsequent visits. For the open-loop isokinetic trials, the maximum comfortable KE moment, and amplitude, were selected for the 100 repetition exercise trials. 33 pps were used for singlet ES and the minimum number of doublets/S required for tetany was selected [default spacing between the 2 pulses in the doublet was 1000 uS]. Prior to closed-loop ES trials [100 repetitions, isometric] a doublet RC was performed. The doublet frequency selected was the minimum number of doublets/S required to produce a smooth, tetanic contraction. The spacing between the two pulses in the doublet was optimized by increasing the mA until 2-4 Nm of KE was produced and then varying the spacing [leading edge of the first pulse to the leading edge of the second pulse] from 300 to 6000 uS. The spacing that produced the greatest KE moment was used for testing. Singlet stimulation utilized identical single pulses at a prr twice that of the doublet frequency. 75% of the maximum comfortable KE moment was chosen as the target for closed-loop trials. The target KE moment was matched for the singlet and doublet trials. Peak moment, work performance and fatigue indices were documented by a custom software protocol. The size and recruitment pattern of the muaps in the vastus medialis and lateralis were documented on a separate visit. Statistical analyses were performed with BMDP [$p<.05$].

RESULTS

During isokinetic ES recruitment curves, subjects were willing to produce significantly greater KE moment with singlet ES [29.6±9.7 vs 22.7±11.4 Nm with doublet, $p<.05$]. 17 subjects preferred singlet for comfort, 1 chose doublet and 12 had no preference. When subjects were grouped by their comfort preference, those who were more comfortable with singlet ES did not perform as well during doublet exercise trials. 15 of these subjects performed less work and fatigued faster than their no-preference counterparts. 2 subjects could not tolerate sufficient doublet stimulation to perform a RC. The 17 subjects who preferred singlet stimulation demonstrated larger motor unit action potentials [muaps] during early recruitment, generated greater KE moment/body weight, and were more fast fatiguing [FF] during voluntary KE exercise than the remaining 13 subjects [FR or fatigue resistant].

A similar pattern was observed in

closed-loop ES, using the optimized doublet frequency and pulse spacing. 16 subjects preferred singlet and one subject had no preference. When subjects were grouped by muap characteristics and voluntary exercise performance [7 FF and 8 FR], the FF subjects generated significantly less KE moment on the doublet RC [23.6±8.7 vs 39.9±14.0,p<.05, Table]. Although all subjects fatigued more quickly during doublet than singlet stimulation during the closed loop trials, the FF group demonstrated the greatest statistical trends or differences between doublet and singlet.

Table. Recruitment Curve maximum comfortable KE moment [Nm and % maximum voluntary, isometric KE moment].

	Max KE	%MVC
Singlet:		
FR	22.4±10.3	15.5
FF	39.9±14.0	27.0
Doublet:		
FR	19.9±9.9	13.1
FF	23.6±8.7	15.2

DISCUSSION

Comfort preferences appear to be very clear in this sample. In the initial, isokinetic trials, individuals with an athletic profile similar to the power athletic [greater peak Nm/wt, faster fatigue, larger initial motor units] clearly preferred singlet. In the second phase, in which we optimized the doublet stimulation for each individual and then selected a prr for singlet to insure the same number of pulses per second, we anticipated improved comfort with doublet stimulation. This was not the case. The relative discomfort during doublet ES was accompanied by reduced muscle performance [less work and greater fatigue]. All subjects reported a greater "cramping" sensation during doublet, but this was more pronounced in the FF group. The findings of this study indicate that the selection of single pulse trains will be clinically important to the comfort and success of ES protocols for patients as well as athletes.

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A NEW DESIGN OF BLADDER CONTROLLERS

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ABSTRACT

The new design of bladder controllers is one of the many projects developed by the **SP CARE**[1] (**S**ingapore **P**olytechnic **C**entre for **A**pplication in **R**ehabilitation **E**ngineering). The bladder controllers come with two models: the patient and doctor models. Both models use microcontrollers to generate pulses with different frequency and duty cycles, and form pulse bursts with various spaces and marks. For patient model preset resistors are used for adjusting pulse amplitudes. For doctor model a special circuit is designed for completely digital control of all pulse parameters including amplitudes. The new controllers are easily set and controlled. They are not only more reliable, flexible, but also cheaper.

BACKGROUND/PROBLEMS

The Finetech-Brindley bladder controller was developed at the Medical Research Council in the 70s and is used mainly for people with spinal cord injuries. In Singapore there are 15 patients who have been implanted with such systems and more patients are considering to accept the surgery for implantation.

Several patients with this implant had asked us to assist in the repair of their controllers. As there are limited users in Singapore, they could not find sufficient technical support and service for their bladder controllers. Many patients have to buy two or even more controllers as spares for urgent replacement. The controller is quite expensive for most patients. The existing controller uses the 70s technology with 8 ICs and a 45V battery. Due to the complexity of the design the controller is not very reliable. The batteries and their charger are not easily available too.

On the other hand, it is difficult to change pulse parameters and even more difficult to know the exact parameters used by patients for the existing controllers. Because all parameters can be changed only by adjusting preset resistors, one has to open the controller casing for any change and fine adjustment is almost impossible. This is not convenient for new users and completely not suitable for doctors, who want to make research and statistic investigation.

On the requests of the patients, we had reviewed the design of the Finetech-Brindley bladder controller, and decided to design a new controller using the state of art of Micro-controller technology.

DESIGN/DEVELOPMENT

The block diagram of the new design of the bladder controllers is shown in Fig. 1. The microcontroller produces required waveform signals, parameters of which can be easily set by three panel buttons. Most

[1] **SP CARE is a Centre that is specially set up by Singapore Polytechnic to provide technical service and support to the local disabled communities by developing useful projects to enhance their living quality.**

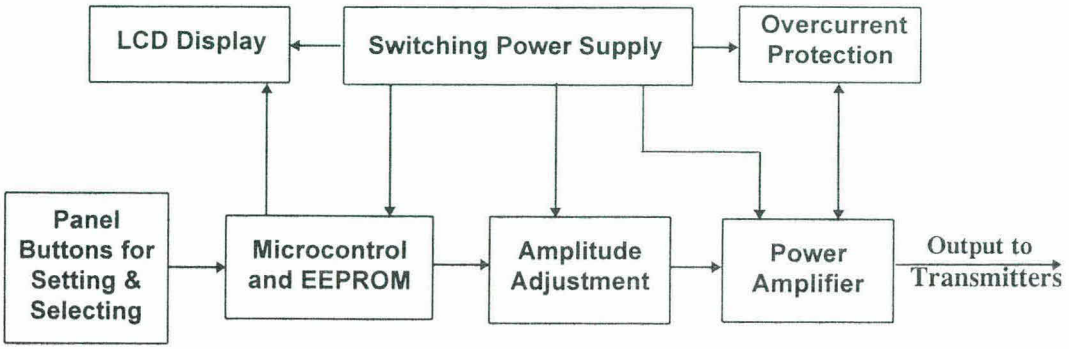

Fig. 1 Block Diagram of the New Bladder Controllers

commonly used sets of parameters can be stored in EEPORM as MODE 1, MODE 2 and so on. One can preset up to 16 Modes that can be easily retrieved and modified through the panel buttons. Working mode and setting parameters are shown on a LCD display. Amplitude and power of the output pulses can be adjusted in two ways depending on the models. Preset resistors are used for the low cost patient model generally used by patients, who use the controller for a long time and know what pulse parameters are suitable for them. A sophisticated designed circuit in the doctor model using common ICs and resistors makes the amplitude adjustment completely digital by pressing buttons. This model is suitable for new patients and doctors because all parameters of pulses can be set at the panel and shown on the LCD display. When one varies any parameter of pulses, outputs of the controller will immediately follow the change. Patients may set the optimal parameters according to the comfort level he feels. In the new design, a switching power supply is added on the circuits. So the 45 volts battery is replaced with a 7.2 volts handphone battery that is more readily available in the market. The controller can actually accept a very wide voltage range, such as 6 volts to 24 volts. Patients will no longer worry about the batteries and their chargers.

The specifications of the controller outputs are as follows:

Pulse period: 20ms - 125ms in 100 steps.
Pulse width : 28μs - 728μs in 100 steps
Burst Space: 2s - 33s in 100 steps
Burst Mark : 1s - 17s in 100 steps

For doctor model, digitizing amplitude with certain accuracy, resolution and low costs is relatively difficult. We choose common ICs and resistors to achieve the following results: theoretically amplitude will vary from 24.5% to 100% in 36 steps; the maximum variation between two adjacent settings is 2.73%, and minimum is 0.82%. Two third of all step variations are between 2.0% and 2.5%. Actual measurement of a prototype gives step variations 2.62% of maximum and 0.95% of minimum under DC condition.

EVALUATION

The new designs of bladder controllers had been consulted with Dr. Brindley when he visited Singapore. He also hoped that new bladder controller would have more flexibility for generating various waveforms so that the controllers could be best satisfied by different patients.

By comparing our prototypes with the Finetech-Brindley bladder controller, it shows that the new bladder controllers can produce same waveforms. The new controllers have overwhelming advantages that they can produce predetermined waveform and adjustable waveform precisely.

The new controllers have been tested by a patient, who trusts the new controller and hope that we can provide him with a product as soon as possible.

DISCUSSION

Now standard components are used in the design. The SMT technology will be adopted for most parts of the next version of products.

As suggested by Dr. Brindley, software of the bladders will be modified for the generation of different waveforms, which will be tested by patients under direction of doctors. It is expected that optimal parameters of waveforms could be figured out.

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IMPLANTATION OF MICROSTIMULATORS ON THE BLADDER WALL: HISTOLOGICAL RESPONSE

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ABSTRACT

Small wireless microstimulators were implanted on the bladder wall serosa in three cats. The microstimulators were secured with a single polypropylene suture. Two to three microstimulators urinary were implanted in each animal. The stimulators were implanted for eight weeks, and gross observation revealed encapsulation of the microstimulators with no perforation into the bladder lumen or migration from the bladder wall. Histological evaluation confirmed that all the microstimulators were encapsulated with a thin connective tissue sheath and a thickened subserosal layer. Only two microstimulators in one cat revealed a moderate to severe inflammatory response confined to a small area around the stimulator. These results indicate that the microstimulator can be further evaluated for implantation on the urinary bladder.

INTRODUCTION

Sacral nerve root stimulation has been accepted through extensive clinical studies as an important method for micturition (2). However, invasive surgical procedures are needed to implant the electrodes, and alternative methods such as direct bladder stimulation continue to be investigated.

Device and biocompatibility problems have been highlighted in several studies with direct bladder stimulation (2,3,4). Koldewijn et al. (3) reported in an animal study that devices implanted on the bladder wall either perforated or migrated from the site of implantation. The implanted cables passing into the peritoneal cavity and extending onto the bladder wall may have contributed to these adverse results. One clinical trial using the Mentor stimulator had four of eleven implanted devices removed due to infection and impending penetration off the receiver through the skin (4).

In animal studies, we have evaluated new types of electrodes for activating the bladder (5,6). A promising new approach is microstimulators. Microstimulators are small radio frequency controlled devices that do not require connecting cables. Microstimulators implanted on the bladder wall may minimize infection and erosion problems reported with traditional implanted devices. In this study, we sought to evaluate microstimulator fixation to and biocompatibility with the bladder wall in an animal model.

METHODS

The microstimulator developed at the University of Michigan was 12 mm long, 2.5 mm wide, and 2.5 mm tall. The microstimulator consisted of a silicon substrate that supports two large iridium oxide stimulating electrodes and an integrated circuit chip that was supported by the silicon substrate The electrodes were placed outside of the glass capsule.

For this study, the test devices lacked the internal circuitry. Explanted microstimulators were evaluated for corrosion and integrity of the hermetic seal with light microscopy.

Three male cats were sedated with ketamine and xylazine followed by inhalation anesthesia of 0.8% halothane and 30-50% nitrous oxide in oxygen. The bladder was surgically exposed via an anterior midline incision, and the microstimulators were implanted on the bladder serosa. A prolene (5-0) monofilament suture loop was used to secure the microstimulator to the serosa. Two or three microstimulators were sutured at either the base mid-wall or

dome of each bladder. The surgical incision was closed routinely.

The cats remained healthy for eight weeks after implantation. They were then sacrificed by intracardiac injection of saturated KCl after adequate sedation. The bladder was then excised and filled with 20 ml of 10% formalin. A single incision over the microstimulator facilitated its removal. Bladder tissue surrounding the device was embedded in paraffin for histology. Four to six tissue sections were viewed per stimulator. These sections were stained with either Masson trichrome to identify fibrous connective tissues or hematoxylin and eosin to identify inflammatory cell responses. Inflammation was subjectively classified *focal* if inflammatory cell accumulation was limited to one small area, *moderate* if inflammatory cells were composed of major nucleated cells in a particular area, or *severe* if inflammation appeared to traverse tissue planes.

RESULTS

Observation *in situ* revealed that the microstimulators were attached to the bladder wall without any obvious defects. The microstimulators on the base, the mid-wall, and the dome were covered with thin connective tissue and were adjacent to adipose tissue. No overt inflammatory response or migration was noted. During histological preparation, the bladder wall was measured to be not more than 1 mm thick in all sections.

Histological evaluation confirmed that all the microstimulators were encapsulated with a thin connective tissue sheath and a thickened subserosal layer of approximately 0.1 mm thick. All layers were intact and there was no evidence of tissue perforation in relation to the stimulators.

Surrounding two stimulators was a moderate to severe inflammatory response and fibroplasia. This inflammation was composed primarily of neutrophils and fibroblasts, with smaller numbers of plasma cells, lymphocytes, macrophages, and cellular debris. Capillary buds were evident demonstrating various degrees of vascular invasion into the subserosal connective tissue. The uninvolved histological sections from the same bladder were normal. The reactive tissue surrounding three additional stimulators contained a mild inflammatory component composed primarily of neutrophils within a maturing fibrous connective tissue. In all of these sections, the inflammatory response was limited to foci adjacent to apparent suture tracts. Histological sections surrounding two final stimulators contained a thickened subserosal layer characterized by an acellular fibrous connective tissue capsule with mature fibrocytes and organized stroma. No appreciable inflammatory cells were present in these sections.

All microstimulators were cleaned and inspected after explantation. They remained intact and did not show any sign of breakage or physical damage due to handling. No moisture was observed inside any of the glass packages.

DISCUSSION

Erosion, migration and lead breakage have been important concerns with direct bladder stimulation studies (2-4). Koldewijn et al. (3) reported that in chronic studies only ten of 36 sensors remained implanted on the bladder wall of goats. Electrode wires that traverse the abdominal cavity may contribute to this problem. Microstimulators, on the other hand, may limit or avoid migration and erosion problems since there are no attaching wires. In this study, implantation of microstimulators on the bladder wall of the cat was conducted without complications of perforation or migration. These results are limited to a short eight week implantation period and no stimulation was applied to the electrodes.

Following this eight week implantation period, evidence of fibroplasia and repair were clearly seen histologically. Two microstimulators had a moderate to severe inflammation surrounding the device. Better cleaning techniques may reduce this inflammatory response. However, in comparison to

large implanted stimulators with connecting cables, the microstimulator should greatly decrease the risk of infection.

The explanted microstimulators maintained their hermetic seals. Thus, these devices should be considered for additional animal studies.

In addition to device/biocompatability problems, there have also been urological related issues with direct bladder stimulation. These problems reported in clinical studies have included poor bladder contractions, pelvic pain and high urethral resistance (2,4). The advent of new procedures may help with these problems (5,6).

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INSTALLATION AND PERFORMANCE OF A 16-CHANNEL IMPLANTABLE FES SYSTEM FOR UPRIGHT MOBILITY

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ABSTRACT

This paper details the case history of an individual with complete thoracic paraplegia receiving a surgically implanted functional electrical stimulation (FES) system for standing and walking. After a period of exercise with surface stimulation prior to surgery, a 16-channel FES system was installed in two surgical procedures. Epimysial electrodes were sutured to seven muscles of each lower extremity, and intra-muscular electrodes were inserted at the L2 spinal roots. Leadwires were routed subcutaneously to the abdomen where they connected to two CWRU 8-channel implantable receiver-stimulators. All implanted components are operational and producing stimulated responses sufficient for re-conditioning exercise. Performance during functional activities remains to be determined.

BACKGROUND

Standing, walking, side and back-stepping, and stair climbing motions are possible in the laboratory with systems employing up to 48 independent stimulus channels and chronically indwelling intramuscular electrodes [1]. Care and maintenance of percutaneous interfaces and electrode reliability are barriers to long-term clinical use of such systems. These issues can be overcome with existing implantable technology.

The overall goal of this project is to develop an implantable FES system to allow individuals with complete thoracic spinal cord injuries (SCI) to stand, walk short distances, and perform household mobility activities with minimal bracing or personal assistance. This can be accomplished with as few as 16 channels of stimulation using readily available and reliable implantable technology originally developed for upper extremity applications [2].

OBJECTIVE

The purpose of this report is to summarize the implementation protocols and initial results from implanting a 16-channel lower extremity FES system in a single test subject. This effort should eventually lead to the introduction of similar systems into the home and community environments in larger scale clinical trials.

Subject AS sustained a low-thoracic SCI resulting in complete T-10 paraplegia in a motor vehicle accident in 1991 at the age of 34. At discharge from rehabilitation he was independent in all transfers and wheelchair function. He is classified as A-complete on the ASIA Impairment Scale with a Motor Score of 52. Although he is self-employed, lives at home with his family, and is independent in wheeled mobility, AS desired to exercise, stand, and step with an implanted FES system.

METHOD

Sixteen channels of stimulation were provided by two CWRU 8-channel implanted receiver-stimulators (IRS-8) and epimysial electrodes with in-lead connectors [3]. Each 8-channel subsystem served the muscles on only one side of the body to eliminate the possibility of lead damage as electrodes crossed midline.

Epimysial electrodes were chosen for the gluteus maximus, posterior portion of adductor magnus, semimembranosus, tibialis anterior (TA), quadriceps, tensor fascia latae (TFL) and

sartorius bilaterally because they could be sutured directly to the muscle fascia. Intramuscular electrodes were used in the erector spinae because of their segmental innervation and lack of a well defined motor point. These electrodes were inserted at the spinal roots to fully activate the nerve trunks innervating the muscles.

In preparation for surgery, AS participated in a two month program of unresisted exercise with surface stimulation to the quadriceps and hip extensor muscles.

APPROACH

The system was installed in two procedures staged to minimize surgical time and trauma. All posterior electrodes were implanted in the first procedure, and anterior electrodes and IRS-8 devices were installed in the second surgery. Each implantation session proceeded from deep to superficial and distal to proximal to reduce the possibility of damaging previously implanted material.

With AS prone, anodes for intra-operative testing were inserted in small flank incisions between the lower rib margin and ASIS. Intramuscular electrodes were implanted at the L2 spinal roots and routed subcutaneously to the flank incisions. Epimysial electrodes were sutured to the posterior adductor and semimembranosus fascia through longitudinal incisions 5 cm distal to the gluteal fold and 5 cm medial to midline on each posterio-medial thigh. The gluteus maximus were implanted through incisions centered between the greater trochanter and the midpoint of a line connecting the coccyx to the posterior iliac spine. Muscle fibers were split and electrodes were sutured to deep tissue near the entry point of the inferior gluteal nerve. Distal leads were passed to the gluteal incisions, and then to the flanks. AS was repositioned on his back and leads were passed from the flanks to connector sites in the abdomen 6 cm above the inter-ASIS line and 3 cm lateral to midline. The anodes were removed and connector pins were capped with silicon sleeves to prevent tissue ingrowth. AS remained on bedrest and restricted activity for two weeks post-surgery.

In the second procedure, anode plates were inserted into subcutaneous pockets located below the connector sites for the posterior muscles (2 cm above the inter-ASIS line and 6 cm lateral to midline). Epimysial electrodes were sutured to the TA through incisions on the anterior-lateral shanks distal to the fibular heads. Quadriceps and sartorius were approached through single incisions on the proximal medial thighs along lines connecting the ASIS and patellae. Incisions on the lateral thighs extending above and posterior to the greater trochanters exposed the TFLs. Leads from the TA were passed to the TFL incisions and all leads were routed subcutaneously to connector sites 4 cm distal and medial to the anode pockets. The leads from the previously implanted posterior muscles were exposed and extracted from the upper connector sites. The anode plates were removed and the IRS-8 devices were inserted. Four leads from each device were channeled to the upper connector sites for the posterior electrodes, and four to the lower sites for the anterior muscles. After connecting and testing all electrodes, the IRS-8s were sutured to the fascia of the anterior abdominal wall and the incisions were closed.

The post-operative course was completed without incident. After one week of bedrest, AS was discharged to home on a program of restricted activity for two additional weeks to allow the implants to encapsulate. He was re-evaluated three weeks after the final surgery.

Threshold and maximal values of stimulus pulse duration were determined with an asymmetrical biphasic charge-balanced wave form at a constant current amplitude of 20 mA and frequency of 20 Hz. Initial exercise patterns were constructed for use with the dual implant system. Exercise consisted of simultaneous bilateral hip and knee extension

with ankle dorsiflexion while supine, and trunk extension with hip flexion while sitting. AS was sent home with an external control unit, coupling coils and charger to complete a five-week course of light exercise with the system.

RESULTS

The proximal components of the dual-implant system are depicted in **Figure 1**. Both IRS-8 devices, the in-line connectors, and an epimysial electrode are visible.

Stimulated responses after five weeks of exercise showed evidence of strengthening effects. Threshold and maximal values of pulse duration were stable and consistent with pre-exercise values. At two months post implantation, the addition of FES to his volitional movement raised the Total Motor Score for Subject AS from 52 to 74.

Because of their medial location, the quadriceps electrodes recruit sartorius and rectus femoris at increased pulse durations, which may compromise standing posture. Similarly, the erector spinae electrodes activate iliopsoas at higher pulse durations. This spillover may augment the hip flexion action of sartorius and TFL to produce stepping motions.

AS will continue rehabilitation in preparation for standing and stepping with the implanted FES system, including progressive resistance exercise, tilt table work, and balance training.

DISCUSSION

This single-subject case study indicates that a lower extremity neuroprosthesis based on reliable and available implantable technology can be deployed successfully. Two 8-channel devices can be implanted and coordinated to produce synchronous movements of the limbs, and initial surgical and rehabilitation protocols have been established that can be refined for larger scale trials.

Stimulated responses of epimysial electrodes in the lower extremity musculature appear to be

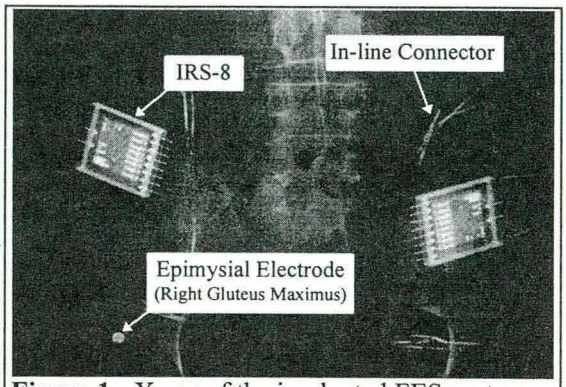

Figure 1: X-ray of the implanted FES system

suitable for exercise and mobility-related functions. A more lateral approach to the quadriceps may be indicated to avoid other structures innervated by the femoral nerve. Performance of the current system during functional activities remains to be determined.

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USING SELECTIVE ELECTRICAL STIMULATION OF THE QUADRICEPS TO IMPROVE STANDING IN PARAPLEGIA

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ABSTRACT

This paper describes the use of selective stimulation of the quadriceps muscles to improve standing function in paraplegia. Intramuscular electrodes implanted in vastus lateralis (VL), and vastus medialis (VM) of five persons with paraplegia were tested for maximum knee extension moment (KEM). The sit-to-stand (STS) maneuver was performed with and without rectus femoris (RF) activation. The effect of RF activation on the quiet standing posture was determined by measuring the forces on the arms and feet. Adequate KEM can be generated for the STS maneuver using one stimulus channel to activate either VL alone, or VL *and* VM simultaneously. While upright, a 6% decrease in load on the arms results when the RF is inactive. Executing the STS maneuver with the RF inactive reduces load on the arms by 8%. These results demonstrate that selective activation of the VL and/or VM to produce knee extension without RF activation can be an effective method for reducing the load on the arms while upright.

BACKGROUND

Standing can be achieved in persons with spinal cord injury (SCI) through the use of functional neuromuscular stimulation (FNS) [1,2]. As in able-bodied individuals, the FNS induced sit-to-stand (STS) maneuver in paraplegia requires significant knee extension moment (KEM) in order to thrust the body from a sitting position into a vertical upright posture [3]. Using the arms for assistance requires unilateral KEM's between 30 and 60Nm [1-3].

Three heads of the quadriceps (the vasti) are uniarticular, while the rectus femoris (RF) crosses both the knee and hip. Nonselective electrical activation of the quadriceps group can therefore produce extension moments about the knee *and* flexion moments about the hip. Using FNS to activate the knee extensors and restore standing function in paraplegia presents a dilemma to the rehabilitation clinician: How does one sufficiently activate the vasti to effect standing, and simultaneously prevent RF activation to minimize hip flexion and upper extremity exertion while upright?

Precise placement of the electrodes on or in the quadriceps group can selectively activate the vasti, and minimize excitation of the RF [4]. Even with judicious placement of the electrodes, however, activation of the RF can occur because at higher stimulus currents or pulse durations (PD), the electric field may spread to RF motor neurons lying close to the target motor point.

Reducing the load on the arms while upright is the primary objective of this study. Selective stimulation to effect knee extension without active hip flexion may be an effective method of reducing the load on the arms while standing with FNS. This study was designed to: 1) investigate whether selective activation of VL and/or VM will generate enough KEM for the STS maneuver, and 2) determine the effects of RF activation on the quiet standing posture.

RESEARCH QUESTIONS

Questions addressed in this study include: 1) Can adequate KEM for the STS maneuver be generated using a single stimulus channel which activates either the VL or VM? 2) Can a bifurcated electrode lead, which splits the stimulus current to simultaneously activate

VL *and* VM, be used to generate enough KEM for the maneuver? 3) What effect does RF activation have on the quiet standing posture? 4) Which paradigm for quadriceps stimulation results in more weight being placed on the feet and less on the arms?

METHODS

Five persons with paraplegia (injury levels T6-T9) volunteered for the study. All 5 are active participants in other FNS studies currently in progress at the Cleveland Veterans Administration Medical Center, and therefore have chronically indwelling percutaneous intramuscular electrodes implanted in VL and VM [4].

In these subjects, the VL and VM electrode recruitment properties were obtained by modulating the PD of charge balanced, asymmetrical, biphasic cathodic pulses at fixed current amplitudes of 10 and 20mA, and a frequency of 20Hz. These properties were obtained with the subject sitting and supine. The absence of RF activity was confirmed by palpating the proximal RF tendon while stimulating the VL and VM.

Using these recruitment properties, the isokinetic (45°/sec) KEM was measured on a Cybex II dynamometer. Three stimulation paradigms were used: VL at 20mA, VM at 20mA, and simultaneous stimulation of VL *and* VM at 10mA to each (bifurcated electrode lead paradigm). In all paradigms, the PD was below that which resulted in RF activation. The 45°/sec angular velocity was chosen since it represents typical paraplegic standing: the knee rotates 90° in the 2 seconds required for the STS maneuver.

To minimize the effects of fatigue, a 33% duty cycle was used (2 sec on, 4 sec off) for the 40 second isokinetic test runs. The analog signal was sampled at 100Hz and digitized for further analysis. The KEM's obtained during the stimulation 'on' times were averaged (n=6).

If adequate KEM (35Nm) for the electrode configuration (VL, VM, or VL *and* VM) was demonstrated, the subject performed the STS maneuver on a force plate (AMTI SGA6-3) using a set of instrumented parallel bars for assistance [5]. Standing was accomplished using 8 electrodes. The target muscle groups were trunk extensors (bilateral surface electrodes on the lumbar erector spinae), 2 groups of hip extensors (bilateral percutaneous intramuscular electrodes in the gluteus maximus, and either the posterior portion of the adductor magnus or hamstrings), and knee extensors (percutaneous intramuscular electrodes in VL and/or VM).

The forces on each arm and both feet were measured during the STS transition and quiet standing. Two paradigms were used to evaluate standing function with and without RF activation: The first had the RF inactive during the STS maneuver, and activated it after 15 seconds, while the second had the RF active during the STS maneuver, and deactivated it after 15 seconds. This RF 'active/inactive' cycle continued while upright to evaluate the posture with and without RF activation. Total standing time was 90 seconds. For data averaging, the STS maneuver with subsequent upright standing was performed 5 times in the course of 1 hour. The 5 trials were averaged for consistency. The analog signals were sampled at 100Hz and digitized for further analysis.

RESULTS

Isokinetic data from the VL and VM show that using a single stimulus channel which delivers a 20mA current at 20Hz (PD's from 9-70μS), to VL, adequate KEM for the STS maneuver can be generated. The bifurcated electrode lead, which uses a single stimulus channel and splits the current (10mA to each muscle) to simultaneously activate VL *and* VM, can also generate adequate KEM for the maneuver. Adequate KEM was not generated using VM alone.

The preliminary results from the standing trials show a 6% decrease in load on the arms while upright with the RF inactive. Executing the STS with RF inactive reduces load on the arms while upright by 8%.

The results from both standing paradigms are summarized below. The data are averaged over the 3 periods of RF activation and inactivation.

STANDING WITH RF:
inactive / active / inactive / active / inactive / active

Weight Distribution (weight = 778N)		
	RF inactive	RF active
feet	67%	61%
left arm	18%	21%
right arm	15%	18%

STANDING WITH RF:
active / inactive / active / inactive / active / inactive

Weight Distribution (weight = 778N)		
	RF inactive	RF active
feet	59%	54%
left arm	22%	25%
right arm	19%	21%

DISCUSSION

Isokinetic testing of both VL and VM demonstrates that using a single stimulus channel to activate VL generates adequate KEM for the STS maneuver. This is consistent with KEM values taken from PCSA and moment arm data in the literature [6]. In this study, activation of RF at higher stimulus PD was the limiting factor in providing maximal knee extension without active hip flexion. It stands to reason that if the larger electric field provided by longer stimulus PD's recruited more VL or VM motor neurons, instead of RF motor neurons, maximal knee extension moments without hip flexion would result. By employing a more effective electrode and/or implantation technique, perhaps load on the arms during the FNS induced STS maneuver could be reduced.

Preliminary results from the standing evaluation suggest that the load on the arms while upright is dependent on the initial state of the RF: If RF is active from the onset of the maneuver, there is more load on the arms while upright. This raises the possibility of hip extensor fatigue resulting from co-contraction at the hip. Improving FNS standing in paraplegia by minimizing loads on the upper extremities while upright would therefore have the RF *inactive at all times.*

From the STS data, it is clear that additional methods need to be investigated which minimize or eliminate load on the arms. One possibility is improving hip extension. If electrically activated hip extensors can hyperextend the hip, the skeletal structure and passive joint moments would enhance the upright posture, leaving the arms free for manual activities.

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SIG-11
Computer Applications

ADAPTIVE ONE-SWITCH ROW/COLUMN SCANNING FOR TEXT ENTRY

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ABSTRACT

This paper describes a one-switch row/column scanning system that automatically adapts its scan rate to measurements of user performance in an effort to increase text entry rate and limiting errors. Empirical results indicate that automatic adaptation has the potential to enhance communication rate without a concomitant increase in task complexity.

INTRODUCTION

Row-column scanning is a very slow method of communication. An able-bodied individual using an optimally-designed matrix of 26 letters and a space can produce between 6 and 8 words/minute using this method (Koester and Levine, 1994). One method for increasing text entry rate with row-column scanning is to dynamically change the configuration of the matrix of items (letters, punctuation marks, words, etc.) to reduce the number of scan steps required to reach the most likely selections. Another alternative is the use of a rate-enhancement technique such as word prediction or abbreviation expansion. However, recent work indicates that the increased cognitive load these methods impose on the user may result in little or no improvement in text generation rate (Demasco, 1994; Koester, 1994). An alternative that has not been fully explored is the possibility of increasing a user's text entry rate by dynamically adapting a system's scan delay during run-time.

Cronk and Schubert (Cronk and Schubert, 1987) represents an early attempt to automate the selection of row/column scanning parameters. An expert system was developed that, given a set of user characteristics, would usually make the same scan delay settings as a panel of three speech/language pathologists. The system was developed as an assessment tool rather than an on-line adaptation mechanism, so its ability to adjust system parameters during use was not examined.

Our research differs from this previous work in two respects. First, we are exploring mechanisms to adjust system parameters "on the fly" as opposed to setting parameters during a separate assessment period. Second, the underlying reasoning method used to make decisions in our work is a probabilistic reasoning technique known as Bayesian networks (Charniak, 1991). Bayesian networks can be thought of as a means of organizing information to allow the convenient application of a form of Bayes' theorem:

$$P(\mathbf{H}|\mathbf{e}) = P(\mathbf{e}|\mathbf{H})P(\mathbf{H})/P(\mathbf{e})$$

where, in an adaptive row/column scanning system, **H** represents the choice of increasing, decreasing, or maintaining the current scan delay, **e** is a set of measurements of user performance, and the value of the probability $P(\mathbf{H}|\mathbf{e})$ represents the probability that performing a particular action (for example, increasing the scan delay) is the correct decision given the evidence presented to the Bayesian network.

IMPLEMENTATION

Figure 1 shows the Bayesian network used in this research. This network is implemented within a one-switch row/column scanning system that has one scan delay for both rows and columns with no additional delays before the first row or column. The system presents subjects with a fixed matrix of letters and punctuation marks. The sentence the subject is expected to transcribe is displayed on-screen beneath the matrix. The characters entered by the subject are shown beneath the target sentence.

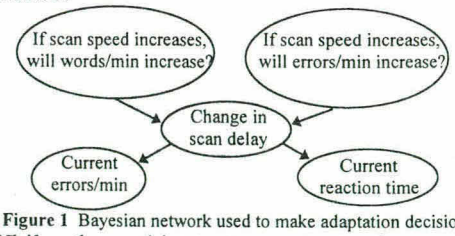

Figure 1 Bayesian network used to make adaptation decisions.

While the subject enters text, the system records performance data for a predetermined time interval. At the end of each interval, the Bayesian network uses the recorded information to decide (1) whether to raise,

lower, or maintain the current scan delay, and (2) how big a change (if any) should be made. This process of recording data for an interval of time and then making an adaptation decision is repeated continuously during use.

RESEARCH AIMS

The goal of the experiment described below was to empirically evaluate the Bayesian network's performance. The two questions of primary interest to us were: (1) What effect did the Bayesian network have on user performance relative to a non-adaptive row/column scanning system? and (2) How well did the network's behavior correspond with user's expectations?

METHODS

Eight able-bodied subjects (two male, six female) participated in an experimental evaluation of the Bayesian network. Subjects were randomly divided into two groups based on whether the row/column scanning system did (condition AA) or did not (condition NA) automatically adapt the scan delay during trials. Three measures of the subject's performance were recorded during the experiment: *timing errors* (every occasion in which the subject pressed the switch at the wrong time), *missed errors* (every occasion in which the subject let the highlight scan past the target row or column), and *adjusted text entry rate* (the ratio of correct column selections to total time).

The structure of the experiment was the same for each subject regardless of experimental condition. Each subject had an initial scan delay of 750 msec. Each subject first completed three one-sentence "warmups." Subjects then completed four four-sentence trials, with a warmup in between each trial. After every trial and warmup the subject was given the opportunity to adjust the scan delay. Subjects were allowed to reduce the scan delay after a warmup or trial only if timing errors were less than 5% of total selections and the number of missed errors was less than 10% of total selections. The only difference between conditions was that, in the AA condition, the Bayesian network was active during trials. The network made a decision after every 30 seconds of a trial whether or not to increment or decrement the scan delay. All adjustments (either up or down and either made by the subject or the Bayesian network) were made in 25, 50, or 75 msec increments.

Two performance measures were compared between conditions: *total errors* (the sum of timing errors and missed errors) and adjusted text entry rate (ATER). Two analyses were performed. First, the data for each measure from all four trials was compared between conditions using an ANOVA with a between-subjects factor of adaptation condition and a repeated measure factor of trial. Second, the data for each measure from trial 4 alone was compared between conditions using a standard t-test. A significant difference was defined as one whose p-value was less than .05.

RESULTS

As expected, ATER (Fig. 2) increased over trials as subjects gained proficiency with row/column scanning. The difference between conditions was not significant either over all four trials or for trial 4 alone. There was a significant effect for trial.

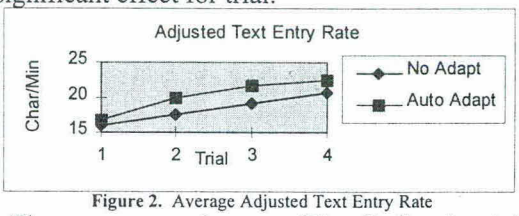

Figure 2. Average Adjusted Text Entry Rate

The average total errors (Fig. 3) for the AA condition dropped over the course of the experiment but rose for the NA condition. However, the effect of trials was not statistically significant. The difference in total errors between conditions, both over all four trials and for trial 4 alone, was not statistically significant.

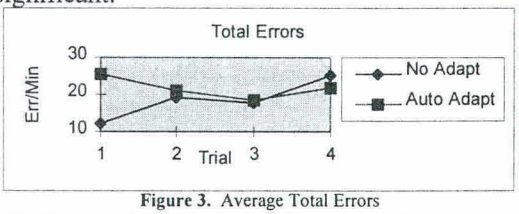

Figure 3. Average Total Errors

Subjects from both experimental groups changed the scan delay by approximately the same amount (-116.67 for group NA, -106.25 for group AA) during the warmup period before Trial 1. The Bayesian network reduced the scan delay (based on the difference between the initial and final scan rate) by an average of 25 msec per trial for those subjects in the AA group. This made up slightly less than half of the total average adjustment made per trial by group AA. The total adjustment made per trial (the sum of average change during a trial and average change following that trial) for the two

experimental conditions was almost identical (-52.08 msec for group NA, -60.42 msec for group AA).

Grp	Avg Change in Scan Delay Before Trial 1	Avg Change During Trials by Bay. Net.	Avg Chng Between Trials by Subjects
NA	-116.67 msec	0.00 msec	-52.08 msec
AA	-106.25 msec	-25.00 msec	-35.42 msec

Table 1. Scan Delay Adjustments Made by the Human Subject and Bayesian network

Following the experiment, each subject in group AA was asked to rank how often they agreed with the adaptation decisions made by the system from 1 (never) to 10 (always). The average score from all four subjects was 7.65.

DISCUSSION

Figure 4 shows how the Bayesian network adjusted the scan delay during one trial for one subject in group AA. The Bayesian network often increased the scan delay in response to increased errors rose and decreased the scan delay after intervals in which no errors occurred. However, because the subject's reaction time, as well as past performance measures, were also used to select an action, neither response was guaranteed.

During the experiment the Bayesian network shared the parameter adjustment task with test subjects, which reduced, but did not eliminate, their need to make manual adjustments on their own. The Bayesian network did not confer any performance advantage upon users, but also did not decrease performance, either. The near-identical performance of both groups indicate that the adaptation expert was not aggressive enough in terms of adjustments to the scan delay. The adaptation expert often made the correct decision in terms of which direction to adapt the scan delay, as indicated by subjective rankings and lack of difference in performance measures, but did not make large enough adjustments, as indicated by the large average between-trial adjustment by members of the AA group.

The primary advantage of the adaptive row/column scanning system is that it attempts to increase text entry rate without complicating the visual display. This implies that dynamically adapting the scan delay should impose less additional cognitive load upon the user than other rate enhancement techniques (e.g., dynamically reorganizing the scan matrix and word prediction). It is unclear whether performance between groups would have been so similar if trials had been longer or subjects had not been given so many opportunities to manually adjust the scan rate. Future work is planned to refine the Bayesian network and test its performance in text-entry tasks (1) of longer duration and (2) with actual row/column scanning users.

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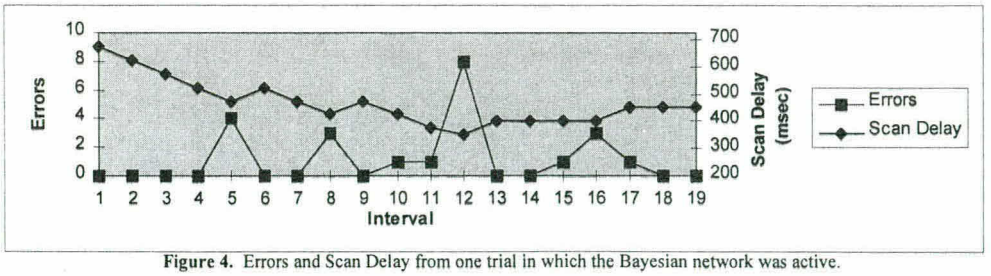

Figure 4. Errors and Scan Delay from one trial in which the Bayesian network was active.

IMPROVEMENT IN COMPUTER CURSOR POSITIONING PERFORMANCE FOR PEOPLE WITH CEREBRAL PALSY

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ABSTRACT

This paper contains the results of a preliminary exploration into the improvement of cursor positioning performance for people with cerebral palsy. The positioning performance of several subjects with cerebral palsy (CP) when using a standard mouse is compared with their performance when using an isometric device. This work is part of an investigation into the differences between isotonic and isometric activity by people with CP.

BACKGROUND

With the dominance of Windows™ and related operating systems, the computer mouse has become a critically important computer input device. Windows' heavy reliance on cursor movements for basic actions like icon selection, scrolling, desktop management, and a host of other activities has made the mouse an essential device for almost all computer applications. The spasticity associated with cerebral palsy makes it extremely difficult, if not impossible, for many people with CP to use a mouse, and thus they face great limitations when using most current software applications.

Previous work on the motor control abilities of people with CP had suggested that some of their spasticity might be related to the velocity of their movement; that is, some spasticity might arise solely from the motion of the limb in question, not from the muscle contractions themselves.[1] Since the mouse is an *isotonic* control device (relying on movement for control), it has been postulated that the cursor control of a person with CP might be improved if an *isometric* control device (relying on force, without movement, for control) was used instead of the mouse. Accordingly, a project was undertaken to explore the possibility of improving computer cursor positioning performance through the use of an isometric device.

RESEARCH QUESTIONS

The primary goal of this study was to determine whether a person with CP could improve their cursor positioning performance by using an isometric input device rather than a mouse. A secondary goal was to explore the issues (practical implementation, optimal device design, etc.) associated with the use of both devices by people with CP.

METHOD

Five subjects (hereafter subjects A - E) participated in the study; the ranking of the subject's letter reflects the degree of their CP (i.e., subject A was the least affected, subject E the most). The five subjects consisted of three females (subjects A, B, and D) and two males (subjects C and E). Every subject except for subject A required a wheelchair for mobility.

An experimental program was developed which required each subject to control the computer cursor, using it to move a small box across the screen and position it within a larger box. This positioning task had to be completed in less than thirty seconds. Each subject participated in a single session that required them to attempt between twenty to fifty (depending on their abilities) of these tasks with each device. In addition, because of her more extensive abilities, subject A was chosen to participate in

an additional five-week long study which involved weekly work with one-hundred isometric tasks and periodic work with isotonic tasks. For the one session study, performance was evaluated by comparing the number of tasks successfully completed with each device. For the five-week study, long-term changes in task completion time were also analyzed in order to provide a quantitative measure of performance improvement.

The Spaceball *Avenger*, a force-sensing, tennis-ball shaped device marketed by SpaceTec Corp., was chosen as the isometric input device. In order to make it more usable by people with CP, the exterior housing was redesigned so that it could sit on a desktop, and it was equipped with a handheld button for use in selecting (like the left mouse button). The forces registered by the device during the experiment were scaled by a configurable transformation matrix and converted into cursor velocities on the screen.

RESULTS

Subjects D and E were unable to use either the mouse or the *Avenger*, because their spasticity kept their upper limbs in a flexed position, and thus they had difficulty utilizing objects on the desktop. Furthermore, along with subject B, they exhibited flexion contractures in their hands which prevented them from gripping either the *Avenger* or the mouse.

Subject C did not exhibit severe tremors; instead, his movements were extremely slow and somewhat uncoordinated. He was able to use both the mouse and the *Avenger*, but his movements were so slow that he became bored with the experiment very quickly and only completed a few tasks, thereby making any significant data analysis impossible.

Subject B exhibited both tremors and athetotic movement. She was unable to grip the *Avenger* and instead used her finger to push the ball in the desired direction. She used both the *Avenger* and the mouse, but completed only five of twenty-four tasks with the mouse while completing eighteen of those same twenty four tasks when using the *Avenger*. She expressed a marked preference for using the *Avenger*.

Subject A exhibited severe tremors and some athetotic movements, but she was able to partially grip the *Avenger*. She completed only thirteen of thirty-three tasks with the mouse but thirty of thirty-three tasks with the *Avenger* (even though twenty of these tasks were more difficult than the respective mouse tasks).

Because subject A was able to partially grip the *Avenger* (unlike subject B) and thus use the device without constantly moving her hand, she was chosen to participate in the extended, five week study. Over the course of the five weeks, subject A was able to reduce the time that she took to complete the tasks when using the *Avenger* (Figure 1). The underlying source of these improvements has yet to be determined.

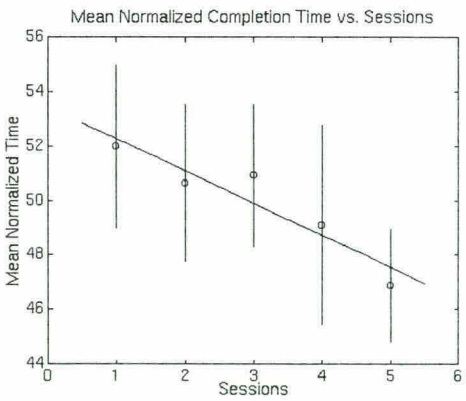

Figure 1. Mean completion time vs. Sessions. The error bars indicate ± 2x the standard error

In addition to the examination of task learning with isometric control, the study also allowed time for more work with the mouse, thereby shedding light on the causes of some of the difficulties experienced by subject A when using the mouse. First, it was noted that when the

subject attempted to "click" with the mouse button, her tremors often caused her to inadvertently knock the mouse out of position, forcing her to reacquire the target. Although she was able to improve her performance by using the handheld button developed for the modified *Avenger* rather than using the mouse button, she still exercised better positioning control with the *Avenger*. Figure 2 contains trace plots of subject A's cursor movements for one task when using the mouse and then when using the *Avenger*. The marked difference in the

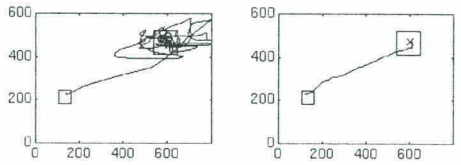

Figure 2. Trace plots of cursor movements with (a) the mouse and (b) the Avenger (coordinates in pixels).

complexity of these cursor paths is typical of the differences that appear when comparing subject A's other trace plots for the two devices, thus indicating that subject A was able to exercise better positioning control with the *Avenger*. However, it was later noted that the subject had difficulty keeping the mouse in the proper orientation in the horizontal plane, which may have also affected her performance.

DISCUSSION

For the subjects who exhibited tremors and athetotic movements, the isometric *Avenger* was undoubtedly a better cursor position control device than the mouse. In light of mouse design issues revealed in the extended study, it is not yet determined whether the performance difference resulted from the difference in isometric control versus isotonic control or simply from the awkwardness of the mouse as a control device for people with CP.

From a practical viewpoint, though, isometric control may be better than isotonic control for people with CP. Unlike isometric control, isotonic control requires a large workspace, especially since the device sensitivity must be set as low as possible in order for a person with CP to utilize the device effectively. For example, subject A, who had the best motor control abilities, frequently ran the mouse off the table or into other objects on the desktop (although a space about 2' wide and 1 1/3' deep had been cleared); moreover, it was observed that she had difficulty repositioning the mouse once this had occurred. Isometric devices, on the other hand, do not require a very large workspace. This issue of workspace size is extremely important for people with CP since many of them (like subjects D and E) are subject to flexion contractures that limit the effective range of their motion.

In light of this study, it is clear that the performance of computer cursor positioning tasks by people with CP can be significantly improved by using the isometric *Avenger* rather than the isotonic mouse. Although a redesigned isotonic device may result in improved performance, if a control device is to be designed for use by a wide segment of the population with CP, it seems that the device should utilize isometric control.

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LAPTOP COMPUTER-BASED SYSTEM FOR COMMUNICATION, ENVIRONMENTAL CONTROL, AND COMPUTER ACCESS VIA SINGLE-SWITCH ACTIVATION

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ABSTRACT

This case study details the development of a laptop computer system for communication, environmental control, and computer access for a patient able to operate only a single switch.

BACKGROUND

The subject sustained a C-5 level spinal cord injury in a diving accident 6 months prior to commencement of this project. Surgery for decompression and stabilization of the original injury resulted in hemorrhaging and ascent of the injury to C-1/brain stem level. The patient was cognitively intact but suffered from what is commonly called "locked-in syndrome". He was able to hear and see but was unable to speak; motor function was confined to blinking, up/down gaze of the eyes, and some eyebrow and mouth movement.

After several months of rehabilitation, the patient achieved ventilator independence for 12 or more hours during the day and was able to sit at a 60° angle in a manual tilt-in-space wheelchair (LaBac Corp.). With inadequate volitional ventilatory drive and poor visual field, the subject was not a good candidate for sip-puff control of a power wheelchair. Communication was limited to yes/no responses given by an up/down gaze of the eyes and some spelling using a handwritten alphabet board, oral interrogation of a scanning nature, and the up gaze of the eyes. To facilitate communication, an Eyegaze Computer System (LC Technologies, Inc., Fairfax, VA) was purchased. The system incorporates a video camera, speech synthesizer, and scanning software. Speech synthesis is triggered when the user's gaze dwells on a target area of the computer screen for a fixed duration. This solution proved unsatisfactory since the subject was unable to maintain a stationary gaze for sufficiently long periods of time and with adequate reproducibility to successfully operate the system. A further review of commercially available speech systems revealed no suitable alternative. Generally, the speaking systems operable by single switch activation: 1) were designed for children, 2) were limited to preprogrammed words and phrases, 3) required manual intervention to modify the library of phrases, and/or 4) used a display too small for the subject to see. Hence, the decision was made to create a proprietary speech system using C++ object-oriented programming.

OBJECTIVES

The primary purpose of this endeavor was to develop a speech system operable by a single switch, using sufficiently compact hardware to mount on the subject's wheelchair. The system was to be entirely mobile and, to the greatest extent possible, configurable by the subject himself. Secondary objectives were to add word processing, general computer access, and environmental control capabilities to the system.

METHODS

Speech Software

On startup, the software scans options to 1) send a stored phrase to the speech synthesizer, 2) construct and "speak" a phrase using a spelling board, or 3) execute changes to the speech system.

Stored phrases are grouped in categories according to subject matter. For example, a category called "CONVERSATION" may contain phrases such as "Thank you for coming to visit" and "How have you been?" Each category lists an "EXIT" phrase which is not spoken upon selection but returns scanning to the initial menu of options.

To construct new phrases, the software provides for scanning of an alphabet board. A phrase is constructed letter by letter on the screen and is sent to the speech synthesizer when a period or question mark is selected. At the subject's request, the layout of the computerized alphabet board was made to resemble the handwritten one used previously. It also includes selections for deleting the last letter chosen (i.e., backspace), deleting the last word of the phrase being spelled, or deleting the

entire phrase (i.e., starting over). The spelling board employs a word prediction algorithm using a customized dictionary stored on the hard drive. As the user adds letters to a phrase under construction, the software makes available at the top of the board whole word selections having the same initial letters as the word being spelled. Each time the user exits the alphabet board, he has the option to save for future use the phrases he has just constructed. All phrases, saved or discarded, are parsed into words with new words added to the dictionary.

User-initiated changes to the system include increasing/decreasing the scanning rate, deleting words from the dictionary, renaming phrase categories, and reorganizing the phrase book. The alphabet board is used to spell out words to be deleted from the dictionary as well as new titles to be assigned to phrase categories. The user may reorganize the phrase book by selecting a given category of phrases. The phrases in that category are presented one at a time with scanned options to delete the phrase, leave the phrase unchanged, move the phrase to a different category, or stop editing. Electing to move a phrase causes existing category names to be scanned for a destination. All changes to the system of a destructive nature (i.e. deleting words or phrases) are followed by an "Are you sure?" prompt.

The speech software was initially implemented on a 486 desktop computer. Given the subject's vision impairment, it was necessary to experiment with a variety of text positions, fonts, and colors as well as positioning of the monitor and subject to arrive at a configuration in which the subject was consistently able to read the contents of the screen. (For maximum flexibility, the software scans language elements as text strings not icons.) Once an appropriate switching mechanism was found, the subject was able to produce coherent "speech" after minimal instruction. He showed little initial interest in the system's stock phrases, gravitating instead toward the alphabet board. One of the first phrases constructed expressed a desire to "write letters".

Migration of the speech software to a laptop environment required minimal modification.

Laptop System Components

The complete system consists of: a Dell Latitude LM P1331ST laptop computer (Dell Computer Corp., Austin, TX), DECtalk Express speech synthesizer (Digital Equipment Corp., Marlboro, MA), PROXi environmental control unit (ECU; Madenta Communications Inc., Edmonton, AB, Canada), ComrAd wireless data link (Communications Research & Development Corp., Indianapolis, IN), WiViK2 Scan scanning access software for Windows (Prentke Romich Company, Wooster, OH), and the proprietary speech software described above. The Dell Latitude computer was selected for its 12.1" active matrix display and dual battery operation rated at 6-10 hours. The laptop came equipped with one serial and one parallel port; a second serial port was added via a Socket I/O PCMCIA serial card (Socket Communications, Hayward, CA).

The speech synthesizer was attached to the built-in serial port of the laptop computer. The "host" unit of the wireless data link was attached to the RS232 port of the ECU's base unit. The "remote" wireless unit was connected to the laptop's second serial port, thus enabling wireless environmental control. Switching for all scanning software was accomplished by interfacing a simple mouth switch to the parallel port. The subject is able to use his mouth to depress a small plastic disposable pipette connected to a pressure sensor (World Magnetics) via plastic tubing encased in flexible conduit ("gooseneck").

The laptop, speech synthesizer, and remote unit of the wireless data link are battery powered, have a combined weight of 9 lb. and a combined footprint of 156 square inches. The laptop, speech synthesizer, and remote unit of the wireless data link were attached by Velcro to the platform of an adjustable monitor arm which, after minor modifications, was affixed to one backrest cane of the subject's wheelchair. Since the monitor arm is adjustable in all dimensions, it facilitates positioning of the laptop display for optimal viewing by the subject. A strip of Velcro was placed around the perimeter of the monitor arm platform to allow repositioning of the remote unit of the wireless data link, if necessary, to yield the clearest transmission path to the host unit. The mouth switch conduit was clamped directly to the monitor arm. Thus, all hardware forms a single unit which may be rotated away from the subject and behind the wheelchair backrest when not in use.

On start up, the laptop immediately launches Windows 3.1 and a custom WiViK

scanning "keyboard" ("Main Menu" keyboard). The "Main Menu" keyboard presents the user with options to: 1) access the proprietary speech software, 2) interact with Windows applications, and 3) control devices through the ECU.

Windows Software

Using a standard WiViK keyboard, the user may launch and operate any Windows application. However, since the subject is known to be particularly interested in word processing and computer games, main menu options were provided for these activities. When the "Word Processing" key is selected from the main menu, Microsoft Word is launched in full screen mode and control is passed to a standard WiViK keyboard to allow manipulation of Word documents. Similarly, when the "Solitaire" key is chosen from the main menu, the game application is launched in full screen mode with control passing to a WiViK keyboard devoted primarily to control of the mouse. Both the standard keyboard and mouse control keyboards include keys which return control to the "Main Menu" keyboard.

Environmental Control

Submenus of environment control options are presented to the user via custom WiViK scanning keyboards. Operating devices with infrared remote controls (television, VCR, stereo, CD player); turning on or off appliances connected to the ECU through X10 modules (lamp, radio, fan); and using the ECU's built-in speaker phone are all possible by single-switch selections from the appropriate scanning keyboard. A macro is assigned to each key of the scanning keyboard which activates the ECU control software and sends to it the appropriate ASCII command sequence. Each ECU keyboard includes a key to resume scanning of the "Main Menu" keyboard.

RESULTS

The hardware and software components described above were successfully integrated into a system to provide speech synthesis, environmental control, and access to Windows 3.1 applications via activation of a single switch readily controllable by the subject. The system is designed to require little outside intervention, specifically: power up/down of battery operated components, periodic recharging/replacement of batteries, placement of the switch pipette in the subject's mouth, and positioning the laptop display (as well as the subject himself) for subject's best visibility.

DISCUSSION

C++ programming with its user-derived objects (data structures) was particularly well suited for implementing the speech system. Each phrase in the phrasebook and each word in the dictionary is an object (a "WordEntry") consisting of a character string (the word or phrase itself) and an integer value. The integer value indicates frequency of use and is incremented each time the associated phrase is spoken or the associated word spelled. Several WordEntry objects were grouped in lists to make up a dictionary or phrasebook. Each time the phrasebook or dictionary is saved to the hard drive, the WordEntry objects are sorted by their integer values. In this way, the lists may be scanned sequentially while ensuring that the user is presented with more frequently used words and phrases first. In addition, since the C++ language possesses significant functionality for list processing (writing/reading to/from files, sequential scanning, adding/deleting list members) and the programmer is able to define new functions for manipulating large collections of information as individual objects, coding is quite efficient. (A fairly powerful speech system was implemented using fewer than 2,000 lines of code.) These factors combine to produce a system that is quite dynamic. Addition of new words, phrases, and categories of phrases is limited only by the size of available memory. Since language elements are easily manipulated, the software facilitates the user's ability to structure his own environment for speech in a way that serves him best.

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EVALUATION OF AN ISOMETRIC JOYSTICK AS AN INTERFACE DEVICE FOR CHILDREN WITH CP

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ABSTRACT

Humans are increasingly interacting with machines, especially computers, through various interface devices. This has led to an increase in research on various aspects of human-computer interactions especially related to the design and implementation of effective interface devices. Although several researchers have done work on various aspects of human motor control by analyzing different input devices concentrating mainly on adult subjects, few have evaluated the use of different input devices on preschool children with disability. The present study investigates the interactive effects on the use of a force (isometric) joystick with preschool children, and attempts to model their behavior in target reaching tasks under different control-display gain settings. Our findings show that a force joystick can be used as an effective input device.

BACKGROUND

With the increasing use of computers with a menu based environment, the operator often needs to use different positioning devices like a mouse or a joystick in order to reach and select a position on the screen. The act of pointing and selecting depends upon the speed and accuracy of the user's movement, which in turn depends on the type of interface device being used. Although able body subjects accomplish point/select task using standard input devices, subjects with cerebral palsy have difficulty in accomplishing similar tasks using these devices.

Several researchers have evaluated human performance using various input devices. Card et. al. (1) compared movement time using different cursor devices in order to find the optimum interface for a target acquisition task, and found that the rate controlled joystick performed worst while the mouse was superior. Stewart et. al. (4) analyzed both isometric and position joysticks on preschool children who use wheelchairs, and propose the use of an isometric joystick as an alternate input device. Kim et. al. (2) have found that a position control joystick performed superior to rate control regardless of joystick type, gain and display mode for a small work space. McGill et. al. (3) have shown improvement in tracking performance when individuals with cerebral palsy and intention tremor used an isometric joystick as the interface device.

OBJECTIVE

In order to have a thorough understanding of the complex interrelationships between man and machine several researchers have done performance studies, mostly, on adult human subjects in their target reaching abilities using various devices.

This work was driven by the shortage of in-depth knowledge of the fundamental principles in the use of interface devices by children, which has led to either rejection or grudging use of these devices. Our aim is to investigate the use of isometric joystick as a potential input device for children with disability in their interaction with the outside world at the preschool age. In using an isometric joystick the limb displacement, and hence muscle length, does not change, making it easier to understand movement control. In addition, the cues associated with the motion are absent. Non-disabled subjects, because of their

inherent coordination between displacement, forces, and the activity of involved muscles performed better than subjects with disability, where this coordination is missing.

Finally, our objective is to model the human-device interaction on the basis of performance of positioning tasks.

METHOD

Subjects Four preschool children without disabilities and three children with disabilities participated in the experiment. All three subjects had quadriplegia with different degrees of disability. They had no prior experience in the use of a joystick either on a computer or on a wheelchair. The tests were performed in a quiet room in a school environment, with the subject comfortably seated in a chair.

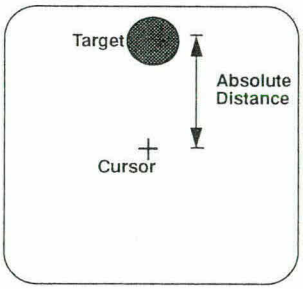

Fig. 1 View of display screen.

Procedure

A position controlled force joystick was used for interaction with a computer by both able bodied as well as by the motor-impaired subjects. The force joystick, instrumented with strain gages was interfaced to the computer, and the displacement of the cursor was programmed to correspond to the magnitude and direction of the force applied. The test protocol involves reaching a single target with the cursor (Fig. 1). The cursor is initially located at the center of the screen which corresponds to zero force on the joystick. Targets appear in 3 different sizes, 1 in., 0.75 in., and 0.5 in., at 3 different distances, 1 in., 1.9 in., and 2.9 in., in 8 different directions under 3 different control-display gains. Control-Display gain refers to the relationship between the magnitude of the force and the magnitude of cursor displacement. In each session, only one target appears at one location at a fixed distance from the center, under a particular control-display gain. The subjects were given practice trials to familiarize themselves with the experimental setup. A similar setup was used for testing with a rate-controlled displacement joystick from Kraft Inc.

RESULTS

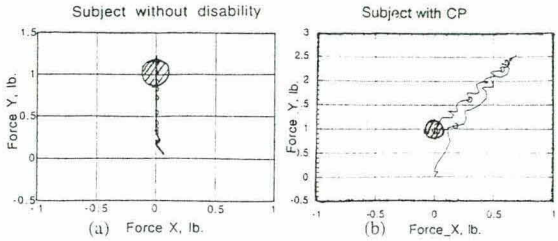

Fig.2a Trajectory of the cursor movement in reaching a 0.75 in. target located in the North direction by able body subject, **Fig.2b** Similar task done by the subject with CP.

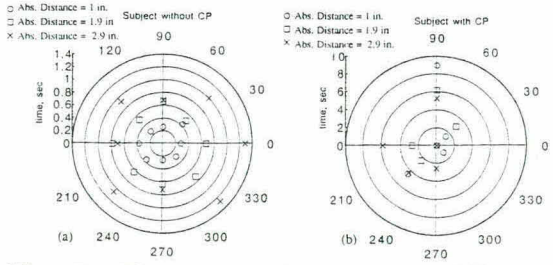

Fig. 3a Time to reach targets at different distances, located in 8 directions by able body subject, **Fig. 3b** Similar task done by subject with CP

For each subject, the following variables were computed:

1. Reach Time (sec): Time taken to move the cursor from the home position to successfully reach the target.
2. Instantaneous velocity (in/s) of the cursor on the screen.

3. Total Distance (in): Total path distance taken to move the cursor from the home position to final position.
4. Average speed (in/s): Total Distance over Reach Time.
5. Percentage Distance Error: ratio of difference between Total Distance and absolute distance over absolute distance.

DISCUSSION

Comparison of results shows that, while able body subjects can apply force, and successfully acquire targets appearing in all directions and at different distances, subjects with disability had difficulty reaching targets in certain regions (Fig. 3). This shows that they had limited ability in applying a controlled force in a particular direction, which maybe indicative of their neuromuscular limitations. The 'Percentage distance error' was much higher in subjects with CP than the non-disabled subjects because these subjects did not approach the target directly (Fig. 2). In their effort to acquire the target they exhibited primitive control pattern. Thus subjects with CP traversed a larger 'Total distance' resulting in higher 'reach time' as compared to able body subjects.

The time taken to reach a target was consistently shorter under higher 'joystick force to cursor displacement' gain. There was no significant difference in 'reach time' in approaching different size targets.

The performance with the rate-controlled joystick was far worse than the isometric joystick, in fact subjects with disability were unable to acquire the target with the rate-controlled joystick.

The knowledge derived to date advances our understanding of children's ability to operate an isometric joystick as a control interface. Further work on this research is currently in progress.

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Usability of World Wide Web Browsers by Persons with Visual Impairments

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ABSTRACT

The results of this study indicates the World Wide Web (WWW) has significant barriers to persons with visual impairments. The study compared performance of four visually impaired with four matched able bodied subjects on five WWW related search tasks. It took the visually impaired subjects almost 3 times longer to access WWW pages the first time they use the page. After the fourth session the performance difference was about 2 times longer. One task of accessing information from a HTML formatted table was impossible for most of the visually impaired subjects to access even after the fourth session.

BACKGROUND

One of the main issues facing persons with disabilities is access to the WWW and other information technologies. There is serious concern over current accessibility of the WWW and design guidelines are being developed to improve the accessibility of the WWW (1,2,3). The study presented in this paper was conducted to quantitatively determine the magnitude of the problem faced by persons with visual impairments accessing the WWW.

RESEARCH QUESTION

The purpose of this research is to study the accessibility of WWW browsers by people with visual impairments, and how they use browsers for completing search tasks through different types of HTML formatted documents. The main question of interest is to identify completion time and behavior differences between persons with visual impairments and their able body peers.

METHOD

In this study, subjects are asked to perform search tasks on the WWW in a series of four sessions, with six tasks per session. These tasks are performed using NCSA Mosaic version 2.0 for Windows 3.1. Sessions are recorded using a direct video feed and microphone, so the images on the monitor and all sounds in the room are recorded onto videotape. The six tasks for each session are counterbalanced across subjects and sessions. Statistical tests can only control type II error to $p < 0.0625$ due to the small sample size (4 subject pairs). All statistical tests we based on the binomial distribution of probable outcomes.

Subjects

The subjects consisted of a test group of four persons with severe visual impairments and a matched control group of abled bodied persons with normal vision (20/20). Subjects are matched by academic major or type of employment, age, and level of computer experience. Two pairs of subjects are female and two pairs are male. Two pairs of subjects had no experience with WWW browsers prior to participation in the study. One pair of subjects was composed of experienced computer users who used Web browsers regularly prior to participation in the study. One pair was composed of expert computer users who use Web browsers extensively and have written and maintained Web pages. Subjects received no monetary compensation or class credit for participation.

Tasks

For each of the four sessions, the subjects were asked to perform five tasks. Each set of tasks was presented on a Web page that the subject returned to throughout the session. Each set of tasks was of similar structure with slightly different content. The following are descriptions of the types of tasks used in the study:

Task 1: Involves using the Yahoo™ search engine to find a piece of information. Using search engines is a common activity among people who use Web browsers and is an important skill in using the Web effectively. This task looks at how effectively the subjects

perform keyword searches.

Task 2: Involves using the Internet Movie Database to look up the year of birth of a specified actor or director. The purpose of this task is to explore how effectively the subjects are able to use forms.

Task 3: Involves finding a picture of a cast member using the Seinfeld homepage. The Seinfeld pages feature a number of graphics and icons.

Task 4: Involves using the Home Automation Catalog to find a price for a specified product. For this task, the subject has the option of navigating graphic or standard links, or using a search form.

Task 5: Involves using a HTML formatted table of course listings to find information on a specified course.

Procedures

In an orientation session, the investigator introduces the subject to the NCSA Mosaic Web browser. If the subject has a visual impairment, the browser is configured for the subject, adjusting text size and text and background colors. In each of the four test sessions, the subject is given a review of the orientation material. The subject is then shown a WWW page containing a set of six tasks. The subject is asked to follow the instructions given on the WWW page using the underlined links to perform each task. The sessions are videotaped for later analysis.

RESULTS

Session Performance by Group

For each matched pair of subjects a percent differences score was calculated, with the time of the abled body subject for each pair used as the basis for the percentage. The formula used to calculate the percent differences is (TVI - TAB) / TAB. Figure 1, Percent Difference of Session Times shows that the combined percent time difference per session between the AB group and VI group is 143% in the first session but that number decreases steadily with each subsequent session to 70% in the last session. In short, the V subjects were significantly slower for overall average performance difference ($p < 0.0625$) and for performance differences during sessions 1, 3 and 4 ($p < 0.0625$) as a group than the AB subjects. For pairs 1 and 4, the novices, the gap seems to narrow as they became more experienced. For the experienced Pair 2, and expert Pair 3, there is not a clear trend. Note that the highest session percent difference (750%) was seen with Pair 3, the expert computer users, in Session 1. In Session 2, the only case occurred in which a VI subject completed a session in less time than the corresponding AB subject. This occurred with Pair 3, the expert users.

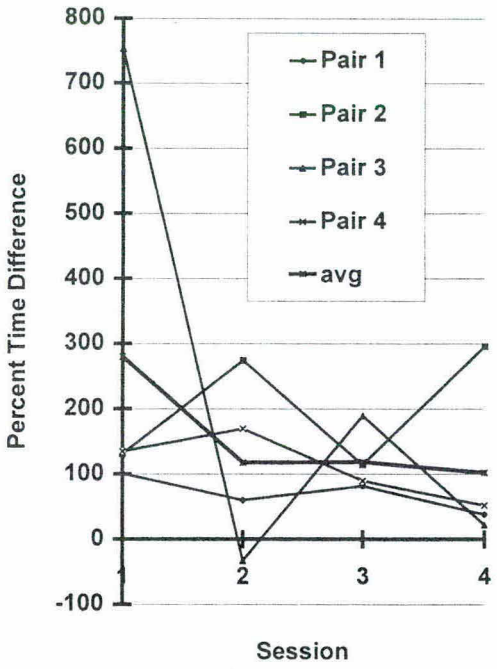

Figure 1: Percent Difference in Total Completion Time by Session

Task Time by Group

Figure 2 shows the average Percent Time Difference Between Pairs for each task. There are significant differences between the subject airs for sub tasks 1, 2, 3 and 5 ($p < .0.0625$). From the mean values it can be seen that for tasks 1, 2 and 3 percent differences are fairly consistent with the visually impaired subjects

taking 139, 140%, and 218% more time the matched sighted subjects. The task with the smallest performance difference of 55% occurred in Task 5. The largest percent difference of 1075% occurs in Task 6, (involving the HTML formatted table of course listings) . The percent differences for Task 6 range from 343% (Pair 2) to 2459% (Pair 3). Demonstrating that the table lookup task was trivial for the sighted subjects, but almost impossible for the visually impaired subjects.

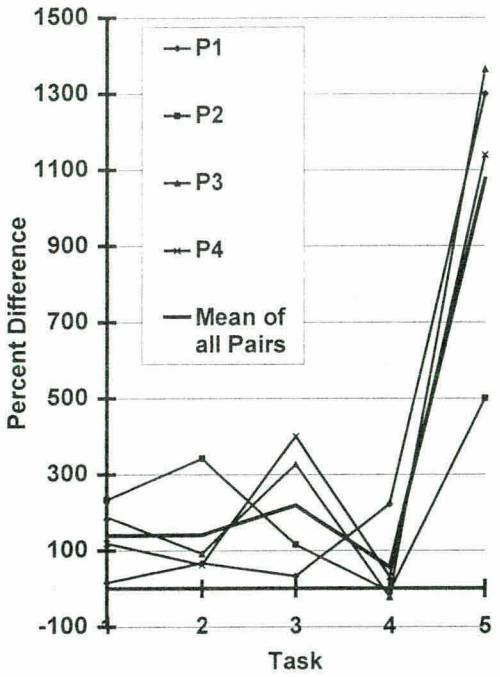

Figure 2: Percent Difference in Completion Time by Task

DISCUSSION

The results of this study indicate that there are significant barriers to persons with low vision to access the WWW. Persons with visual impairments do improve their performance with practice. But the largest differences in performance occur during the visually impaired subjects first encounter of a WWW page (almost 3 times longer). Given the dynamic nature of the visually impaired users are going to be at a disadvantage since they will always be encountering new WWW pages even at familiar sites. New tags like FRAMES and Java applets will continue to compound the visual orientation problems of persons with visual impairments as visual displays become more complex and mix text with graphics.

To improve the accessibility of the WWW two approaches need continued development. One is to improve the accessibility of the source document to provide information that is more accessible(4). The second is improving the design of WWW browsers to provide additional controls to make it easier for persons with low vision to access the structural components of HTML(4).

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GESTURE RECOGNITION - RESEARCH AND CLINICAL PERSPECTIVES

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ABSTRACT

Gestural input systems are gaining popularity in the research community owing to their inherent flexibility and ability to be tailored to particular users [1,2]. However, developing a gesture recognizer is only part of the solution. It needs to be supported by the identification of appropriate clinical conditions under which gestural input would provide improved computer access. The aim of this paper is to present an overall view of an existing gesture recognition system from both research and clinical perspectives using data gathered from extensive user trials. The paper will then discuss the implications for the future development of gestural input systems.

BACKGROUND

In his RESNA presentation last year, Perricos described JesterMouse, a gesture recognition and mouse emulation system that he had developed for Windows 95 [3]. This paper is intended to review the feasibility of such a system, offering both anecdotal and quantitative evidence, gathered from user trials, about the efficacy of gesture recognition using JesterMouse, both from theoretical and practical standpoints.

Briefly, Jester was designed for use with a Polhemus Isotrak transducer that measured head position and orientation. This information was passed on to the computer and the motion segmented, analyzed and classified. Subsequently new drivers have been added for an analogue joystick, serial mouse and Logitech 3D mouse.

One important point to note is that JesterMouse offers two modes for direct cursor control - velocity and position. Position control moves the cursor by a *distance* proportional to the transducer displacement from a central, null position. Velocity control moves the cursor at a *rate* proportional to this displacement.

OBJECTIVE

The objective of the evaluation work performed was to identify whether gesture recognition could provide a viable form of input and to identify who would be most likely to benefit from such a system. The evaluation criteria for this were to see if JesterMouse:

- Offered a technically reliable input system
- Offered faster and/or easier access for existing computer users than their current input systems
- Enabled new users, currently without computer access, to use a computer.

The first of these points was primarily a research concern in its implications, with the following two being based on the assumption that the first criterion was satisfied. Consequently, these issues were addressed by a two-stage approach to the user trials.

METHOD

The first phase of the user trials were held at the Bradbury Progression Center of the Papworth Trust. Seven users with motion impairments of varying degree and nature were prompted to produce specific gestures using their heads (via a Polhemus) and their hands

(using a joystick) by custom-built testing programs. The results from this were stored and analyzed over several months. The programs provided two distinct modes of operation. The first was mouse emulation involving three gestures to simulate the mouse button clicks and the second was gesture input only with a vocabulary of six gestures.



Figure 1. The user trials at Papworth - note the Polhemus sensor on the baseball cap and the joystick

The second phase of the trials was conducted at a community rehabilitation center and involved able-bodied users, with experience of people with motion impairments, attempting specific tasks using JesterMouse. The aim of this was to provide a third party review of the software, outside of the developers, by specialists in the clinical rehabilitation field. Having gained experience with JesterMouse, they then identified various types of user for whom the system would offer additional functionality and ease of use over existing input systems.

RESULTS

The results from the Papworth trial were primarily numerical, in line with the emphasis of the tasks being performed and Figure 2 shows the recognition rates obtained for the two tasks. The "Head - 3 Gestures" results correspond to the mouse emulation trial, while the two "6 Gestures" results sets refer to the direct prompting program. The trials, however, were not solely about obtaining data, another goal was to identify specific user difficulties with the interface through observation of their interaction with the computer. Consequently, several modifications were made to JesterMouse to facilitate easier interaction.

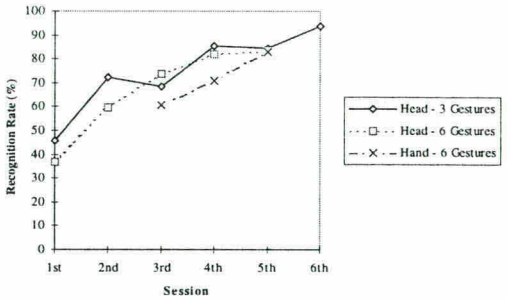

Figure 2. The recognition rates recorded

Having established that JesterMouse achieved good recognition rates with diverse users, the next step was to evaluate its performance with respect to other existing input systems, such as switch access. A preliminary study at the community rehabilitation center showed that for simple text entry, using switch access through a keyboard emulator was faster than using an unmodified version of JesterMouse through the same emulator.

Work is in hand to undertake a more comprehensive benchmarking for quantitative analysis involving document editing and multiple software applications. It is also intended to run further clinical trials using potential users.

DISCUSSION

From a research/development perspective, the basic functionality of JesterMouse is complete and reliable, approaching 90% recognition rates with practice. Hence the first of the evaluation criteria is satisfied.

The second consideration was whether JesterMouse offered easier or faster access than

other input methods. The preliminary results from the second set of user trials showed that in its unmodified form, JesterMouse is slightly slower than switch access. However, there is scope for modifying the interface, which it is anticipated will yield improved interaction rates.

From a clinical point of view, it is interesting to note that a very large number of people with physical disabilities drive a powered wheelchair using either a hand or chin joystick. Of these a small, but significant, proportion, while having sufficient fine motor control to steer the wheelchair using a precisely mounted joystick, have insufficient gross motor function to transfer from the joystick to another input device.

For such individuals there are two barriers surrounding ready and effective operation of a computer. Firstly it is necessary for another individual to remove the wheelchair joystick and replace it with the computer joystick, an operation which is often impractical. Secondly, having gained positional control of the mouse, there may be insufficient function to provide mouse button operation.

Recent developments in wheelchair control systems give the prospect of using the wheelchair joystick for a number of different purposes including wireless emulation of a computer mouse. While such developments will enable severely disabled individuals to drive the wheelchair up to the computer and take control, they are likely also to result in more users experiencing difficulty with mouse button operation. It is in this group of users that the practical benefits of gesture recognition are likely to be found.

As a final note, these results, whilst directly based on JesterMouse, are equally applicable to other gesture recognition algorithms, albeit not necessarily other systems, as this is dependent upon the specific interface used.

CONCLUSION

In conclusion, JesterMouse offers a potential source of input for users with motion impairments. However, the range of potential users of this system could be increased by modifying the interface and supporting other input devices, especially a wheelchair control joystick.

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IMPLEMENTING A GENERIC GESTURES RECOGNITION SYSTEM

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ABSTRACT

This paper describes the implementation of a system to recognize generically different gestures made by any person without the training of a neural network for each individual. An instrumented glove and specially developed software were used for data collection and labeling. By experimenting with multiple neural network architectures, we selected one which would serve as the generic recognition system. Using this architecture, the system was trained and tested on one person. The trained system was then able to be tested on multiple individuals with a moderate level of accuracy.

BACKGROUND

In today's society, communication is essential. Whether literate or not, all people who wish to succeed in life must be able to communicate effectively. People with disabilities can be at a great disadvantage because of their limited level of general communications skills. Different methods have been used to overcome these setbacks. For example, a person severely inflicted with cerebral palsy may use sign language to communicate his thoughts, however, without someone there to interpret him , he will have trouble communicating his thoughts. The obvious solution to this problem is to have different interpreters available twenty-four hours a day, seven days a week. However, this solution is impractical for the common person who cannot afford such an expense. Eventually, such a person may learn to communicate effectively, and relatively inexpensively, with the assistance of the computer.

Computers have been used in the past to recognize different communicative gestures. Most systems are designed for each individual person. The person would have to make a series of gestures which would be placed in a database as the training set, In order for the system to recognize subsequent movements, the person would have to perform the gesture almost exactly the way he did when he made the training set. This process is usually long and arduous. Also, the training set is not commutable with any great degree of accuracy to a data set which was entered by another user.

If it were possible for one person to train the neural network in such a way that it could be reasonably and accurately be employed by any individual, it would be of great use. The advantage of this is that it would not be necessary for each person to take the time to record a new. This saves both time and money on part of the user.

A second advantage is the accurate sampling of a gesture. It is very difficult for a person with CP to repeat a gesture accurately enough for a computer to recognize it easily. Therefore, if there exists an accurate sample of the gesture from which a reference can be drawn, the movement made by the person must only resemble the intended gesture.

METHOD / APPROACH

The equipment used included a Silicon Graphics Indigo computer which did all of the processing. Flocks of Birds which took 6 measurements for each frame, were used to track the position and orientation of the wrist.

The training set consisted of 10 different gestures which had on average 50 raw data samples that were collected with the gloves and placed in to separate files. These gestures included different hand movements: left, right, up, down, forward, back, two diagonal movements and two rotational ones. The raw data were then translated to a usable set of ASCII characters. Each sample consisted of about 50 frames of data. This new set of data

was then subjected to hashing techniques to extract a specified number of frames from the overall sample, the beginning and the end of the movement, and 1 or 2 frames during the movement. These new smaller samples were concatenated into the training set. A similar process was used in the development of the testing set. The samples were processed and split into different frames. A different testing set was created using a random function which placed multiple randomly selected gestures in to a file.

The training and testing sets were then subjected to various neural network architectures. Within the architectures various variables were manipulated. The number of inputs, which consisted of data frames, numbers of hidden nodes, and types of neural networks, and the number of outputs were varied until suitable architectures could be found. Back-propagation methods were selected as the main neural network paradigm

The newly created architectures were then saved and were later tested by a different subject.

The neural network recognition program was developed using Matlab and Matlab Neural Network Toolbox.

RESULTS

Many different architectures of back propagation neural networks were explored by traversing different initial conditions.

For the recognition of 6 movements using 18 inputs, the best recognition accuracy came from using a single hidden layer of 40 hidden nodes with log-sigmoid transfer functions. As a result of training, no errors were detected. For the full testing set there was only a 2% recognition error, and for the random set there was only a 1.4% recognition error.

For the recognition of 8 movements with 24 inputs, a single layer of 120 hidden nodes was used with the same processing as used previously. This yielded a 2.5% error for full testing set and a 3.8% error recognition in a random selection of testing samples.

For the recognition of 10 movements, 24 inputs were used with 60 hidden nodes to yield an average error of 3% on the random set. With 18 inputs, it yielded a 4.1% error. These were the best architectures for recognizing 10 different gestures.

The experiments on the developed neural network architecture using data collected from the person different from the data the system was trained on shown comparable results.

DISCUSSION

Different network architectures responded differently to the testing. Using more frames tends to "smooth" the gesture. Therefore, the chance of recognizing a particular gesture is higher, but there is also a greater chance of error when an independent subject is used. The number of nodes needed tended to reach an equilibrium point as the number of outputs increased.

The more frames there are, the more rigid the recognition will be. For using the recognition system on a single person, the more frames that the architecture uses, the better the recognition rates were received. However, in order to be used with multiple users, the number of frames should be decreased in order to allow for variations of the gestures.

For the rotational movements, a minimum of 4 frames are needed for proper recognition. With any less than 4 frames the movement may easily be confused with a variation of one of the planar movements. With 4 frames, the confusion is minimized by the wide berth of the movements.

Conclusions

A step was taken toward the automatic identification and recognition of human movements. These movements play an important role in human gesture analysis problems, such as translation from American Sign Language, recognition of gestures produced by people with different physical impairments, and rehabilitation robotics.

A high accuracy of recognition rate has been achieved using relatively simple neural network architecture. This permits the adaptation of trained neural networks to dif-

ferent individuals.

The developed system could also be used in a variety of applications other than rehabilitation.

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HABITAT ASSISTIVE LIVING SYSTEMS USING VOICE RECOGNITION

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ABSTRACT

The possibilities of voice recognition and automation as they apply to the handicapped are explored. The design and implementation of a real-time, voice activated control system along with the advantages and drawbacks of the design are given.

BACKGROUND

The Assistive Technology Program (ATP) was established in 1989 by Prof. Donn A. Clark and Alan Rux at the University of Massachusetts at Lowell to provide senior Electrical Engineering students with the opportunity to participate in meaningful and challenging design projects and concurrently use it as an opportunity to aid handicapped people in the surrounding community.

Through the ATP, coordinators learned of Sam Afroh, a quadriplegic living in the greater Lowell area. When alone, Sam inherited the state of the apartment as it was left; unable to alter the temperature or lighting until someone returned. After collaborating with Sam, the desire to make him more self-sufficient emerged.

The means by which this freedom would be attained was then determined. Having very limited use of his arms, a system requiring considerable button pushing was eliminated as a long-term solution. Because Sam could speak freely, it was recognized as an attribute that offered many advantages. Whereas a mounted control panel necessitates spatial locality for operation, a microphone system allows the user the freedom to move about in his/her environment without losing any of the system's capabilities.

STATEMENT OF THE PROBLEM

The goal of this project was to design and realize a voice driven system able to control certain aspects of the environment within Sam Afroh's apartment safely and reliably.

RATIONALE

When considering what devices to control, it was agreed that those which could in anyway become injurious or life-threatening would not be incorporated into the design. A prime example of this type of apparatus is the motorized front door to Sam's apartment. If the door were converted to voice control, Sam could be anywhere in his apartment when giving the "open" command, conceivably in the path of the inward swing of the door. Thus, it was avoided.

An additional device which may have posed a threat was the telephone. In the event of a power outage the system itself would be inoperable. If only accessories such as the television set and lights were under control of the system, no problem would be presented as they too would be inactive. However, if the phone was connected to the system, there existed the possibility of also losing the telephone. As it would be crucial that the phone still function, it was decided that only

the lights, television set, and ventilation system could be safely included in the system.

Another consideration that was addressed dealt with the issue of microphone location. Ceiling mounted microphones would be ideal as they offer a continuous power supply and would remove the need for any worn equipment. The problems introduced concerning cancellation and the filtering of other voices (whether from guests or the TV) were solved by using a remote headset instead. Although this solved the issue of filtering, it presented a weakness dealing with its power usage. Rechargeable batteries would have to be cycled at least once a day.

DESIGN

The heart of the system is a 486 based PC. Its responsibility is to take voice input and perform the related events. It does not and should not serve any other purpose. The main program is divided into separate branches. First an attention word must be given to activate the process and release the program from its "Sleep" mode. This in turn opens a menu of available room choices. After specifying the room, another menu is displayed containing available options for that room.

The program will reject all input that is not relevant to its current context (or dictionary). For example, the input "TV" is not recognized under the "Bathroom" context. By reducing the number of choices in each menu and changing the context when a new menu is opened, the recognition is extremely accurate and sufficiently tolerant to invalid input.

Audible prompts are heard relating which context the program is currently in. If for any reason the user becomes lost, there is a command "Reset", which returns the program to its "Sleep" condition. The "Reset" command is available in all contexts.

From input to execution, there must be a translation from the spoken word to an associated string which can then be interpreted and used to manipulate the hardware outside the computer. Via an RF link from the wireless microphone, the spoken word is translated to its associated phonemes by pre-existing voice recognition software. Phonemes, numbering approximately 50 for the English language, are the sounds that distinguish one word from another[1]. The word "bed" is made up of the phonemes: B, EH, and DD.

The phonemes are then compared with entries in the current context; each matching a certain combination of phonemes to a user-defined string of characters. This string is then passed to the main program which deciphers it and takes the appropriate action. If the command is an intermediate one (requiring no light to be turned on, channel to be changed, etc.), a new menu and context are opened. Otherwise the program sends an appropriate sequence of bits to a digital I/O board which is terminated by a modified universal remote control. The ordering of the bits determines which button is asserted. Using "Plug 'n Power", lights and outlets can be toggled, and the remote can communicate directly to the TV once the correct manufacturer's code has been entered.

The ventilation system is controlled by a series of logic gates and relays which manipulate the signal to change the High, Low and Off fan settings. Fortunately, one of the team members is a licensed electrician, allowing for the wiring of these high amperage devices to be performed professionally and within code compliance. It is important to note that this fact alone allowed the project to be expanded to include this extremely important function.

DEVELOPMENT

Once the layout of Sam's apartment was specified (e.g. the placement of lights and outlets), the main program and context files

were finalized. The apartment was then simulated in a laboratory at Umass/Lowell. After extensive testing, the prototype was deemed ready for installation.

EVALUATION/DISCUSSION

What is presented above represents an important step towards self-sufficiency for many. Due to the simplicity of the design, the fabrication of a working unit is remarkably inexpensive in comparison with commercially made systems. Similarly, the manufacturing time can be as short as a single day once the necessary components are on hand. A final note can be made concerning its flexibility. Once installed, the system can be easily altered for the addition or removal of devices.

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USER PERFORMANCE MODELING AND COGNITIVE LOAD

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ABSTRACT

The traditional approach to enabling computer access for the motion impaired is to adjust the input from the users to fit into a predetermined, usually commercial, interface system. However, such interface systems are optimized on basic assumptions about user parameters and the input devices used, which are unlikely to be valid for users with motion impairments. Consequently any interface system based solely on a modified input strategy is, at best, treating the symptoms. This paper will describe current research to analyze the interaction of such users with computers to enable construction of a calibrated user model and will be illustrated by results from extensive user trials.

BACKGROUND

User interface design is based on fundamental models of the user. A very simple model, that illustrates the general types of parameters used is the Model Human Processor[1]. This assumes that all actions can be broken down to three stages and hence the time to complete an action is just the sum of the appropriate number of steps of each type, i.e.:

$$\text{Total time} = x\tau_p + y\tau_c + z\tau_m$$

where τ_p = perceptual time
τ_c = cognitive processing time
τ_m = motor response time

More detailed models, such as the Keystroke Level Model[1], separate the basic elements of the above equation into more specific steps. For example, the motor response time when using a keyboard can be split into time to home in on a particular key and the time to depress and release the key once reached.

Such timing information is vital to the designers of interfaces when deciding which method of data entry will provide the optimal data transfer rate for a particular circumstance.

OBJECTIVE

The problem that exists for those with motion impairments who wish to use a computer is that virtually all existing interfaces have been designed and optimized according to data from user models of able-bodied people. In order to solve this, ongoing work is being performed to develop and calibrate user models based on motion impaired users' performance parameters[3].

METHOD

Two methods have been adopted to the research. The first was analyzing empirical data gathered over a series of user trials with a set of users who exhibited a range of motion impairment types and severities. Of specific interest for this was the performance of the users under increasing cognitive and physical load.

The trials conducted were originally part of a series of trials to evaluate the performance of a particular gesture recognition package[2] and assess its potential for use in a multi-modal input system. An important step in this process was to determine how well users

could produce multiple gestures both serially and in parallel. A vocabulary of 6 gestures was selected for the trial, these being YES, UP, DOWN, NO, LEFT and RIGHT. Users were prompted for these gestures in a random sequence, until each gesture had been performed seven times. Initially the users were asked to perform single gestures using their heads using a Polhemus Isotrak transducer mounted on a baseball cap and then with their hands, via a joystick. On completion of this, the users were then asked to produce two identical gestures simultaneously using their heads and hands. Finally, two different gestures were prompted for and the users had the choice of producing the gestures sequentially or simultaneously.

The second method, still continuing, is more theoretical in its approach. This is based on clinical neuropsychological methodologies for the quantification of the perceptual, motor and cognitive response times. In particular, two computer applications have been written to measure response times to specific stimuli. These vary from simply pressing a button in response to a screen change to selecting whether a symbol displayed on the screen is a letter or a number. A third program will shortly be written to test whether Fitts' Law, which says that the time to reach a target is directly related to the size of the target perpendicular to the approach direction, holds for cursor movements controlled by different mechanisms.

RESULTS

For the multi-modal gestural input test, any correctly recognized gesture earned a score of +1 point. A gesture that was not recognized received 0 points and an incorrectly recognized gesture was penalized by -1 point. These scores were then summed and normalized to a maximum potential score of 100 points. As a point of note, if any of the scores fell below 0 then the system would be unusable as the user would spend more time correcting errors than actually producing any input. The results obtained are shown in Figure 1.

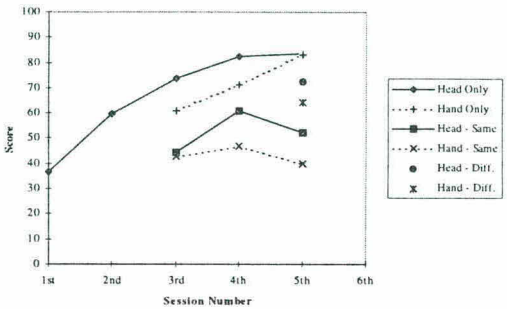

Figure 1. The scores recorded for different input tasks

Figure 1 shows that when users were presented with different gestures to perform on each input mode a lower score resulted even though the physical load was no greater than for the gestures being requested on each mode individually. This decrease in performance is attributable to the increase in cognitive load only. When combined with an increase in physical load, as for when the users were prompted to produce two identical gestures simultaneously, an even lower score resulted.

Preliminary studies of the two programs specifically written to calculate the perceptual, cognitive and motor response times were performed using able-bodied subjects to verify the algorithms used. The times produced and the predictions from Card et al [1] are shown in Table 1 below:

Response Step	Observed Time (ms)	Predicted Time (ms)
Perceptual, τ_p	81	100 (50~200)
Cognitive, τ_c	92	70 (25~170)
Motor, τ_m	72	70 (30~100)

Table 1. The observed and predicted response times

Whilst not precisely matching the times predicted, the results do fall well within the

levels of tolerance given. Discrepancies can be explained by the stimuli used, which have a direct effect on the times observed and that the users were not 'expert' users in this program and consequently had a greater cognitive processing time than predicted in theory.

DISCUSSION

The results from the preliminary trials of the user model calibration software shows that the these programs will produce valid data for a model based on user with motion impairments. The next stage is to carry out trials with such users.

The results from the gestural input test show that cognitive and physical overloading of the user can produce decreased performance quality. This was shown by the reduced scores obtained for the more complex gesture prompts. Therefore, the linear equations used in the user models can be thought of as being bound limited by the loading on the user.

As an interesting observation from the course of the trials, it was noted that whenever given the choice users would opt for whatever minimized the load on them despite the time penalty incurred. This was shown by the almost total choice of all users to produce the different gestures sequentially rather than simultaneously. It would be unwise to attach too much significance to this result, though, as the time penalty associated with this was relatively small, being of the order of some 50%, and there was no particular task to be accomplished beyond completion of the required number of gestures.

As a final observation, when the test was repeated with able-bodied users, they showed much more willingness to experiment with producing the gestures at the same time. This leads to several possible conclusions. One is that the motion impaired users lacked the confidence to try more outlandish approaches. The other is that the cognitive and physical load on the motion impaired users is sufficiently increased compared to able-bodied users to effectively rule this out as a possible method of input.

This has important implications for any multi-modal input system based on multiple movements and also highlights the inconsistencies between able bodied and motion impaired users. It shows why it is necessary to develop specific user models for particular users.

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COMSPEC - OPENDOC COMPONENTS SUPPORTING COMMUNICATION

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ABSTRACT

Comspec is a modular architecture for communication aids and access systems. *Comspec* is implemented in the OpenDoc environment which supports extendibility and adaptability. The basic *Comspec* tools are editors for layout, configuration and vocabulary. This paper describes how the *Comspec* architecture is mapped onto OpenDoc and how features of OpenDoc are utilized to realize the *Comspec* protocols and functionality.

BACKGROUND

Communication aids and access systems tend to be increasingly adaptable and they offer a growing number of functions and features. The result is complex systems that require extensive support and are hard to maintain. The *Comspec* system and software architecture is a proposed solution to growing complexity (Lundälv, 1995). It is based on a modular approach, where the communication aid or access system is made by butting together and setting up cooperating software components.

The *Comspec* software architecture has been developed through several steps, and in an international setting. It started as a survey of requirements to new communication aids, continued with the design of a modular architecture and a prototype system made to demonstrate the ideas of the proposed architecture. The prototype was evaluated by therapists, and currently the basic modules and tools are developed by the *Comspec* consortium within the European TIDE program (*Comspec* - TP 1169).

The outcome of the TIDE-project will be the basic tools for defining layout, configuration and vocabulary of a communication aid, and a set of layout and configuration elements to be used when an end-users system is made. The project will also provide a symbol-based personal communication aid and an environmental control system, both made by utilizing the *Comspec* tools and components.

STATEMENT OF THE PROBLEM

The *Comspec* architecture was designed without a specific development tool or software technology in mind. The modular aspects of it calls for an open and extendible technology.

During the technical specification of *Comspec*, three major issues were raised. The first question was how *Comspec* could allow addition of new components which were not designed as parts of the initial system. Secondly, how should the components cooperate, and in what way could the architecture be prepared for new schemes of interaction between components? The third question is how to support future developers who want to create new components to fit in with *Comspec*?

RATIONALE

The *Comspec* architecture was designed to support easy tailoring of communication aids and access systems to the end-user's needs. The architecture defines three major aspects of a communication aid system: layout, configuration and vocabulary.

The layout is the visual user interface, giving the user access to select words or utterances in the process of communication. The configuration shows how the communication aid is set up and how the events from user actions to output of messages take place. The vocabulary organizes language elements or words, and each word may have different

representation types like text, graphic symbol, picture, sound and so on.

DESIGN

OpenDoc is an open system which allows independent component developers to make small software modules to be used as building blocks in larger applications. OpenDoc defines how components should interact and be integrated. OpenDoc is supported by a large number of software companies, and is available on Windows 95/NT, MacOS and OS/2. This is the motivation for the *Comspec* consortium to base the implementation of the *Comspec* system upon OpenDoc (Tyvand, 1995).

OpenDoc provides a set of features that can be utilized when implementing the *Comspec* architecture. One of them is embedding. OpenDoc parts can contain or embed other parts. This mechanism is used to implement the hierarchical aspects of the *Comspec* layout. A layout page may embed container elements, and the container may again embed simple elements. The embedding mechanism is also used for integration of other components, like configuration and vocabulary.

The extension mechanism of OpenDoc is utilized to implement the *Comspec* protocols for cooperation between components. When a developer wants to implement a new component, (s)he just makes sure that the part uses the appropriate extension and implement the response to the messages of the protocol. When this new component is embedded in a *Comspec* part, the embedding part uses the extension mechanism to find out whether the new part supports one of the protocols.

OpenDoc provides mechanisms for dispatching messages and coordination of input focus. These mechanisms are used to monitor input events and route the input to the right component.

DEVELOPMENT

The OpenDoc Development Framework (ODF) is an object-oriented framework developed in C++ which is targeted for building cross-platform OpenDoc component editors. ODF provides ready made implementation of the basic behavior of OpenDoc parts, and all the basic *Comspec* components are based on ODF. This makes the porting of the system from MacOS to windows 95/NT fairly easy.

The *Comspec* system is built as a set of OpenDoc parts. The components can be arranged in three groups, shown in Fig. 1. In addition to these components, a *Comspec* application will normally contain other OpenDoc parts. Examples are picture and text parts used as representations in the vocabulary.

Main components	Layout Page Configuration Vocabulary
Layout elements	Simple Element Container Display
Configuration elements	Switch Single Switch Scan Two Switch Scan Selection Set Layout Output Emit Tag Filter

Fig. 1: Overview of basic Comspec components

The layout, configuration and vocabulary of an example application may look like in Fig. 2-4. The basic *Comspec* components and the source code for them are available in the public domain, and may be downloaded from a web-page given at the end of this paper.

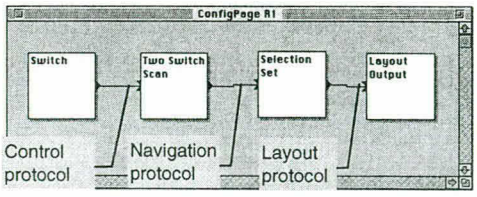

Fig. 2: Comspec configuration

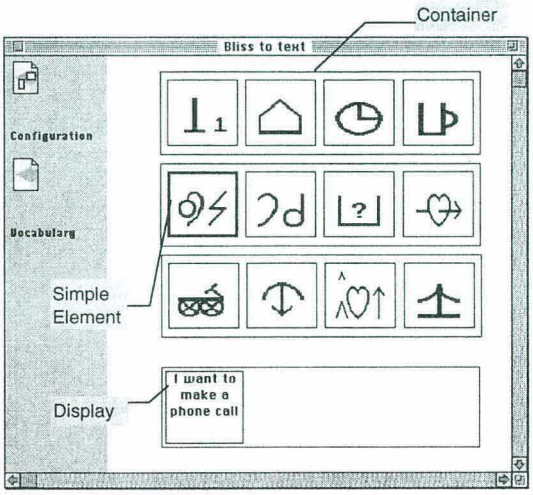

Fig. 3: Comspec layout

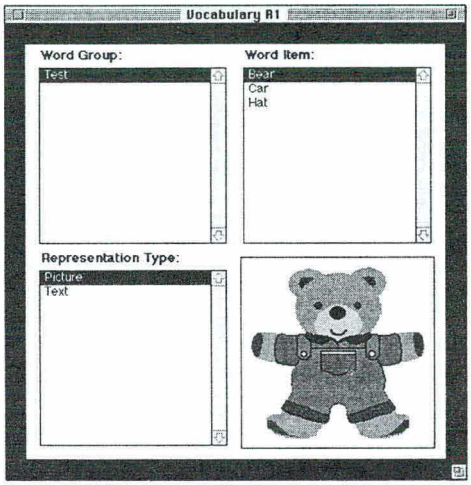

Fig. 4: Comspec vocabulary

EVALUATION

The *Comspec* system will, during the TIDE-project, be evaluated by therapists and system integrators. The evaluation will focus on how therapists can make relevant setups for end-users by using the current components.

DISCUSSION

The *Comspec* system is currently (December 1996) available as a minimum version. It is lacking support for facilitators who want to make minor adjustments to setups (like changing scanning speed), but do not want to use the full functionality of the configuration editor. The current version is for MacOS, but *Comspec* will be available for Windows 95/NT during the first half of 1997.

The *Comspec* system is open in the sense that developers can make new components which will fit into the system. The *Comspec* consortium provide source code for all the basic components, and a C++ class library with base classes for protocols and generic layout and configuration elements.

The cooperation between parts is taken care of by ready made extensions, and it is possible to make new extensions to support upcoming interaction schemes. Developers are supported by detailed guidelines on how to make components *Comspec*-compliant.

System integrators may use components from different developers when they make a setup for a given end-user.

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PROSODY IN THE ASEL DIPHONE SYNTHESIZER

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ABSTRACT

Natural sounding speech prosody is an important feature of synthesizers intended for AAC applications. This paper discusses the implementation of prosody in the ASEL diphone speech synthesizer. The synthesizer employs a rule based front end that calculates prosody based on linguistic information extracted from text input. A high degree of user control is provided, as well as a macro capability that allows control of complex effects. This is the first step in developing a synthesizer capable of producing speech with emotion.

BACKGROUND

Prosody refers to the durational and intonational characteristics of speech. These characteristics depend on a number of phonetic, linguistic, and extralinguistic properties of words and phrases, many of which can be extracted from text input by natural language processing. Commercial products are available that produce good quality prosody for neutral utterances (declarative sentences) and have a limited ability to produce some alternatives. However, if a synthesizer is to be used for conversational speech, a neutral tone of voice is often inappropriate. Speakers vary prosody systematically and meaningfully varied in ways that are not predictable from a written text.

One example is focus. Focus refers to the word in a sentence with the most pronounced pitch and duration values . In a neutral context, the focus is usually the final content word of the sentence. In conversation, however, there are often context effects that favor a non-final focus:

A: We're having fish for dinner.
B: But I don't LIKE seafood.

C: Where is my radio?
D: I think JOHN took it.

These context effects are usually unpredictable from the text input alone.

Other intonational characteristics are used to signal meaning. Some can be derived from the text, such as the difference between statements, questions, and continuations. Punctuation is a sufficient cue for selecting the appropriate pattern. Many other intonational contours used in conversation are not predictable from the input, however. One example is shown in the following exchange:

A: Who broke my vase?
B: I didn't do it.

The response of B is more natural when the first word begins on a high pitch, drops to a low pitch, and ends with a high pitch on the final word - this is referred to as the contradiction contour (Pierrehumbert and Hirschberg (1990). This contour is often used when the speaker is denying or contradicting a previous assertion.

Speakers also use overall trends in duration, pitch, and pitch range to signal emotions such as happiness, sadness, and anger.

Control of these non-predictable prosodic effects is necessary in order to develop a synthesizer capable of reproducing natural sounding conversational speech.

STATEMENT OF THE PROBLEM

For AAC applications, the prosody of speech synthesis should be capable of producing a wide range of effects that signal both speaker intention and emotional states. The user control should be simple and not require detailed knowledge of English prosody.

DESIGN

The implementation of prosody consists of four parts: (1) calculation of linguistic information, (2) conversion to duration and pitch values (3) user control, and (4) concatenation and modification of diphones. This paper will be limited to the first three aspects of the implementation, and will concentrate on the intonational aspects of prosody.

DEVELOPMENT AND RATIONALE

The design of the intonational component of the synthesizer is based on the linguistic theory

of Pierrehumbert (1980) and the TOBI standard (Beckman and Ayers 1993). Intonation is described in terms of pitch accents and boundary tones. Pitch accents designate points of high pitch, low pitch, and more complex patterns within an intonational contour. Boundary tones describe the pitch values at the end of phrases. Pitch accents and boundary tones are mapped to a phonetic model described by the following parameters: average pitch, pitch range, and declination. Accents are realized as rises and falls from the average pitch towards the lower or upper limit of the range. Declination refers to a progressive lowering of pitch and compression of the pitch range with time. The declination is reset after the end of a sentence, so the next sentence begins at the original pitch and pitch range.

Automatic Linguistic Calculation

The front end of the ASEL synthesizer is a rule based natural language processor that calculates the linguistic structure of the input text, and then uses the linguistic structure to determine the prosody and the diphones of the speech. The text input is first converted into a completely alphabetical format, and then a series of rules are used to determine the phonemes, stress, and part of speech for every word. The intonational contour is determined automatically from the part of speech information and the punctuation.

Most content words (nouns, verbs, adjectives, adverbs) receive an accent. The focus is usually assigned to the last accent within the sentence. Accented words normally receive the high (H*) tone, although the focus may receive a different accent in some cases. Punctuation is used to determine the boundary tones. Sentences that end in a period or no punctuation at all are assigned a H* tone on the focus, followed by two low boundary accents. This causes a drop in pitch towards the end of the sentence. Sentences ending in a question receive the opposite pattern , a low (L*) followed by high boundary tones, which causes a rise in pitch towards the end of the sentence. Other punctuation (comma, exclamation point) are mapped to other pitch accents and boundary tones.

Conversion to Pitch Values

The pitch values for the accents and boundary tones are calculated by a phonetic model with the following parameters: (1) initial pitch, (2) average pitch or midline, (3) offset, (4) pitch range, and (5) declination. Pitch accents are converted to high and low fundamental frequency (f0) values, determined by the upper and lower limits specified by the pitch range. Each pitch accent has a rise time and a fall time. Once the pitch accent values are determined, the rest of the contour is filled in. Interpolation begins from the initial pitch to the start of the first accent; the starting f0 value of this accent may be at the midline (adjusted by the offset), the bottom, or the top of the pitch range, depending the type of accent to be interpreted. Then the intonation contour rises or falls to the accent level, and then afterwards returns to the midline, and interpolation continues on to the next pitch accent. One set of boundary tones (L- H-) change the midline to one extreme or the other, and the other set of boundary tones (L%, H%) set the final pitch target for the sentence. Then the contour is adjusted for declination.

User Control

The user has complete control over both the linguistic and the phonetic stages of the prosody synthesis. This control is provided by both inline commands and a macro capability. The ASEL synthesizer implemented for Microsoft Windows also has pop-up user screens for setting all the durational and pitch accent interpolation parameters. Due to space limitations only four of the many possible controls are discussed: (1) pitch accent/boundary tones, (2) default accents, (3) intonational contours, and (4) macros.

Individual pitch accents and boundary tones may be specified directly in the text, using an abbreviated format similar to TOBI, with some simplifications. For example, the focus accent may be specified with one command. The focus examples in the introductory section would be corrected as follows:

But I don`t |^F like seafood
I think |^F John took it

A second feature to aid prosodic manipulation is the control of default accents.Normally, all accents are H*, but any pitch accents may be selected for the default. This allows the user to express changes in meaning or style appropriate for the context. For example, Pierrehumbert and Hirschberg (1990) have shown that the

downstepped (!H*) accent is often used when a speaker wishes to convey a somewhat authoritarian tone, and the scooped (L*+H) accent is used to express surprise and uncertainty. With one command the user can select any accent to assign to all the appropriate words in the sentence. Once set, accenting will remain in this mode until the user wishes to change to another pattern.

A third feature is the ability to construct intonational contours with different accents. This feature is necessary to implement the "contradiction contour" and other complex patterns. A user may specify the first, the final, and one middle accent, all potentially different from one another. Specifying intonation contours is much simpler than entering accents one by one. The user does not have to know which words should receive the first, last, and middle accents. However, the user must be familiar with details of English intonation in order to program this command effectively.

To make the task of controlling prosody as simple as possible, a macro capability has been provided, where any string of user commands may be assigned to a one or several character codes. It is our goal to develop a number of macros that implement various intonational contours for the user, providing an easy to use pre-programmed selection. Work is also underway to develop macros that simulate various emotional prosodic effects. This will be accomplished by manipulating parameters such as speaking rate, average pitch, pitch range, and the type of pitch accents associated to content words.

DISCUSSION

The prosody of the synthesized speech is very natural sounding and has the advantage of being highly configurable and programmable. The automatic algorithms are very successful at implementing neutral intonational contours, accenting the appropriate words, and providing a limited amount of variation in accordance with textual cues such as punctuation.

The different TOBI accents permit accurate control of the intonation by a user trained in English prosody. For users without such training, the macro commands using the intonation contour feature provide a very simple mechanism for specifying different patterns without having to align pitch accents manually. Currently, the contradiction contour, the calling contour (Pierrehumbert 1980), the surprise-redundancy contour (Pierrehumbert & Hirschberg 1990) and other effects have been implemented using these macros.

Progress has been made towards implementing prosody with emotion. Macros have been developed that produce effects suggesting happiness and sadness. To evoke happiness, the macro changes several prosodic parameters as follows: increased speaking rate, wider pitch range, higher pitch. The pitch accent association is changed to make greater use of the pitch range. To evoke sadness, the prosodic parameters are changed as follows: slower speaking rate, narrower pitch range, lower pitch. These simple changes are reasonably effective at conveying the two opposite emotional states.

However, much work remains to be done. Attempts at implementing anger via prosody have so far not been very successful, although one of the experimental macros is very suggestive of frustration. More sophisticated or different prosodic controls may be necessary to adequately model the prosody of anger and other emotional states. Ongoing research is directed at improving the prosody so that more emotional effects can be produced.

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VOCASELECT AND COMPUTER ACCESS SELECTOR: SOFTWARE TOOLS TO ASSIST IN CHOOSING ASSISTIVE TECHNOLOGY

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ABSTRACT

Two new Windows-based software packages have been developed in order to assist in the choice of assistive technology for people who have a disability. VOCAselect contains a database with most of the available voice output communication aids (VOCAs), and Computer Access Selector contains most of the computer access products available.

Each program enables the user to quickly choose the important features of a solution. The programs then use expert knowledge to suggest potentially suitable products. Computer Access Selector does more than select individual products: it chooses a **combination** of products that will successfully work together to form a **complete** access solution.

BACKGROUND

Professional assessment is generally required to determine the needs and abilities of a person with a disability who could benefit from assistive technology. Even when the individual's capabilities are understood, selection of specific products is not straightforward due to the large number of products and product combinations available.

STATEMENT OF THE PROBLEM

The increasing number and complexity of assistive devices means that relatively few professionals are in a position to provide up-to-date informed advice in choosing an appropriate solution for an individual.

Our aim in designing and developing VOCAselect and Computer Access Selector was to make the most important information on devices readily available in order to allow objective comparison between products. Our earlier work has been described in previous progress reports (1,2).

RATIONALE

Each program uses criteria that broadly classify the characteristics of devices. They allow therapists to choose options under the criteria most important to them. As more choices are made, the number of devices satisfying their requirements decreases. When the list reduces to a manageable size, the individual or therapist can try changing the less important criteria to explore the various solutions.

Having settled on a subset of devices, a report can be printed, including supplier and manufacturer addresses.

These tools are not intended to take the place of proper clinical assessment, but rather to speed the selection of an appropriate AAC or Computer Access device once a client's needs and abilities are well understood.

Selection of the most appropriate device involves a compromise of many different parameters. Often the critical parameters are not known until the device is trialed with the user.

DESIGN

Both programs utilise Graphical User Interfaces (GUIs) to facilitate selection of choices and subsequent display of results. Figure 1 shows VOCAselect's initial selection screen, and Figure 2 shows it after four parameters have been set. Numbers at left show the sequence in which selections were made. Figure 3 is a device information screen for one of the selections, and Figures

4, 5 and 6 show the Liberator's device specification screen, and manufacturer and Australian suppliers respectively.

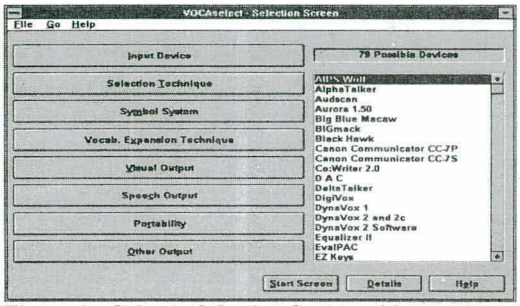

Figure 1. Criteria Selection Screen with no criteria specified.

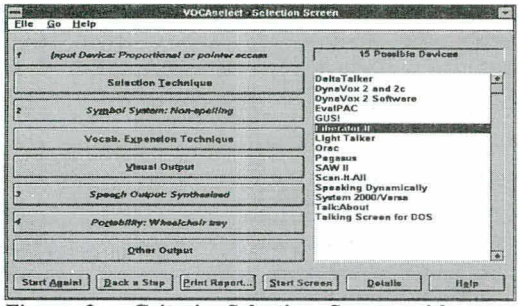

Figure 2. Criteria Selection Screen with some criteria specified (shown in italics).

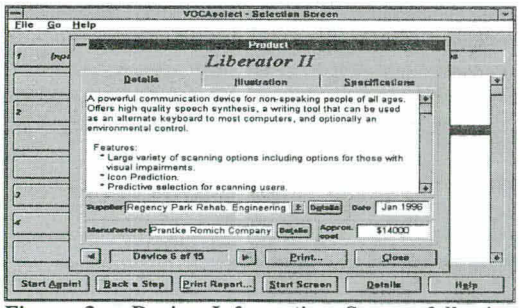

Figure 3. Device Information Screen following selection of the 'Liberator'.

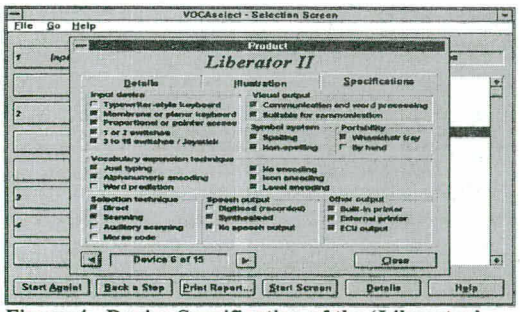

Figure 4. Device Specification of the 'Liberator'.

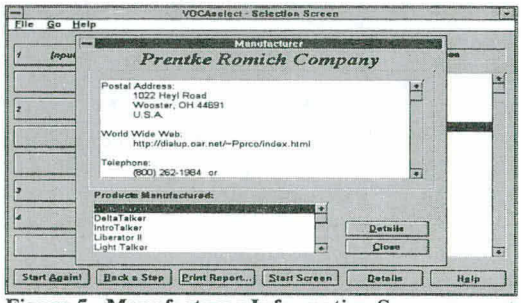

Figure 5. Manufacturer Information Screen.

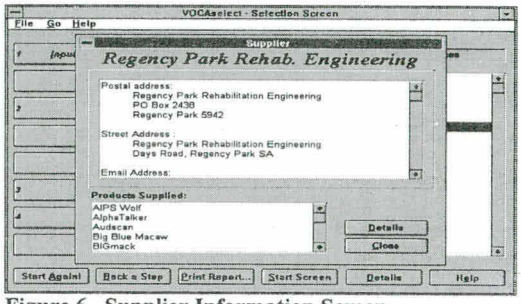

Figure 6. Supplier Information Screen.

The Initial selection screen for Computer Access Selector is shown in Figure 7, and Figure 8 shows it after 5 parameters have been set. Figure 9 is one of the resulting product description pages, and Figure 10 is the corresponding product illustration.

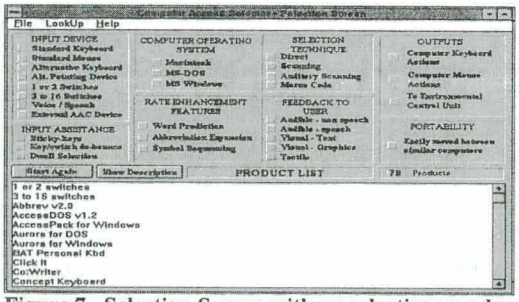

Figure 7. Selection Screen with no selections made.

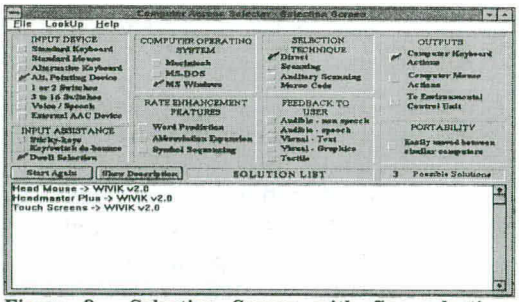

Figure 8. Selection Screen with five selections made, reducing the number of solutions to three.

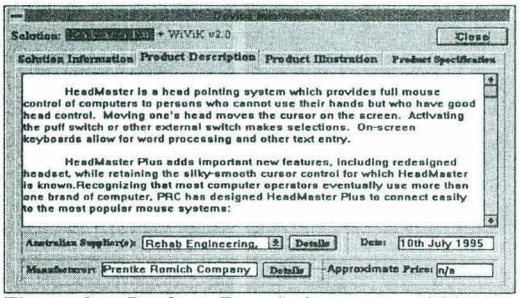

Figure 9. Product Description page within the description dialog box.



Figure 10. The Product Illustration page within the description dialog box.

DEVELOPMENT

VOCAselect was originally produced as a Hypercard stack, and is now also available for Microsoft Windows. Computer Access Selector was produced using Asymetrix Toolbook 3.0, and is only available for Windows 3.1 and '95.

EVALUATION

Regency Park Rehabilitation Engineering is certified to ISO9001, so all our designs go through a verification procedure prior to release, and a validation procedure after release. Both programs have passed those requirements.

In addition, an earlier version of VOCAselect was distributed to many interested people, and 30 questionnaire responses were received. As a result, changes were made to the program in order to increase speed by several times, to expand printing capabilities so that reports can be imported into a word processor, and to remove some ambiguities in the selection criteria. Criteria were also broadened to include the ability of a device to control an environmental control unit.

DISCUSSION

These two programs are now commercially available from us, and during 1997 will be made available on our world wide web page.

We are interested in forming partnerships with organisations in countries around the world who would be interested in customising these programs for their own country.

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Software for Assessing Computer Usage Skills

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Abstract
The goal of this project is to improve interventions in the area of computer use for people with disabilities through the development of functional assessment software. Current efforts are focused on developing an easy-to-use tool for measuring users' skills in using the keyboard and mouse, as well as emulators of these devices.

Background
Accurate functional assessment of a user's abilities is a key component of successful interventions in computer access and other computer-based assistive technologies. A good assessment tool can help diagnose difficulties with an existing interface; evaluate and compare the expected performance with candidate access systems; plan training interventions; track changes in an individual's abilities over time; and measure the overall effectiveness of an intervention.

There is a wide variety of methods currently employed in assessments for computer access, including informal clinical observation, conceptual models, manual data collection, and computerized assessment tools. Computer-based tools have tremendous potential because they can be more efficient, repeatable, and accurate than other methods. Computerization can provide functions unavailable with paper-and-pencil methods, such as showing multiple views of the data, recording raw data for optional in-depth analysis, adapting testing to the client, and tracking performance over time [1].

One computerized approach to assessment is to support the evaluator through all stages of the assessment process and recommend the most appropriate assistive device [2,3,4,5]. Developers stress the need for accurate functional assessment data in making these recommendations, yet most systems provide little or no explicit support for gathering it [2,3,4]. And by focusing primarily on device prescription, assessment data are treated only as a means to that end, which tends to limit the main use for these systems to "one-time" major evaluations lasting several hours or more. They are not easily applicable to performance assessments that take place in a single therapy session and are not designed to track performance across multiple assessments.

A second type of computer-based assessment tool includes programs designed to test only one or two fundamental skills [e.g., 6]. These programs have the appeal of being relatively easy to use, and they provide valuable information about the skills they assess. However, in focusing on one or two specific skills, they lack comprehensiveness, and particularly in the older programs, the data management and display capabilities could be greatly enhanced.

Statement of the Problem
While the approaches reviewed above have advanced assessment methods in computer access, none meets the need for a quantitative tool that fully exploits the possibilities of computerization and focuses specifically on measuring the full range of computer input skills easily and efficiently. Our goal is to develop an inexpensive software tool that will allow an evaluator to validly assess an individual's computer input skills and compare performance across different devices and time periods.

Design criteria for the evaluator interface include: ease of use with little training, greater efficiency than alternative methods, support for multiple views of the data, and management of data collected over time. Design criteria for the tests themselves include: broad coverage of computer input skills, sensitivity to different levels of client impairment, and compatibility with commercial computer access devices.

The first phase of this project involves the design, development, and evaluation of a prototype for the computerized assessment of keyboard and pointing input skills. The

intended user population includes professionals in either educational or clinical settings who perform computer access evaluations and implement interventions based on these evaluations. The client population includes children and adults whose physical disabilities may affect their ability to use the standard computer keyboard and mouse.

Design

A user-centered design process is being employed throughout the project to identify user needs and evaluate potential ways to meet those needs. Structured methods of obtaining user feedback have been used from the initial stages of the design process, including written scenarios of use to get feedback on user goals and desirable system features, and walkthroughs of hypertext mockups of the design to gain feedback prior to actually coding the design [7]. The major components in the system will include the evaluator interface, client interface, and report component.

Evaluator Interface. Used by the professional performing the assessment, this allows the evaluator to configure and perform new client assessments and review the results of previous assessments. Structured support is provided for evaluations that are the most common, in order to efficiently guide the evaluator through the process. One way to accomplish this is through the liberal use of default settings at all levels of the interface. At the top level, entire assessment protocols may be selected to allow, for example, comparisons in performance between two candidate input devices. At a lower level, parameters defining the details of specific tests (e.g., number of trials, type of stimuli, etc.) are set by default to provide simplicity and consistency in the evaluations. The evaluator can override these default values as desired.

Client Interface. Used by the client who is being assessed, the client interface presents the actual assessment tests and collects the performance data resulting from them. The client interface for the prototype system will test the skill families of keyboarding and pointing skills. These skills are assessed through a hierarchy of tasks which tap into successively more complex aspects of the overall skill. For example, keyboarding tasks, in order of complexity, include matching single keys, key combinations, single words, and sentences.

A hierarchy of complexity helps accommodate differing client abilities. For example, matching single letters of the alphabet or color-coded keys may be a more appropriate assessment of keyboarding skill in a young elementary student than transcription of full sentences. The hierarchy also provides a way to isolate the physical component of the task from its perceptual and cognitive aspects. As one moves up the hierarchy, tasks incorporate more perceptual and cognitive skills. Performance on higher level tasks may be compared to that at the lower level of the hierarchy to reveal how perceptual and cognitive issues affect keyboarding for a particular client [8].

Report Component. This presents a variety of views of the assessment data to help the evaluator and client understand and interpret the results. The evaluator is the primary person who interacts with this component, although the resulting output will be useful to a variety of individuals, including clients and their families, insurance companies, and physicians. The view/report component supports multiple views of the data. For example, performance may be examined across time, to show how a skill is changing with experience, or across different task configurations, to show how skill depends on the type of configuration being used.

Development

The current prototype is being developed for the Macintosh platform, as it is very common in schools and assistive technology clinics. We are using HyperCard because it allows very efficient implementation of complex prototypes.

As of January 1997, development has focused on prototyping different variants of the evaluator interface and obtaining feedback from potential users. The basic framework for the evaluator interface is now complete. Tests have also been developed for two keyboarding tasks: single letter matching and sentence transcription. By June 1997, we expect to have at least preliminary versions of all keyboarding and pointing tests. Final refinements will be completed by September 1997.

Evaluation

In addition to the user-centered design process described above, which provides for continuous evaluation during design and development, two formal evaluation phases are planned. The first is bench testing, to assess the prototype's technical feasibility. This includes measures of correctness, cost, reliability, and speed. Bench testing will measure response time for all functions in the system and allow us to identify components that need to be made more efficient.

The second evaluation phase is clinical testing, to assess the extent to which the prototype is functional and usable from the perspective of actual target users, including both evaluators and clients. Clinical testing will occur at two sites: the New Horizon School in Ypsilanti, MI and the University of Michigan Medical Center in Ann Arbor, MI. Four evaluators from each site, including rehabilitation engineers, occupational therapists, and special educators, will test the prototype with a total of sixteen clients.

In the first stage of clinical testing, evaluators will use the system with non-disabled individuals to ensure that it incorporates the desired functions and to rate its usability. They will be asked to assess a colleague's keyboard and pointing skills, using each of the tests supported in the system, and generate a summary report of the results that matches a supplied sample report. Evaluator-colleague pairs will be observed by an investigator, and the session will be videotaped to record the evaluator's behavior in interacting with the system. Following the mock assessment, evaluators will complete a survey which asks for interface feature requests, bugs, the time required for the assessment, and judgment of the system's usability and usefulness. The assessed colleagues will fill out their own survey regarding the clarity of the assessment tasks, their level of interest in performing them, and any sources of confusion in the tasks.

In the second stage of clinical testing, the evaluators will perform assessments with actual clients. The testing and analysis protocol to be followed will be identical to the first stage testing, except that evaluators will be free to select the assessment tests and reports that are most appropriate to the particular client.

Discussion

Although it is still quite early in the project, we have been encouraged by the feedback we have received so far. The primary challenge in meeting our design criteria is to find an appropriate balance between power and simplicity. We hope that by working with users throughout the project, we'll strongly enhance our chances of providing relevant features while maintaining ease-of-use.

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AN EVALUATION OF KEYBOARD-ONLY ACCESS TO WINDOWS FOR "SINGLE-DIGIT" TYPISTS

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ABSTRACT

This paper describes the current status of keyboard-only access to Windows 95 for *single-digit typists* — individuals who operate a computer with one finger, toe, or stump; or who use a head-stick, mouth-stick or similar appliance. The analysis emerged while planning and implementing an accommodation for an adult who types with one toe. The paper asks whether keyboard shortcuts are usable in practice; establishes requirements for Windows-compatible expanded keyboards; and highlights barriers faced by anyone who demands keyboard-only access to Windows.

BACKGROUND

Manipulating a mouse or other pointing device may be difficult for people who type with a single finger, toe, or stump; or who use a head-stick, mouth-stick or similar appliance. Computer accommodations for these people — who henceforth will be referred to as *single-digit typists* — generally include a regular or modified keyboard; key latch software; and perhaps mouse emulation software or a pointing device. Most single-digit typists use sticky keys to capitalize letters, and have difficulties using conventional pointing devices.

For better or worse, Windows 95 (and its inevitable successors and spinoffs) seems destined to become the standard personal computer (PC) operating system (OS). A number of related developments give rise to the hope that the Windows environment is fully accessible to keyboard-only users:

1. Microsoft incorporated hundreds of keyboard shortcuts directly into the OS. See, for example, *Microsoft Windows Keyboard Guide* (1), a comprehensive list of keyboard conventions that are supported by most Windows 95 and NT 4.0 applications.

2. Microsoft encourages software developers to build programs that can be operated by keyboard alone. *The Microsoft® Windows® Guidelines for Accessible Software Design* states that "An application should be designed so that a mouse is not required for its use." (2)

3. Microsoft bundles *StickyKeys* with Windows 95. Unlike some other key latch programs, *StickyKeys* allows latching *and* locking of the three modifier keys (Shift, Alt and Ctrl). This feature is necessary to use keyboard shortcuts to full advantage.

4. Windows 95's mouse emulation software, *MouseKeys*, gives the user control over the pointer via sixteen keys on the numeric keypad. Greater precision is achievable by using *MouseKeys* in conjunction with *StickyKeys*.[1]

OBJECTIVE

Nothwithstanding these recent trends, questions remain about the viability of keyboard-only access to Windows 95 for single-digit typists. This paper explores three issues:

1. Windows is arguably the most mouse-intensive computer environment ever devised. Functionality is highly concentrated in the pointing device. The new "shortcut menu," for example, normally is activated by clicking

[1] For example, to select a columnar block in Word 7, lock Alt *and* press the drag lock button (keypad 0). Then use the directional mouse keys to select text.

mouse button 2 on a screen object. Toolbars, which are not easy to access by keyboard, are now ubiquitous. Although keyboard equivalents for mouse functions exist, the question remains as to whether they are usable in practice.

2. Single-digit typists often benefit from using modified keyboards, i.e., keyboards that are extra-large or small, adjustable, programmable, reconfigurable, made for left-handed people, and so on. To the best of my knowledge, all IBM-compatible adapted keyboards (and the interface systems that allow them to communicate with a PC) use their own proprietary sticky key and mouse emulation software. Three expanded keyboard systems were evaluated to determine their compatibility with Windows 95's accessibility options.

3. Not all software developers provide good keyboard interfaces. In these cases, how efficiently and effectively can applications be used by keyboard alone?

APPROACH

I conducted this research while providing accommodation services to an adult with cerebral palsy. He was enrolled in a training program to upgrade his computer skills. His most reliable control site is his left foot, and he prefers to type with his big toe. He cannot easily manipulate a pointing device. I was assigned to select and adapt a Windows 95 system, and train him to use it. Over eight weeks I taught him Windows 95 basics, a word processor, an e-mail program, a Web-browser, and access software.

DISCUSSION

Mouse keys vs. keyboard shortcuts

Keyboard-only access to Windows is possible with a standard keyboard using *MouseKeys*. However, not everybody can use *MouseKeys*, and the technique is extremely cumbersome. A simple drag and drop operation may require ten different keys and 30 or more keystrokes. Choosing an item from a pull-down menu is easier, but still tedious.

Keyboard equivalents, on the other hand, are quick and positive. For example, in Word 7, pressing a three-key sequence selects "*Page Setup...*" from the "*File*" menu: Alt, F, U (or F10, F, U). Clearly, single-digit typists benefit from using these shortcuts whenever possible.

Access problems with expanded keyboards

Not all expanded keyboards are equal to the task of keyboard-only access. A single-digit typist can take full advantage of Windows 95's keyboard interface only if all keys on the standard keyboard are available. In addition, the keyboard must support latched *and* locked modifier keys, singly and in combination, with all keys, including the mouse keys.[2] Unless these criteria are met, functionality will be compromised.

My client and I considered three expanded keyboard systems: the Intellitools *IntelliKeys*; the TASH *WinKing*; and the *Unicorn Model II* keyboard/*DARCI TOO* Computer Control Device. Neither the *WinKing* nor the *Unicorn/DARCI* met these criteria. The *IntelliKeys* satisfied both.

Other factors (relating to the size and spacing of the keys and his seating posture) compelled us to choose the *Unicorn/DARCI TOO* system. He liked the bigness of the *Unicorn*, and was willing to trade a modicum of function[3] for long-term physical comfort.

There is no "perfect" expanded keyboard for single-digit computer work. When helping a single-digit typist select a new keyboard, tradeoffs must be made between productivity, tech-

[2] For example, to switch between three (or more) tasks using the Alt+Tab shortcut, Alt must be locked.

[3] *DARCI TOO* does not support mouse button 2 (keypad-minus); mouse button 1+2 (keypad-*); and locking modifier keys. Microsoft *StickyKeys* do work — albeit unpredictably — in conjunction with *DARCI TOO*.

nical features, health and safety factors, and personal preferences.

Access problems associated with Windows 95

Problems associated with keyboard-only access to the OS itself are minor, but need to be addressed. A few examples:

The *StickyKeys* flag, which provides valuable feedback to single-digit typists, is extremely small, and may be hard to see. Furthermore, the flag does not differentiate between latched and locked states.

A number of features of the OS cannot be accessed without the mouse pointer. Paradoxically, there is no keyboard equivalent to invoke one of Windows 95's accessibility features, the floating modifier key status window.

Some keyboard shortcuts are onerous. For example, Ctrl+Esc, Esc, Tab, Tab moves the focus from the current task to the desktop. (Keyboard shortcuts that are based on the two new Windows keys are unavailable to individuals who use expanded keyboards.)

Inconsistencies in the keyboard interface complicate access for keyboard-only users. For example, there are two techniques to move focus between tabbed pages in a dialog box: Ctrl+PgUp, Ctrl+PgDown and Ctrl+Tab, Shift+Ctrl+Tab. In some contexts, the first method works; in others, the second; and sometimes both methods work.

Access problems associated with Windows 95 applications

Significant barriers to keyboard-only access stem from developers who ignore keyboard interface design standards, such as those set out by Vanderheiden & Lee (3), Microsoft (2), and others. Ironically, Microsoft's own software products occasionally miss the mark. For example, in Word 7: certain help screens ignore navigational keystrokes; files displayed by the "*Open*" and "*Save As...*" dialog boxes cannot be sorted without a pointing device; and the "*Open*" dialog box is difficult to use because keyboard navigation begins near the bottom of the box instead of the usual position at the top. These barriers are maddening to users and completely unnecessary, given that the principles of accessible software design are widely known.

Conclusion

The keyboard interface of Windows 95 is basically accessible, but not especially usable. Developers, manufacturers and users must cooperate to define new standards for accessible, usable keyboard *and* graphical interfaces.

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SURFING THE INTERNET WITH AN AAC USER

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ABSTRACT

In this paper we describe our successful efforts to connect an AAC user to the Internet. The challenge was to find a workable interface solutions that permitted Internet access through an AAC device. The result of this endeavor has opened the Internet to this individual and allowed him to communicate and gather information in a way that makes his communication challenges transparent.

BACKGROUND

We have been researching methods to increase communication rates and ease of access for AAC users. In one of our projects, we incorporated the assistance of an AAC user in the development and testing of a reusable text system[1]. We interfaced his Liberator™, a communications device manufactured by the Prentke Romich Company (PRC), through a T-TAM™, an emulating interface device also manufactured by PRC, to a Macintosh™ computer to facilitate navigation control of the reusable text application. Our initial studies showed that the AAC user faced a tremendous learning curve simply in controlling the application.

OBJECTIVE

We are developing a "next generation" reusable text application on a Windows™ based personal computer (PC). Thus, our original goal was simply to get the AAC user familiar with controlling a Windows environment prior to testing our application. Motivating the AAC user to practice using the Liberator to navigate a Windows environment while the application was in development was actually very easy. Since the user showed great interest in the Internet, specifically in the acquisition of information pertaining to chess, we decided to set up this user with an Internet connection in his home. What we discovered might be of interest to other AAC users and those in their support networks.

APPROACH

Since controlling a Windows environment and Internet access was not the primary focus of our original research, a simple trial and error approach was taken to find solutions to several issues associated with interfacing an AAC device to the PC.

First, a method was necessary to meet the functional requirements of keyboard and mouse input. Then a method to enable an AAC user to enter control key sequences, where several keys would have to be pressed simultaneously to execute the desired command, would have to be devised. Finally, the AAC user would have to be taught how to use each part of the system. Therefore, we strongly desired to keep the entire system as simple and familiar as possible.

METHOD

First we connected the Liberator's serial port to one of the communications ports on the back of the PC using a specially configured serial cable from PRC. Second, we loaded PRC's Mouse Interface and Keyboard Emulation (MIKE) software. MIKE provides all the necessary keyboard, mouse, and menu commands to maintain full access to a PC by emulating the functionality of a keyboard and mouse on the Liberator in two distinct themes.

Next we loaded and configured the Access Pack software developed by the Trace Center at the University of Wisconsin in conjunction with Microsoft Corporation. This application, now included in all Windows operating systems, uses a "sticky key" concept to facilitate key combi-

nations which start with control, shift, alt and escape. This application allows the user to press two and three key combinations, such as control-shift-A, in three individual key strokes by remembering what was pressed immediately prior. This is crucial for interfacing the Liberator directly to the PC. AAC users may not possess the fine motor coordination necessary for simultaneous two and three key combinations. Also, the Liberator's keyboard theme is designed for single key input, where each icon represents a key on a standard keyboard, but each icon is sent to the PC immediately after it is depressed.

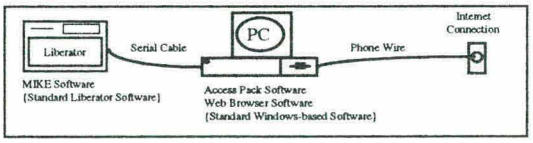

Figure 1.

After the Liberator was successfully interfaced to the PC and the PC was connected to the Internet, most of the work of learning how to use this system was done by the AAC user. The user began learning the keyboard and mouse theme overlays that MIKE provided on the Liberator, and the navigation controls provided by Windows and each Windows application. Two hours a week were spent helping the AAC user to learn the various applications on the system, such as a web browser, e-mail, etc. Most of this time was spent reviewing many of the application and operating system-specific control sequences that could improve navigation control for an AAC user. However, the typical scenario was the AAC user demonstrating what he had learned on his own.

RESULTS

Our original goal was to simply make the AAC user more proficient in controlling applications in a Windows environment. What we discovered in the process was encouraging for all AAC users.

In today's society it is becoming difficult to find anyone who does not know someone with an e-mail address. This is also true of our AAC user. It turns out he had several family members and friends who were already on the Internet. This opened a whole new line of communication to these people, bypassing the typical delays and limitations AAC users encounter. It did not matter how long it took to compose a message or how many revisions it went through. After the message is sent over the Internet the person receiving it would not know of these communication limitations unless they personally knew the AAC user.

Since the AAC user was interested in chess on the Internet, he found and downloaded an interactive application which allows members to play rated chess games over the Internet. Now instead of having a volunteer write his moves on a postcard and mailing them to the other player, the AAC user could play games in real time without any assistance. This is quite an improvement from his previous routine.

DISCUSSION

We have all heard of people becoming addicted to the Internet, but in our case, this virtual world has created new unrestricted opportunities for an AAC user. This excitement has spread from the AAC user to his family, friends, and acquaintances. Other family members are purchasing equipment and Internet access, so they too can communicate with the AAC user devoid of several difficulties present in current methods. Who would have thought something as simple as e-mail would have such a profound effect on the life of an AAC user.

Several equipment failures were encountered due to lateral stress on the serial port of the Liberator, as well as the cable itself. Access to the Internet for an AAC user is more than a toy, hobby or alternative means of communication. Rather this AAC user came to depend on his Internet access as a primary means of communication with a rapidly growing number of people. This meant that down time due to equipment failures could not be tolerated as easily. We attempted to fabricate sturdier ca-

bles, but to date we have only increased the time in between equipment failures and have yet to eliminate this problem. The Prentke Romich Company has recently released the "Director II IR." This is an infrared serial communications device, in which one portion of the device will attach directly to the Liberator's serial communications port and the other portion will attach to the PC via the communications port. This will allow the AAC user to maneuver his wheelchair and Liberator device in a line of sight to the PC and remotely control his PC with the Liberator without any cables between the PC and Liberator.

Another situation we are attempting to facilitate is the movement the cursor in the mouse theme. We noticed whenever he encountered a situation where the selection zone of an object, icon or web link was relatively small on his video display, it was difficult for the AAC user to move the cursor over the desired object. MIKE's mouse theme provides three degrees of movement (small, medium and large) with each direction. While this has proven to be sufficient for a majority of the applications, there are enough situations where this selection zone is too small for this method of cursor movement. Therefore, we connected a Microsoft EasyBall™ to facilitate an alternative means of cursor navigation. Although the AAC user felt he could move the cursor easier with the EasyBall, it was still necessary to change from keyboard theme to mouse theme on the Liberator so the selection could be made by using the "single click" action on the mouse theme. Future investigation is still necessary to find a solution which facilitates simple cursor navigation and selection in current web browsers.

While the Internet has made a profound impact on the lives of many people, it has yet to make its full impact known on the segment of society who use AAC devices. In closing, we can see no better way to convey this impact than a few quotes from an AAC user who has touched this virtual future.

When asked his thoughts on his new access to the Internet, this AAC user stated, "It is like having the whole world at your fingertips. When I make a phone call, I usually need a third person to dial and translate for me. Now, with e-mail I can talk to my brother privately, independently and when I feel like it."

It is certainly difficult for anyone to express such a deep emotional feeling. However, this short story, which this AAC user gave at a recent conference, may give us some indication: "The first Friday of the NCAA basketball tournament, someone asked me to show them how my Liberator works with the computer and the Internet. During this time, I had my television off. When I was done showing her what she wanted to see, I put the television back on. The game I was watching was over and the station was not showing the final score. I was on the Internet anyway, so I went to the ESPN Sports Zone. I was able to get the score I wanted inside of two minutes. I did feel really powerful that day!"

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SPEECH ARTICULATION AND HEARING PERCEPTION SOFTWARE FOR THE WEB

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ABSTRACT

The interaction between audio and visual information has been an interesting, and complex, research field for many years. A simple example is the well known fact that the perceptual quality of a video can be significantly enhanced if it is associated with high-quality sound. For human speech perception, audio-visual interaction is even more prominent.

Fonetix is a multimedia software kit developed for the Web for improving speech and hearing perception. The initial phase involved development or modification of existing Web applications to accommodate interactive repositories of audio and video and an assessment of the most appropriate aspects of speech therapy that can effectively deployed on the Web. This included the display of animated mid-sagittal views of the vocal tract in real-time on Personal Computers.

BACKGROUND

Several existing speech programs allow patients to experiment with notions of pitch and volume but are of limited benefit without a speech pathologist present to assist in improving the person's speech. Fonetix addresses this issue by being Web-centric, using the Internet to provide interaction between the patient and therapist, albeit remotely. Fonetix also includes animation which allows the person to see how the mouth, tongue, teeth, and lips (Oral Cavity), are used in producing phonemes or isolated words. The Fonetix system permits users to see in a graphical and an easily comprehensible way how closely they approach the targeted speech pattern.

Fonetix also provides valuable comments and suggestions on the modification to articulation needed to improve speech. This is useful for patients in rehabilitation, who have problems with speech, resulting from various injuries such as; stroke, brain damage, hearing loss, and head injuries, as well as for students who are learning English as a Second Language (ESL). The types of tools being developed here are intended to augment current practices and techniques being used by speech pathologists.

An immediate advantage of Fonetix is that, it is being developed for the Web and takes advantage of the exiting Internet and associated application development environments.

SYSTEM DESCRIPTION

Attempting to model a native speaker's pronunciation of a word is difficult because the place of articulation is often not apparent, especially for phonemes like /r/ or /sh/ where tongue position is not visible.

Fonetix software has been developed to address this problem whether in speech therapy or learning (ESL) with a real-time display of the vocal tract. This is accomplished by using both animation and video.

Furthermore, the prototype system allows the patients to record audio and video of his/her speech. Real-time comparisons of the captured and repository video can then be played back and compared. This provides an effective mechanism for bio-feedback. In the future these comparison can be automated using techniques such as artificial neural networks as the computational power of the desktop

computer evolves. Figure 1 provides an illustration of the major clusters and trajectories through the Fonetix system.

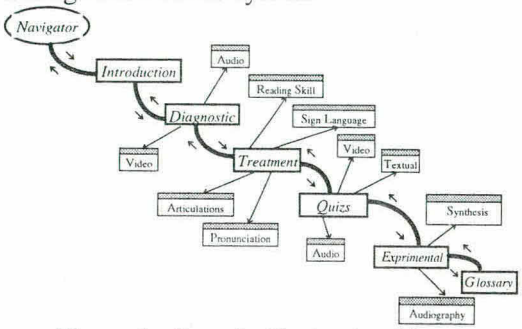


Figure 1. Fonetix Navigation Clusters

Fonetix is intended to run on any type of personal computer with a standard audio and video card (Fig. 2). The audio card records the voice through an ordinary microphone that plugs into the digitizer, and video is recorded from an ordinary camera that plugs into serial port or video editing board. This allows the user to record and the view aspects of the oral cavity during speech production.

The system produces an animated mid-sagittal picture of the vocal tract. Speech segments are displayed in an idealized manner, as if they were spoken by a native English speaker.

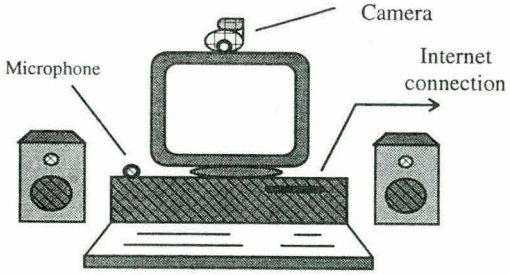


Figure 2. Fonetix Multimedia Kit

Since the goal of speech therapy is to articulate words accurately, regardless of compensatory muscle movements that may be used, Fonetix can also be used to produce appropriate feedback based on the audio alone. It would be disheartening for a stroke patient, for instance, to be informed that a vocal tract position was unacceptable, even though he had produced the correct sound.

FEATURES

In the development of the Fonetix prototype a new phonetic alphabet was used. This alphabet is similar to International Phonetic Alphabet (IPA) which is widely used by phoneticians, linguists, and speech pathologists. The new alphabet was required to support font types which are Web friendly and supported by commercial browsers. The Fonetix system involved the development of graphical animation and application software (Fig. 3). This included the use of commercial video and audio editors to produce and display animation of places of articulation.

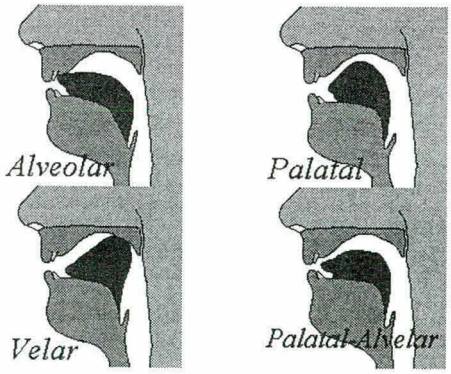


Figure 3. Articulation Animation

USER DEMONSTRATIONS

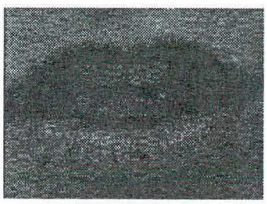
Fonetix shows an idealized vocal tract, and displays how a native speaker would produce the correct sound.

The program has been optimized to handle the sounds that are the most frequent problems in speech therapy: vowels, liquids (L/R) and certain fricatives (th/S/ sh/Z/zh and ch). These are sounds that cannot be modeled simply by looking at the lips.

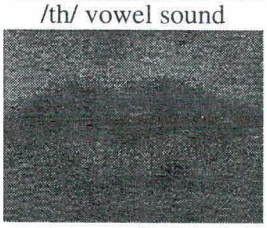
Capturing video and audio the oral cavity of the user allows for playback for visual comparison within Fonetix.

The Fonetix program is currently running on Netscape or any Web browser program, using audio and video tools for communication. It should be stated that we are not interested in a stand alone program but one which has remote training applications. By having similar equipment at the speech pathologist's offices, we are able to monitor and have interactive feedback with the patient remotely.

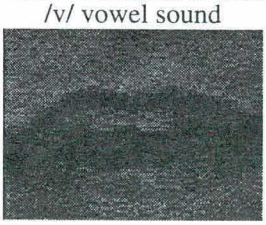
Fonetix also includes articulation animation/video (Fig. 4) for all English vowels, liquids and many isolated words. A database of similar sounding words offers a practice section for recognition and improved differentiation. A movie database of words and practical sentences is also included which the patient can download or view.



/th/ vowel sound



/v/ vowel sound



/L/ vowel sound

Figure 4. Fonetix Video Examples

SUMMARY

A Web based application has been prototyped to assist hearing impaired persons in the production and recognition of speech. Fonetix has been written to be as platform independent as possible using Java and JavaScript as the development language. This will allow easy access from any browser on the Internet facilitating remote speech pathology. Extensions currently under development include facilities for remote monitoring of progress and remote interaction with a pathologist. The Fonetix Web site can be found at,
http://www.ee.umanitoba.ca./~morawej/Speech

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ASSESSING USER PROFICIENCY THROUGH VIRTUAL SIMULATIONS

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ABSTRACT

This paper describes a virtual simulation environment used for the following: 1) evaluating architectural designs, prior to construction, for ADA compliance, 2) as a simulation environment to provide users with appropriate training for power chair upgrades, and 3) as an environment for assessing the proficiency of users for using power chair equipment. We describe the configuration of the system, its hardware and software components, and our methods to improve the users' sense of immersion. Finally, we present our current focus on system improvements used for assessing user proficiency.

BACKGROUND

Trial and error has traditionally determined whether following construction guidelines provides adequate accessibility for handicapped people. We have developed a system that integrates computer visualization with innovative interface technology to create a virtual environment that simulates the movement of a power wheelchair through synthesized architectural environments. The objectives of this project are to investigate simulation technology for accessing architectural data sets, to provide an environment for user training, and to provide a vehicle for health-care providers to assess the proficiency of users for using power wheelchairs. In previous publications, we have presented work on developing a virtual platform for the virtual simulation of navigating through pre-visualized architectural data sets for assessing compliance with ADA standards (Carlson et al. 1994, Swan et al. 1994, Stredney et al. 1995). In this paper, we focus on methods to increase the users' sense of immersion and the integration of the simulation environment for assessing user proficiency.

RESEARCH QUESTION(S)

The overall objective of this effort was to create a robust simulation environment that provides a tool for three groups of people:

1) for architects and designers, it provides structure previsualization and analysis that can both improve the handicapped accessibility of building designs and test structures for compliance with the Americans with Disabilities Act of 1990

2) for wheelchair users, it provides a robust simulation environment for assessing more appropriate device fitting and training with wheelchair control systems

3) for health care professionals, it provides a system for assessing user performance and for determining the best power chair control mechanism for a particular patient.

In addition, our charge was to explore the development of new software and integration of interface equipment to increase the realism and accuracy of the simulation for both the user and the evaluator.

METHODS/RESULTS

The simulation environment includes a high-end graphics workstation capable of providing stereo images. We have chosen a Silicon Graphics IRIS Crimson VGXT™, with a 150 MHz R4400 CPU and 16MB of RAM running IRIX 5.3™. The monitor provides stereovision through a pair of CrystalEyes™ polarized

viewing glasses manufactured by StereoGraphics.

Our system uses SGI's Performer™ libraries, which are optimized for efficient rendering on Silicon Graphics computers and therefore facilitate real-time frame rates for visual data bases. We have implemented a more efficient visibility preprocessing algorithm, in addition to the use of Performer, to handle architectural models.

Our software has been ported from its original Performer 1.2 implementation to Performer 2.0 in the past summer. In our previous implementation (Performer 1.2,) we've seen about 30-50% performance increase over the non-VP version in a small test model. We expect to see improved rendering speeds with more complicated models. We are modifying the scene data base format to facilitate integration with Performer 2.0. We will then compare this using a large model or replicating the current model .

There are two advantage of incorporating visibility preprocessing. 1) We gain increased performance for a given model, and 2) it allows us to use much more complex environments, thereby increasing the sense of immersion for the user. This increase facilitates our objective of evaluating architectures for ADA-compliant design. In architectural models, many detail features such as chairs, desks, and interior decorations are scattered in different rooms. The preprocessing uses space subdivision and cell-based visibility algorithm to cull model details that are not visible from a "cell" (a subdivided space region). We take advantage of the occlusion caused by wall connections to decide the cell visibility.

The system's user interface is simple. The wheelchair is connected to the workstation with a standard RS232 serial cable. The user sits in an Invacare Action wheelchair utilizing a standard joystick interface. The user dons the CrystalEyes glasses, and through the joystick control, navigates through a computer-synthesized environment. The system depicts the dynamics of the wheelchair in the particular environment. The virtual chair moves with the same speed and turning radius as a chair in the physical world. The system easily supports chairs with different control mechanisms. Invacare's power chairs are fitted with a variety of controls in addition to the joystick, including a chest muscle actuator, a halo device, which detects the tilt of the user's head, and a sip&puff device, which the user controls with their breathing. Wheelchairs with any of these control mechanisms can be instrumented with a serial computer interface. When the chair is connected to a computer, we disengage the motors so the chair does not move while connected to the simulator. The speed and direction of rotation of each of the wheelchair's wheels are sampled through the serial interface.

In addition. we have integrated a 2 degree of freedom force reflecting (haptic) joystick developed by Immersion Corporation This joystick allows both passive feedback (braking) and active feedback (applying a 2D force to the joystick). Both methods are used in our simulation. In passive mode, the joystick will discourage the user from going towards obstacles by making it harder to push the joystick in that direction. For example, if the simulation is facing down a narrow corridor, the joystick will allow only travel forwards or backwards and restricts the user from steering into a wall. The strength of the response of the joystick is proportional to the proximity of obstacles.

In active mode, the joystick exerts a force that will guide the user towards a less-congested direction. As the user steers towards an obstacle, the joystick will provide a moderate force to guide the user away from the obstruction. The correcting force becomes proportionally stronger based upon both the velocity of the chair and proximity of the obstacle. Descriptions of trials that investigated integration of a haptic joystick can be found on the Web (WEB96).

Our colleagues who evaluate individuals for upgrade to power chairs are interested in reaction times and cognitive disorders, such as side neglect. In response, we have implemented a graphical user interface for the healthcare evaluator to interact, albeit surreptitiously, with the user and the environment. This interaction can take place

on a remote workstation, provided it is capable of running the same software. The evaluator sees both a subjective camera from the viewer's perspective, as well as a "god's eye" view of the environment and the location and movements of the user. The evaluator can trigger a movable object (e.g., a representation of another human) to move toward the wheelchair user in a certain speed and trajectory. While watching the patient remotely, the evaluator can observe the reaction of the patient to that obstacle. This observation includes simple tracking, such as the number of collisions the user undergoes, which location (left, right, front or back), as well as the reaction response to the moving object. We are integrating a head mounted display with the system. Our goal is to provide the precise location of objects in the user's field of view at the time of reaction. All of this information is automatically filed for the evaluator, providing a comprehensive analysis of the user's performance.

DISCUSSION

To date, we have developed a robust system that provides previsualization of architectural data sets and assists in assessment for ADA compliance. In addition, the system provides an immersive environment for users to train themselves in the use of a powerchair, therefore limiting the application of unsuitable technology that may never be fully, or even partially, utilized.

In addition, we are completing an evaluator's environment for trials to evaluate individuals in power chair proficiency. The system provides a wide range of interface devices for both simulation of chair interfaces as well as simulation interfaces for creating an immersive simulation.

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WEB: www.osc.edu/Biomed/wc.html

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3D GRAPHICAL ANTHROPOMETRIC MODELS OF CHILDREN FOR THE CREATION OF REHABILITATION AIDS

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ABSTRACT

The objective of the work presented in this paper is to create a complete 3D graphical anthropometric model database of children [Figure 1], which is to be used in the creation of rehabilitation aids. This creation of model altering "behaviors" has produced a unique resource for envisioning the changes of the geometry of a child over time. This model database is the result of an effort to use new computer visualization techniques to help reduce the cost of rehabilitation devices.

INTRODUCTION

This research is a small part of a consumer focused design program investigating methods of product design that are adaptable to consumer needs, are cost effective and exploit new methods of rapid prototyping. This includes exploring ways in which virtual models and computer visualization software can be used to reduce the cost of designing rehabilitation devices [1]. Part of this work focuses on creating software tools and resources for designers, which will assist them in the creation of new devices.

BACKGROUND

A major consideration in the recommendation of rehabilitation aids for children is the amount of usability a child can get out of a device. The Winsford Feeder [3] and the Magpie [2] are examples of widely used rehabilitation devices which are suitable for a wide range of disabilities. However, the major disadvantages of these devices are their inability to be readily adapted, their long manufacturing time and their high cost.

To avoid these problems in the future, a method of designing and fabricating rehabilitation devices has been proposed that attempts to separate the user interface design from the supporting features design [5]. The fundamental assumption of this method is that most of these supporting features can be acquired from conventional design techniques, whereas the user interfaces must be customized for each individual. This project has adopted this methodology and attempts to help the designer in identifying

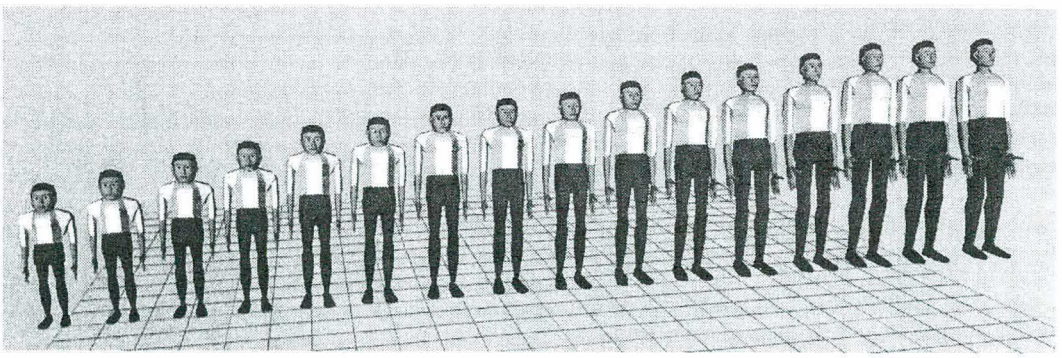

Figure 1: The 3D Graphical Anthropometric Model Database of Children, Ages 2-19

the configurable and extensible features of a device by enabling them to interact with a virtual model of the device. By having the designer experiment with virtual computer models, as opposed to the costly and time consuming fabrication of physical prototype models, this approach reduces the cost of device design and production.

The difficulty in identifying these features is the lack of tools and resources for the visualization and alteration of human models which exhibit dynamic attributes. This research addresses this problem by creating a 3D geometric model database of children, which is capable of representing those dynamic features.

METHODS

A 3D graphical anthropometric model database of children has been created to help designers see how the physiology of a child changes over time. This model database enables the designer to visualize changes in a child, such as aging, and its effect on the usability of rehabilitation devices.

This aging is accomplished by model altering "behaviors" which change the geometry of the child model to simulate the anthropometric changes of aging. "Behaviors" in this context can be defined as an automatic process which interpolatively alters the geometry or attributes of a 3D graphical model via a dependency variable or multiple dependency variables. In most cases this dependency variable is time. These "behaviors" can be used to alter such articulated model attributes as geometry, kinematics and strength.

Currently this project has implemented a database of 3D graphical models of children ages 2-19, which are based on the anthropometric data gathered for the Consumer Product Safety Commission in 1977 [5]. The database contains data for the 5th, 50th, and 95th percentiles of 16 groups ages 2-19. In creating this 3D geometric model database from this data, the following steps were taken:

1) Computerize the Consumer Product Safety Commission anthropometric data using an desktop scanner and optical character recognition software
2) Process the anthropometric data and create 16 separate anthropometric girth databases for the JACK human modeling software
3) Generate 16 model geometry data files from the 16 separate anthropometric girth databases

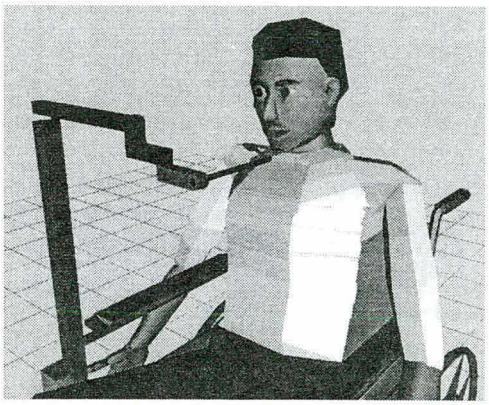

Figure 2: Child model age 14-15 and an adapted Magpie

The 3D graphical models are displayed to the designer on a Silicon Graphics Indigo, using JACK, a human modeling software application which allows interaction with articulated geometric figures. JACK is the software medium by which the child model and the altering "behaviors" are displayed to the designer and through which the designer interacts with the models of the child and device they are designing..

DISCUSSION

The aging "behavior" allows designers to understand what features of the mechanisms they design should be adaptable. By having an anthropometrically correct model which can

be interactively aged, a designer can better visualize the consumer of a rehabilitation device. This aging model also allows the designer to predict how many years a device will be ergonomically usable by a consumer and will enable the designer to alter the design of the device so that it will be more adaptable to the consumer's aging.

This anthropometrically dynamic child model also helps the designer realize what aspects of the device design can be fixed and which aspects need to be variable from user to user and also variable as the consumer naturally ages and changes over time.

CONCLUSION

Further work is now in progress to implement additional model altering "behaviors". Some of these other "behaviors" already exist, but have been designed for a full-size human model as opposed to an age range of child models. These "behaviors" include joint strength and linkage stress. Also underway are some more complicated "behaviors" which can alter other "behaviors". Some examples of this are: 1) fatigue based "behaviors", which reduce strength of the child model over the time and 2) disability specific "behaviors", which alter the size, strength & fatigue "behaviors", in a manner which is characteristic of a particular disability. The complete 3D graphical anthropometric model database of children is available on the world wide web from the Applied Science and Engineering Laboratories' Assistive Device Model Library:

http://www.asel.udel.edu/rapid/virtual/models/

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ACKNOWLEDGEMENTS

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SIG-12
Rural Rehabilitation

TANGO WITH 'TELLY' THE TELEASSISTIVE TECHNOLOGY DEVICE

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ABSTRACT

The Underwood Advanced Technology Center (UATC) has developed a method of utilizing teleconferencing to deliver assistive technology to rural Texas. The prototype that has been developed by UATC can be left in the remote setting following the assessment and can be used to provide training, follow-up patient monitoring, and trouble shooting if needed.

Background Texas has many remote and sparsely populated areas. There are few professionals in these areas available to serve on a rehab team in he evaluation of an individual needing assistive technology. Due to its location on the campus of Texas Tech University (TTU) and it affiliation with the Texas Tech University Health Sciences Center (TTUHSC) the UATC can provide the rehab team members that are missing in the remote areas and are necessary to perform a comprehensive evaluation of an individual needing assistive technology. This has been accomplished by the development and use of "Telly" the teleassistive technology unit.

OBJECTIVE

"Telly" was designed by UATC to accomplish the evaluation of individuals who need assistive technology and live in remote areas and to provide an avenue for follow-up training and patient monitoring if needed. If left in the individuals home, school or work place, the unit can provide a link between the individual and the professionals at UATC. This link can serve as a conduit for the supervision of additional training and monitoring if needed.

METHODS

Teleconferencing was first explored by UATC to determine if it could be used to provide a viable link between the home, school or work site of an individual living in a rural area who needed assistive technology. The initial units used by UATC consisted of an adapted PC system coupled to a camcorder. The original system used software which allowed the computer at the individual's site to communicate over standard phone line with the computer remaining in the Center. This method proved useful in increasing the amount of information that could be obtained by UATC regarding the needs of an individual in the setting where the assistive devices would be used. The movement of the individual could not be evaluated directly because

of the decreased rate of frame delivery over standard phone lines; however, the subsequent evaluation of a video recorded on site provided this information in real time. This information allows the professionals to better visualize the needs of the individual and to make appropriate recommendations as a team. In the future it is anticipated that the computer teleconferencing unit will become an assistive device itself. As such it will be left in the individuals home and will provide a direct route for the individual to assess information from the professionals regarding training, health monitoring, and general health information.

The major considerations in the development of "Telly" were:

- to be easily utilized by a person who is not computer literate
- to be easy to troubleshoot when and if it needs repairs or adjustments
- to improve the resolution of the transmitted image
- to develop a unit that can be produced as an affordable cost
- to be expandable for use as an assistive device for the monitoring of an individual needing in-home health monitoring, information, etc.

RESULTS

Sparsely populated regions do not have access to the professionals who are required for the development of a rehab team. The most feasible method of delivering this service is through the use of teleconferencing over standard phone lines. Satellite communication can be used to transmit high quality images; however, the cost is prohibitive and the unit cannot be left in place for follow-up training etc. The current system accomplishes the necessary link between the individuals home site and the center at a reasonable cost. This link can be used to solve many of the problems that exist in the delivery of assistive technology in rural areas. Future plans call for the continued development of systems capable of delivering better quality images and data for the home health care provider and the rehab team members. This will involve the development of video compression, improved video capture and delayed transmission techniques if needed, and the development of a system that can be interfaces with different health monitoring devices.

DISCUSSION

Currently, the available money for the delivery of health care is decreasing. This has limited funding for individuals who need assistive devices. In rural areas, this problem is compounded by the lack of professionals who are available to make recommendations, deliver the services and provide follow-up training. The most logical solution for this is the use of technology to improve the delivery of assistive technology in a more cost effect and efficient manner. Teleassistive technology as developed by UATC is designed to achieve this goal by incorporating the use of teleconferencing in the evaluation of individuals needing assistive technology. It will also increase the effective of the system by using a modified version of the unit to provide in home training and health care monitoring of the individual living in rural areas. The use of standard phone lines for the transmission of the signal

makes the system more accessible and at a lower initial cost as well as a lower cost of operation.

The use of technology for the delivery of health care to individuals living in rural areas is essential if we are to achieve the uniform delivery of quality service equal to that provided in cities. Future advances in technology will undoubtedly make this task easier; however, future plane must be developed now to provide a vision for the future.

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SIG-13
Assistive Robotics and Mechatronics

CLINICAL EVALUATION OF THE HELPING HAND ELECTRO-MECHANICAL ARM

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ABSTRACT

Rehabilitation robots can serve as interactive aids for performing tasks and improving the quality of life of persons with severe mobility impairments. The Helping Hand (HH) is a wheelchair mounted electro-mechanical arm that can be operated in an unstructured environment. Fifteen subjects with quadriplegia participated in a multicenter evaluation of the HH. Results indicate that the system was 1) well accepted with regard to design, appearance, and ease of installation; 2) safe and easy to learn to use and operate; 3) able to facilitate performance of a variety of tasks reliably and in a reasonable time period; and 4) considered a desirable prosthetic appliance for home, community and, especially, vocational applications.

BACKGROUND

Application of robotic systems in rehabilitation are intended to replace or augment a person's manipulative skills. In this way the robotic aid can decrease dependence on attendant care, improve self-esteem, promote mental stimulation, and permit greater mastery of the physical environment. Additionally, spinal cord injury (SCI) research has shown that increased client involvement in purposeful activity enhances personal health and increases longevity (Heck, 1988; McCormack, 1988).

Rehabilitation robotics can be divided into two main categories: workstation (fixed-location) and mobile systems. The Helping Hand, developed by Christopher Cobb at Kinetic Rehabilitation Instruments (KRI), Hanover, MA, is a precommercial mobile system consisting of an electro-mechanical arm which is mounted on the wheelchair. Persons with severe physical disabilities can operate the arm by means of their existing wheelchair control device and use it to perform a variety of tasks.

The Helping Hand is modular in design, can be mounted on either side of most powered wheelchairs, interfaces with some wheelchair controllers and is guided by the user's existing chair switching mechanism (e.g., joystick, sip and puff). The width of the chair is increased approximately one inch and the slimness of the arm minimizes blocking of the user's visual field. System weight is 11 kg. At full reach (120 cm), the arm can pick up 1.8 kg. The five degrees of freedom of the arm (more if one considers the user repositioning the wheelchair) are driven by four 24V motors powered by the wheelchair battery.

Using the terminal control device, the operator initiates the action of retrieving an object by guiding the HH one degree of freedom at a time until it is in the correct position; the user then activates the gripper mechanism to grasp the object and directs the arm to the desired end point Safety features incorporated into the design of the system include an emergency stop switch for the trainer, a limit on the grasp strength of the gripper and slip clutches at each motor.

RESEARCH QUESTIONS

The goals of the evaluation were to verify the utility, operational and performance features, required maintenance and safety of the system. The study also identified modifications that were needed to improve the HH. Seven Department of Veterans Affairs Medical Centers and the Eastern Paralyzed Veterans Association, Jackson Heights, NY participated in the evaluation.

METHOD

The study was conducted for a six month period. Fifteen persons with quadriplegia examined the HH in the medical center environment. Two participants also evaluated it in their home. Evaluation tasks were divided into two levels: Basic Tasks (e.g., retrieving an object from the floor); and Advanced Tasks (e.g., eating) during which the arm operated close to the user's head. The Advanced Tasks were performed only by subjects who demonstrated a high degree of proficiency with the Basic Tasks Set. All subjects who were proficient in the required tasks were encouraged to perform additional tasks personally useful to themselves. At the end of the trial, subjects were interviewed regarding their impressions of the system.

RESULTS

All participants had spinal cord injuries. The mean age was 43 years. The age range was from 20 years to 57 years. 87% were male and 13% were female. Injury level ranged from C2 to C6. The range of years with a disability varied from 8 months to 31 years.

All subjects and staff rated both the ease of learning to use the Helping Hand and the overall training process as very good or satisfactory. 93% of the subjects were able to operate the system safely and independently in 2 hours or less.

64% of the subjects used the system for a period of 1 to 3 weeks, and 36% used the arm for a month or more. All of the veterans rated the HH's appearance, weight and transportability as very good or satisfactory. Most of the users also rated size and compactness as very good or satisfactory.

93% of the users felt the Helping Hand performed all tasks safely. 87% of the subjects rated ease of operation, reach and reliability of the HH as very good or satisfactory. The noise level was acceptable and the power requirements on the chair batteries were minimal. The arm did not impede wheelchair accessibility nor did the weight of the unit on the lower front of the frame (behind the front caster) affect wheelchair performance.

87% of the users were able to perform all the **Basic** and **Advanced** tasks. Some subjects reported difficulty with several of the tasks. Four participants had difficulty opening the refrigerator door; the magnet force of the door was too strong. 40% of the users felt that retrieving and returning the telephone receiver required too much time and was inefficient. In addition to the designated tasks, most participants also performed a variety of user specific tasks, including inserting a diskette into a computer; inserting a videotape in a VCR and operating the unit; and feeding a cat. The trainers were able to stop the arm using the emergency stop switch or manually at any time with no harm to the HH.

Subjects who rated lifting capacity and gripper force as poor commented that they would like both to be at least 50% greater. Users rating safety, ease of operation and reliability poor all experienced technical problems with the Helping Hand while the evaluation was underway. Subjects rating overall satisfaction as poor were those who were dissatisfied with the lifting

capacity and/or gripper force or users that experienced technical problems.

DISCUSSION

The Helping Hand was well accepted by the majority of users and staff who fully participated in the clinical trials. 67% of the subjects indicated an interest in purchasing the system if it were comercially available. 62% thought the arm would assist them in obtaining employment. 83% of those employed felt that the HH would greatly increase the number of duties they could perform independently on their present job.

73% of the subjects felt that the Helping Hand would greatly expand the number of tasks which they could perform in the home and community, and would significantly increase their independence. The personal attendant who gets the user up and into the wheelchair in the morning would be required to perform some set-up activities such as preparing food portions, arranging medications, folders, or diskettes in accessible locations. However, that individual would then not be needed for a large part of the day.

The HH is an open loop system with no sensors; it does not include other features found in some robotic systems, such as voice control or pre-programming of certain movements. This is in line with the developer's goals of simplicity, maintainability and affordability. Operation of the HH is so intuitive that training time is minimal; less than one hour is typical.

Suggestions for improvements included changes in the shape of the gripper, the ability to telescope the wrist in order to extend the gripper in a more intuitive manner and increase reach, and an increase in the lifting capacity of the arm. In many cases, the addition of features conflicts with the desire to keep the HH simple to operate and affordable. Another design challenge is providing mounting brackets to fit every possible powered wheelchair, and interfacing to all existing wheelchair controllers.

Participants indicated that the Helping Hand system made them feel more independent and provided a new experience, which overall they felt to be very helpful. Subjects indicated that the HH has a great deal of potential for use by individuals with severe mobility impairments. The general consensus was that the system could be very useful in the home, community, and, especially, in vocational settings.

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VIRTUAL PROTOTYPING AND THE SWITCH SELECTION PROCESS

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ABSTRACT

This paper presents initial results from tests to determine the feasibility of virtual prototyping in customizing a human-machine switch interface for disabled users. Results will yield a method for selecting the best type of switch for the individual to control a particular device and will expedite the prototyping process by allowing interaction and feedback using a virtual model rather than physical prototypes.

INTRODUCTION

There are very few individuals with disabilities who are able to purchase assistive devices "off-the-shelf" with no modifications. Many consumers with physical disabilities rely on robotic equipment ranging from motorized feeders to remote control vacuum cleaners to live independently, so it is necessary to customize the input devices that control the equipment. Therefore, it is important to establish a method by which consumers can become involved in the selection of the input device that they will eventually use to control the product. Finally it is important to allow the user to practice with the input device to gain a working knowledge of it.[1]

A method for two-dimensional switch selection in which the user uses a switch to manipulate the cursor on a computer monitor has already been established.[2] This assessment suggests that successful selection based on a two-dimensional process will yield similar success in switch control in a three-dimensional environment. This project utilizes a three-dimensional environment through testing and selecting input devices by having consumers control prototype models in the environment.

> *Virtual prototyping can be defined as the process of planning, designing, and validating physical products or production processes in a virtual environment by using a real-time graphical system which allows a user to immerse into the simulation. In an ideal situation, the physical construction of a prototype can be omitted and the data from the virtual object can be used directly for production.*[3]

A virtual prototype has been developed that allows individuals with disabilities to select the input device that best meets their needs. In this study, a three-dimensional living room environment is graphically modeled on the computer. A remote-controlled vacuum cleaner is modeled in this living room and will be controlled by external switches such as joysticks, and four-button switches. The consumers test each switch by performing target acquisition tasks. The task performance was analyzed both objectively and subjectively to indicate the advantages of this methodology. As a result the users can be matched with the best switch for their needs. To validate the virtual prototyping process, this project seeks to develop a simulation that allows consumers with disabilities to test input devices in order to select the best one for their needs.

OBJECTIVES

Objectives for this project include:

- Creating a system that can be used to test customized input devices for individuals with disabilities
- Creating a tool that can be used to train consumers in the use of the switch and prototype model

- Improving the design process by using virtual prototyping to communicate ideas to and from consumers
- Increasing consumer input in the design process

METHODS

In order to determine the feasibility of this method, a virtual environment was developed using *Jack5.10*, a graphical software package. The test environment consists of a living-room complete with furniture and walls.

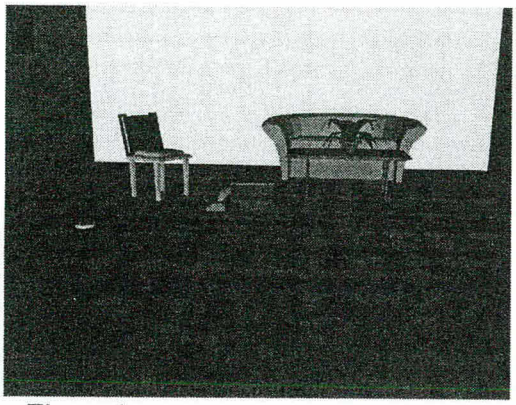

Figure 1. Simulated living-room with Autovac.

Ten circular blue targets are scattered across the floor of the living-room. A remote-controlled vacuum cleaner called the Autovac is located in the center of the virtual room as shown in Figure 1. At the beginning of the test, one of the targets turns yellow indicating that the user must drive the Autovac to that position. The user controls the Autovac using one of four different four-button switches and one of two joysticks. When the user arrives at the designated target, an audible beep is heard and the color of the target changes to red before disappearing, indicating that the user was successful. Targets continue turning yellow in a random order until all ten targets are acquired. The user must try to avoid the furniture in the living-room, but is free to run over non-highlighted targets. Six trials are performed with the user testing all six different switches.

The data collected during each trial follows:

- Time between acquisition of each target
- Distance between targets
- Actual distance traveled between targets
- Number of collisions with walls and furniture

The following switches are evaluated:

1. An 18" pad with four 2.5" circular pads indicating reverse, left, forward and right when reading from left to right
2. A small hand held box with four ½" buttons oriented in north, south, east and west, corresponding to forward, reverse, right and left.
3. A joystick with a cross plate restricting motion to 4 directions; north, south, east and west.
4. A sensitive joystick that does not restrict motion to any particular direction.
5. A button pad oriented in the same configuration as switch 2 with latching buttons.
6. A button pad oriented like switch 2, but with ¼" buttons located ¼" apart.

The experiment was designed to ensure that each user tested the same switch with the same ordering of the targets. Each user saw 6 trials during the test, and these six trials consisted of different ordering. A total of fifteen subjects participated in the study. Of those fifteen, nine were able-bodied, while six had disabilities: Cerebral Palsy, Arthogryposis, or Muscular Dystrophy.

RESULTS

Once the tests were performed the data was broken down and analyzed in three main categories: 1)The time between targets based on the elapsed time between the acquisition of one target and the acquisition of the following target, 2) The distance ratio, determined by comparing the distance covered by the user in his navigation and the actual straight line distance between two targets, and 3) Number of collisions with walls and furniture.

Analysis of the preliminary results as a whole did not indicate a "best" switch for either group. However, when each subject was considered independently, their individual results proved useful in selecting the best switch for them to control a particular device. Tradeoffs must be made between the time, accuracy and frequency of collisions as well as considering the interface that is most comfortable for the individual. Many of the subjects selected a switch before beginning the trials that they believed would be their favorite. After testing it, they realized that with practice, they would be more successful with a different switch.

Although the data results do not indicate a clear "best" switch they do indicate that switch 5, the latching switch, presented both groups with some difficulties. A natural tendency for users is to automatically hit the opposite switch to correct a mistake, which will not work for this type of switch.

The most encouraging result of this analysis was evidence that it is both practical and feasible for virtual simulations to be used in the prototyping process for assistive technology. The simulations proved to be a useful medium for the consumers and designers to exchange ideas. The virtual prototypes allowed consumers to visualize the product and how it would be used and enabled them to provide feedback to the designers on how the product could be changed. Since physical models are expensive and time consuming to manufacture, if consumers can offer feedback and test switches on virtual prototypes, the cost and development time of new products can be greatly reduced.

DISCUSSION

Future research for this project includes developing more extensive virtual simulations for exploring the control of prototype models with more degrees of freedom than the preliminary Autovac prototype. Other applications of this research, such as a tool for training consumers to use new assistive devices before buying them, are being explored.

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Generalized Interface Development for Wheelchair-mounted Robots

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Abstract

This paper describes efforts to develop a generalized interface compatible with a commercially available wheelchair-mounted robot. These interfaces allow computer control of the manipulator which, with appropriate software, provide a platform for development and experimentation of novel user interfaces for the device.

Introduction

The Wheelchair-mounted Robot project at the ASEL explores new ways of controlling portable manipulators for people with disabilities. Our goal is to study how different input devices and strategies may be employed to enable users with various levels of ability to effectively control a wheelchair-mounted robot. Further, we wish to examine the performance of different user interfaces using robots that are currently marketed as assistive devices.

Many of the devices and techniques we wish to explore are computer based, and are appropriate for a generalized interface. This paper describes the hardware and software design of a custom generalized interface in the context of the types of user interface strategies we are investigating.

Hardware and Peripherals

Our approach is to develop a generalized interface that allows a personal computer to control robotic devices that are currently available in our laboratory. This will allow us to concentrate on demonstrating user interface solutions that are effective and novel, yet are practical and readily implementable with equipment that is available. We certainly wish to maintain the portability of the systems and other important characteristics of the manipulators.

With the availability of quite powerful, affordable, and small general purpose computers it is practical for a person using a wheelchair to have the level of computing power required to control a robot available. Indeed, many individuals who would use wheelchair-mounted robots may already have laptop computers for various uses. Thus, integrating the robotic device as something of a peripheral to a small computer seems like a feasible approach.

We have initially developed a general computer interface for the Manus Manipulator, manufactured by the Exact Dynamics Corporation. This includes computer software and interconnection specifications which can be used with other manipulators, and an electronic interface specific to the Manus.

The Manus Manipulator

The Manus is an 8 DOF manipulator that is commercially available for use as a wheelchair-mounted robotic arm. The standard input device for the Manus is a 4x4 keypad which connects to a dedicated control unit via a plug-in card. The standard plug-in card also supports a two-axis joystick which connects to two of seven analog inputs available in the control unit. Software in the microprocessor based control unit maps key press information and analog voltages into robot motions. The control unit is capable of sophisticated operations including commanding robot motion in Cartesian space, fault detection, communication with a host computer for system monitoring and reconfiguration of mappings, etc. Some feedback from the robot is available via 5x7 LED arrays on the robot and through a serial link to a host computer running specialized monitoring software. The reader is referred to [1] for more detail about the Manus.

Although the plug-in-card type of interface found on early versions of the Manus such as ours is somewhat limited (newer

versions are moving toward open architectures such as M3S bus interfaces), several types of input devices besides the standard ones have been successfully connected in this fashion [2,3]. For example Wisaksana describes an interface to the Spaceball 6-DOF isometric joystick using a dedicated microcontroller. The microcontroller converts the byte stream of data from the Spaceball into analog voltages acceptable to the Manus[3].

We have developed a card for our Manus control box which allows a PC equipped with an analog output device and an 8-bit parallel output port to control the robot. Multi-channel analog output cards are affordable and available as standard (E)ISA cards or PCMCIA adaptors for laptop computers. 8-bit parallel output ports are nearly universal on all PC's and laptops. Some additional electronics on our card converts the 8 bits to a 16 bit representation of the keyboard; this one-bit-per-key scheme preserves the any-of-16 functionality of the standard Manus keypad.

Our card provides a simple, but comprehensive hardware interface to our Manus using minimal custom circuitry, and offers the flexibility and power of computer control. While this may not be as flexible or open as an M3S based system, it is more capable and easily adaptable than microcontroller based interfaces.

The feedback provided by the Manus is currently not being handled by any type of specialized hardware or software in our system. This may, however, be part of future work.

Software

The motivation behind the software architecture is similar in nature to that behind the hardware. We wish to have a framework where it is relatively easy to experiment with new types of devices or techniques to control either of the robots. This suggests that a layered software architecture that provides a degree of device independence will be necessary to achieve these goals. Ultimately, this will maximize the flexibility of the system to efficiently accommodate new devices. Again, since the goal of the project is explore user interfaces, we desire to keep the software as simple as possible.

A library of low-level routines is being developed for the Manus that are responsible for directly controlling the specifics of its hardware interface. These driver routines serve to hide the details of the different types of hardware from the next layer of software. This next layer of software serves as the "glue" of the complete system; it provides functions which can access other parts of the software including drivers developed for the input devices and other parts of the operating system where necessary. Finally, driver software for the various types of input devices must be developed if they do not already exist. In principle, it should be possible to replace one type of device with another, either on the input or output side without a large degree of software revision.

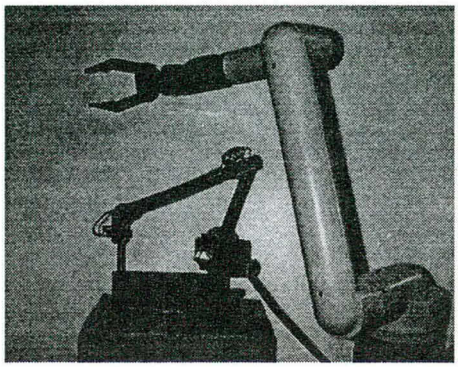
For initial experiments we are using C and C++ to develop the low level driver routines for the robots and the various input devices where necessary. We are using National Instrument's LabView software package for driver development, testing, and basic integration with the Microsoft Windows and Windows 95 operating systems. LabView is a software package which provides a graphical programming environment and graphic user interface tools for rapid development of application programs.

Input Devices and Techniques

We have identified two input devices for use with our system. While this initial set of the devices are products on the market, we plan to test experimental input devices and systems as well.

The Immersion Probe (Immersion Human Interface Corp.) and the Shooting Star (Shooting Star Technologies) are 6 DOF mechanical devices which encode joint angles to describe the position and

orientation of their respective end effectors.



The Manus and the Immersion Probe

The Immersion Probe's end effector is a stylus. The unit is intended as a 3D input device manipulated by the hand. The Shooting Star is primarily designed to be attached to a person's head. It is intended as a relatively low cost input device for Virtual Reality applications. Both devices connect to a PC via a standard serial port; each has a unique format for the data stream transmitted. We are also considering augmenting these two devices with other technology such as speech recognition.

It is not enough, however, to simply connect different devices to a robot in order to make it an effective assistive tool. Techniques must be created which both address the needs of the user, and exploit the characteristics of the interface and the system at the appropriate levels to make the device truly useful. For example, the Spaceball interface to the Manus is well suited to people with spasticity or limited dexterity due to the nature of the device and the intuitive mapping of the force inputs to the robot's action [3]. Therefore, we are interested in developing control schemes which are similarly effective with our devices. For example, we will be looking at ways pointing or gesturing with a pointing device can control the robot.

Conclusion

By developing a more general computer interface to a wheelchair-mounted robot, we can reduce the time and effort it takes to connect different input devices to different robots. We can more easily develop different user interface techniques, and better tailor the devices to the needs of individual users. By having more computational power available, the system can provide more sophisticated types of control, or accommodate a wider range of devices which then could be integrated for increased usability.

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A BODY POWERED REHABILITATION ROBOT

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ABSTRACT

This paper describes a wheelchair mounted, counter balanced, electro-mechanical arm. The arm's end point is controlled and/or powered by a functional body part of the user, via Bowden cables and/or an electric motor. Three important design features are ease and intuitiveness of use, adaptability to different user input sites, and ability to provide external power augmentation. The development and modifications of a new prototype are described along with a discussion of future work.

BACKGROUND

There are currently a handful of electro-mechanical rehabilitation robots commercially available. Some of the more popular ones include the Manus manipulator [1], DeVar workstation [2], Helping Hand manipulator [3], and Handy 1 feeder [4]. While these rehabilitation robotic systems replace lost functionality, they are costly, prone to frequent electro-mechanical failures, and provide only visual feedback to the user. One rehabilitation robot which provides force feedback and relatively low cost, due to its simple mechanical design, is the Magpie [5]. This feeding device is powered and controlled by the user's foot. It couples spoon motions (output) to the user's foot motions (input) through Bowden cables. The advantages of this system are design simplicity, low cost, extended physiological proprioception (EPP), and force reflection. The project proposed in this paper combines the simplicity of the Magpie with the functionality of a higher degree of freedom device. This work is an update to the paper presented at last years RESNA '96 Annual Conference [6].

PROBLEM STATEMENT

The goal of this work is to develop a technologically simple, cost effective, wheelchair mounted manipulator to allow a person with no or very little arm function to interact with his surroundings. Two essential features for a successful design are a three dimensional position mapping and force reflection between the user's input motion and the manipulator's motion. It has been shown that a system which compliments visual feedback with sensory channels is superior to visual feedback alone [7]. The intended population that would benefit from such a device has physical disabilities such as spinal chord injury, multiple sclerosis, and cerebral palsy.

PROTOTYPE DEVELOPMENT

The system consists of three main components:

1. The "slave" arm unit
2. The "master" or interface unit
3. The transmission and control systems

The general idea is that the user engages to the master unit, in this case through biting, and moves his head to control the slave arm. A transmission and control system connect the master to the slave so that the slave follows the master in a natural and intuitive manner. Two of the degrees of freedom (DOF) between the units are connected through pulleys and Bowden cable; the third coupled DOF is through an electric motor and controller.

THE SLAVE

The slave arm is shown in Figure 1. All θ

values represent angular motion about a corresponding axis; all ρ values represent linear motion along an axis. This unit is mounted to a wheelchair such that joint θ_{sp} is at shoulder height and the unit is to the right side of the user. The slave arm was mechanically designed with the same DOF as a spherical coordinate system: θ_{sp} (pitch), θ_{sy} (yaw), and ρ_s (radial). A spherical coordinate system was chosen because it allows any position in space to be obtained with variables (inputs) that kinematically match a person's input (in this case, head) and arm movements.

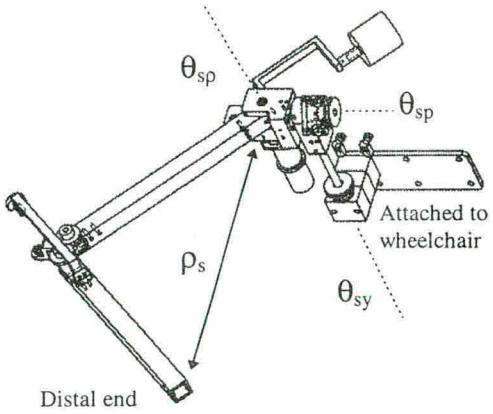

Figure 1: Slave Arm

Pulleys are located at joints θ_{sp} and θ_{sy} which are connected, via cable, to pulleys located on the master. A motor is present at joint $\theta_{s\rho}$; this along with the two meshing gears fixed to the ends of the two main links result in radial motion, ρ_s. The slave arm is counter balanced so that the user does not feel its weight when static. Roller bearings are present in all joints. The two main links are constructed of fiberglass hollow tubing, while most other components are machined from aluminum. In the future, a gripper will be added to the (distal) end of the free link.

THE MASTER

One of the interface or master units is detailed in Figure 2. The unit is fixed to the user's wheelchair such that the θ_{my} joint is positioned above and approximately at the center of the user's head. This head/mouth interface unit has four DOF; the three (θ_{mp}, θ_{my}, $\theta_{m\rho}$,) that map to the slave unit and an additional passive joint (θ_{mr}) at the mouthpiece so the master unit does not constrain the natural head movement of the user. The mouthpiece is constructed of Polyform®[1]; a thermosetting plastic allowing the user's dentition to be molded at low temperature. Roller bearings are present at the yaw (θ_{mp}) and pitch (θ_{my}) joints. Pulleys are present at the θ_{my} and θ_{mp} joints, while a rotary potentiometer is placed at $\theta_{m\rho}$. This potentiometer measures the translation of the mouthpiece, ρ_m, which ultimately controls ρ_s.

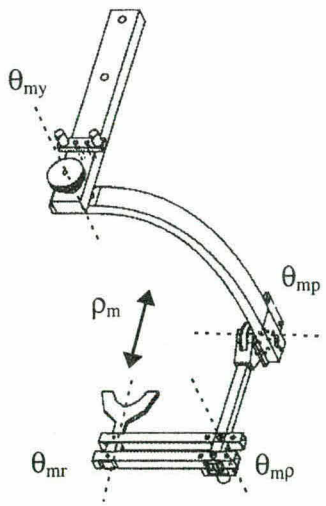

Figure 2: Head/Mouth Interface

THE TRANSMISSION SYSTEM

Although not shown for the purpose of clarity, Bowden cables run between the master and slave units. Two sets of Bowden cables connect the yaw and pitch pulleys of the master and

[1] Distributed by Smith & Nephew, Inc.

slave system; that is, θ_{mp} is connected to θ_{sp} and θ_{my} is connected to θ_{sy}. This set-up causes proportional (in this case, equal) angles of rotation between the two unit's pitch and roll joints. Bowden cables are required since relative movement occurs between pulleys of the master and slave units. Bowden cable is comprised of a flexible outer housing, a flexible steel wire and a polyethylene liner that lies in-between the wire and outer housing to reduce friction..

The radial position of the slave, ρ_s, is achieved through closed loop position control. An electric motor rotates joint θ_{sp} such that the error between the input (master), θ_{mp}, and the output (slave), θ_{sp}, is minimized. External power (a motor) was used at this DOF to allow the person's small translational head input motion to control the larger radial slave motion while still maintaining adequate force capability at the distal end of the slave.

DISCUSSION

The reader is referred to [6] for discussion applicable to this project. One item that needs mentioning is the design change from the system discussed in [6] to the system discussed in this paper. The major change is that counter balancing was used for gravity compensation rather than springs. The springs in the previous prototype introduced too much friction in the slave's motion, thus making it too difficult for the user to move. Other major changes include the addition of roller bearings and a more robust radial movement design for the slave.

FUTURE WORK

The following list highlights future work. The reader is again referred to [6] for a more thorough discussion.

- Gripper - A gripper and its mode of activation need to be added to the system.
- Power Assistance - Work is in progress on designing a means to amplify the user's strength if he/she is too weak to operate the system.
- Locking - A means to allow the user to lock the slave in position needs to be addressed.

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LEG LIFTER

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ABSTRACT

This paper describes the design and development of a leg lifter system to assist a woman with cerebral palsy, characterized by spastic deformities in her upper and lower extermities, in transferring her feet in and out of the bed. The device is similar to a linear actuator system that is utilized on most milling machines. An angle drill was modified to act as the motor, thus powering the device. The device is controlled by simple switch activation and a toggle switch was incorporated to control direction.

BACKGROUND

Cerebral palsy, namely spastic CP, is a condition characterized by spasticity due to upper motor neuron involvement and may mildly or severely affect motor function.[1] For many of us tasks such as standing up, grabbing a pencil, or even talking often go performed without a second thought. However, for individuals with disabilities, carrying out, or even performing, these tasks can be very frustrating.

The client is a 51 year old woman that has been diagnosed with cerebral palsy since early childhood. Her condition is characterized by spastic deformities in her upper and lower extremities. She utilizes a motorized wheelchair for mobility; however, she is able to walk with the aid of crutches. The client has impaired trunk balance with limited abduction in both hips. Right upper extremity grasp and muscle strength are within functional levels. The left upper extermity is used solely for functional assistance. She was referred to the Assistive Technology Unit(ATU) for assistance finding a device to help her place her legs into bed.

Currently, there are very few commercially available leg lifting devices. Most, if not all, commercially available leg lifting and positioning aids are constructed of a cotton webbing with a stiff aluminum insert sewn into it. A large loop is left at one end for foot placement and a smaller loop at the other end for placement of the hand. The patient then uses their own arm strength to raise the leg while retaining the limb in an extended position.

STATEMENT OF THE PROBLEM

Due to the client's disability, she is unable to transfer her legs into bed without assistance. At the present date, the client pays her neighbor to place her feet in the bed each night.

RATIONALE

In approaching this client's problem, several different ideas were presented. First, a manual leg lifter was tried. Due to the client's limited upper extremity strength and weak trunk musculature, she was unable to properly use this device.

Next, it was decided that a lift and transfer system should be utilized. The client has limited space in her bedroom; therefore, the unit would have to be mounted to the wall or to the client's floor. This method proved to be very costly, not to mention, the client had no desire to make any changes to the existing wall or floor space in her home.

Finally, we decided to custom design a leg lifter system since no commercially available method was found to effectively assist the client with her task. It was necessary that the system provide:

(1) ease of operation,

(2) strength and stability,

(3) cost effectiveness, and

(4) reliability.

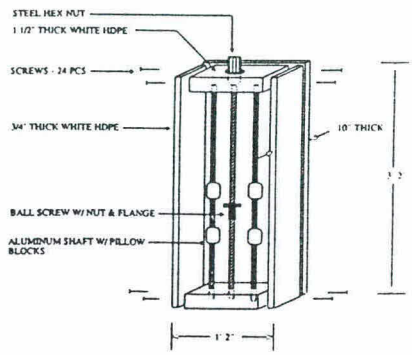
DESIGN & DEVELOPMENT

The proposed design of the lifting system is similiar to that of a linear actuator system used for milling machines. The main design components consist of:

(1) a high density polyethylene casing(HDPE)

(2) a twist angle drill, modified to serve as the motor.

(a)



(b)

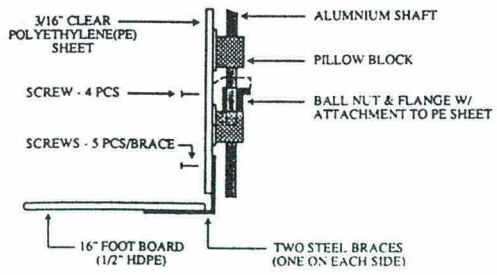


Figure 1: (a) HDPE casing. (b) diagram shows how foot board is attached to the pillow blocks.

A 22" height difference exists between the client's bed and the floor level. Therefore, it was necessary that the foot board travel at least 23" high to allow the client to bring her feet parallel, if not slightly higher then the top of the bed.

As figure 1a shows, the HDPE casing supports two 24" aluminum shafts parallel to and on either side of a 24" steel ball screw. The shafts and ball screw are secured by 1 1/2" thick HDPE blocks. There are two aluminum pillow blocks on each aluminum shaft; the blocks, along with the ball nut and flange on the screw, are attached to a 12" by 12" piece of 3/16" thick clear polyethylene. The polyethylene sheet supports the 16" foot board by means of two steel L-shaped brackets(see figure 1b). A steel hex locknut was welded to the top of the ball screw to provide a means with which the drill may operate the ball screw.

For the motor, a twist angle drill was modified to allow the user to control it by means of a tread switch. A socket attachment on the drill was fitted to the steel hex nut welded onto the ball screw. Thus, when the drill is activated, the ball screw will start to spin. The action of the ball screw causes the ball nut and flange to move up(or down, depending on rotational direction), thus raising the foot board. The pillow blocks assist the foot platform in maintaining a smooth, precisioned path along the aluminum shafts.

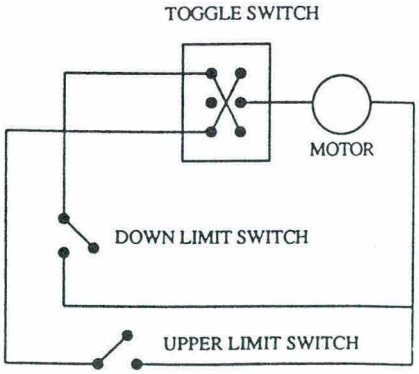


Figure 2: Simple schematic of the control box.

The control box for the motor(figure 2) was designed to allow the user to operate the device from a lying down position. An on-

off-on toggle switch reverses the direction in which the drill spins. Placing the switch in an up position allows the user ro raise the foot board, and vice versa. When the switch is in the off position(in the middle), the device cannot be operated at all. This precautionary measure was used in the event that the user accidentally hits the switch with no desire to use the device. If the switch is in the off position, nothing will happen. Another precaution that was taken was the incorporation of stopping limit switches in the design. These switches prevent the foot board from moving past a certain height or depth. Thus, in the event that the box falls on the ground or the user holds on too long, the device will only raise or lower to a certain height and automatically shut the device off when that limit switch is activated.

EVALUATION & DISCUSSION

The leg lifter system described in this paper costs approximately $500 to build. Building the device required a minimal amount of welding and some use of the milling machine.

The goal of the leg lifting system was to allow the client to independently raise her legs and place them in bed. Upon evaluation of the device, this goal was accomplished. Only a few minor modifications were necessary. Spasticity in the client's lower extremities causes her legs to abduct when sitting down. As a result, the length of the foot board was increased from 12" to 16" to allow both feet to be placed on the foot board and a piece of kydex was attached to the end of the foot board to prevent the client's feet from falling off the board(see figure 3).

Over the course of several months, the client has had some medical difficulties which have hindered the device's effectiveness. This information allows us to conclude that a certain level of physical ability is necessary for this particular device to be useful. For example, possible modifications to address decreased function include installing a folding panel to bridge across the opening between the bed and the device. Also, the installation of a 3" to 4" high piece of ethyfoam on the foot board would assist the client in transferring her legs to the bed by providing a downhill path.

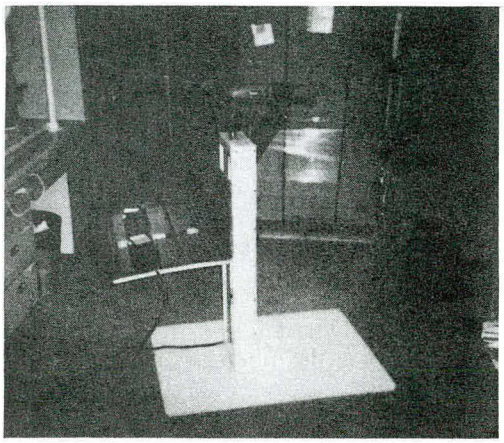


Figure 3: Leg lifter device.

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KNOWLEDGE-DRIVEN CONTROL OF AN INTELLIGENT ASSISTIVE ROBOT

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ABSTRACT

The Multimodal User Supervised Interface and Intelligent Control (MUSIIC) project integrates a multimodal human-machine interface with intelligent planning to operate an assistive robot in unstructured environments. This paper reports on the development of a knowledge-driven intelligent planner that is integrated with a speech and gesture based Human-Machine interface that form the major component of MUSIIC.

BACKGROUND

Prior studies highlight the need of a general purpose manipulation aid for use by people with disabilities to perform everyday activities [1,2]. In an informal study [2], a panel of people with disabilities strongly supported the concept of a rehabilitation robot, but felt the existing interface strategies were lacking. The panel strongly suggested that an effective system should:

- operate in an unstructured environment,
- require low mental load,
- offer opportunities for use in varied environments (as opposed to a fixed workstation),
- be "natural" to operate (i.e., use functions that are easy and intuitive).

Rehabilitation robotics literature describes many demonstrations of the use of assistive robotic devices [3, 4, 5]. Prototype interfaces have generally taken two approaches; command oriented, where the user activates the robot to perform pre-programmed tasks, and control oriented, where the user directly controls all the movements of the manipulator, much like a prosthesis.

While direct control allows the user to operate in an unstructured environment, problems such as physical and cognitive load, the requirement of good motor dexterity, and other real-time perceptual and motor requirements hinder the development of a useful assistive robot.

Command based systems also pose significant problems stemming from having to memorize a large number of commands.

At the other extreme of robot control are autonomous systems, the long elusive goal of the Artificial Intelligence (AI), robotics, and machine vision communities. Although many important incremental advances have been made, this goal seems far from being realized.

RESEARCH QUESTION(S)

Discussions with consumers [2], as well as the previously discussed limitations of current approaches, raised the following issues:

- The robot must be operable in an unstructured environment,
- There must be a natural and flexible Human-Machine interface, and
- The system must have a degree of autonomy to relieve user load.

To facilitate the development of an intelligent, instructible assistive robot, this research led to the development of a novel multimodal (speech and gesture) human-machine interface built on top of a reactive and intelligent knowledge-driven planner. This allows people with manipulation disabilities to perform a variety of manipulatory tasks on everyday objects in an unstructured environment.

This research demonstrates that by combining current state of the art in natural language processing, robotics, computer vision, planning, machine learning, and human-computer interaction, a practical assistive robot can be built without having to solve the major problems in each of these fields, i.e., full text understanding, autonomous robot arm control, real-time object recognition in an unconstrained environment, planning for all contingencies and levels of problem difficulty, speedy supervised and unsupervised learning, and intelligent human-computer interfaces. Current solutions to these problems, when combined with each other and

with the intelligence of the user, can compensate for the inadequacies of each individual solution.

METHOD AND IMPLEMENTATION

The complete system, MUSIIC, includes three major components: a multimodal human-machine interface, a knowledge driven intelligent planner, and a stereo-scopic vision system. In this paper, we describe original research on the development of the first two components and their integration into the implemented MUSIIC system. The knowledge driven planner is based on three knowledge bases: a knowledge base of user extendible plans (PlanBase) and two hierarchical knowledge bases of objects in the world(WorldBase), and objects in the actual domain of operation (DomainBase). Each object, depending on the degree of generalization, has a set of attributes such as shape, size, dimensions, weight, approach point, grasp points, constraints and plan fragments. The hierarchy has four tiers arranged on the basis of abstraction.

Generic: This top level tier contains just enough information obtained from the vision system, with no a priori information about the objects in question.

Shape Based: At this level, objects are classified in terms of general shapes, such as cubic, cylindrical, conical etc.

Abstract: Derived from the previous tier, this tier groups together classes of objects such as cups, straws, and pencils. This information is used to make plans that are more indicative of user intentions and also constrains planning parameters such as approach position, grasp position, and orientation.

Instantiated: This final contains fully instantiated information about actual objects in the domain.

The knowledge bases allow the planner to make plans for manipulating objects about which it knows nothing a priori except what is obtained by the vision system, and to make plans that are a more accurate interpretation of user intentions when more information is available from the knowledge bases.

The intelligent planner uses the three knowledge bases and user/sensor provided feedbacks to synthesize robot plans. The adaptive planner executes user intentions by generating the appropriate robot control commands. The planner reduces cognitive load on the user by taking over most high-level as well as all low level planning tasks. The planner is also able to adapt to changing situations and events, and either replans on its own or interacts with the user when it is unable to construct a plan on its own.

A human-machine interface subsystem uses a multimodal input schema where users of the system use deictic gestures (pointing, achieved by a head mounted laser pointer) to indicate locations, and spoken commands to identify objects and specific actions. This allows the identification of the user's focus of interest without having to perform the computationally difficult process of real-time object identification. This interface is an extension and improvement over Cannon's work on 3-D robot operation [7] since complex vision processing and object recognition is obviated in our method.

The speech input is a restricted subset of Natural Language. The basic grammar has the following structure: *Verb Object Location*

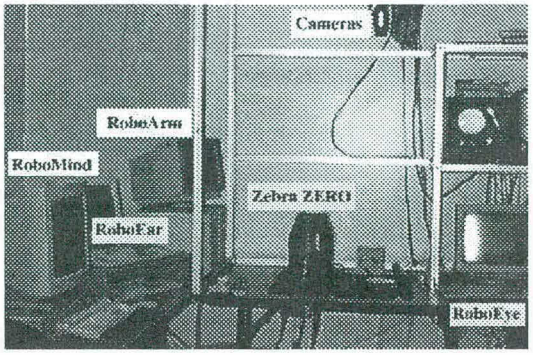
Since this is a manipulative domain, the language structure is essentially an action on an object to/at a location. As an example we may have inputs such as "put that right of the blue book", "insert the straw into the cup", and "put that there".

A parser interprets the combined speech and gesture input and passes on the interpreted commands to the planner for execution.

MUSIIC also includes a vision subsystem for the determination of the three-dimensional shape, pose and location of objects in the domain [6] without performing object recognition.

RESULTS

A test-bed has been constructed to determine the validity of this research. The setup includes a vision subsystem (RoboEye), containing a pair of color cameras, an SGI workstation and associated vision software, a six degree of freedom Zebra ZERO robot and controller (RoboArm), a speech recognition subsystem (RoboEar), and the planning and knowledge base system (RoboMind).



These reside in different platforms and communicate with each other through Remote Procedure Calls (RPC). The implemented system is capable of performing a wide variety of everyday tasks such as picking, placing, manipulating and inserting objects. It is also capable of learning more complex tasks such as feeding and pouring. The system understands the user's speech and gesture inputs and provides feedback through speech. Our evaluation process has begun to test the system with able bodied and disabled users for further fine-tuning of the human-machine interface.

DISCUSSION

We claim that the symbiosis of the high level cognitive abilities of the human, such as object recognition, high level planning, and event driven reactivity, with the native skills of a robot can result in a human-robot system that will function better than assistive robots. We describe a system that can exploit the low-level machine perceptual and motor skills and excellent AI planning tools that are currently achievable, while allowing the user to concentrate on handling the problems that they are best suited for, namely high-level problem solving, object recognition, error handling and error recovery. By doing so, the cognitive load on the user is decreased, the system becomes more flexible and less fatiguing, and is ultimately a more effective assistant.

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ROBOTIC FLEXIBLE FIXTURING FOR CLINICAL AND EXPERIMENTAL STUDIES IN BIOMECHANICS AND REHABILITATION

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ABSTRACT

The use of robots in rehabilitation has been largely confined to the areas of personal assistance for individuals with disabilities and in-clinic assistance to therapists performing repetitive exercises with their patients. This paper describes a third domain: the use of a robot to facilitate the set-up and data collection of a basic science study to develop a neuro-biomechanical model of two-fingered human grasp. This application is projected to lead to the use of the same robot for in-clinic measurement of finger-strength and diagnosis of functional limitations in grasp. The robot's advantage is the ability to perform fast customization of force sensor positioning to the geometry of each subject's hand.

INTRODUCTION AND BACKGROUND

During rehabilitation following high-level spinal cord injury and upper-extremity trauma, the restoration of grasp often involves surgical interventions that include tendon transfers. The goal of such interventions is primarily to restore the most functionally useful 2-finger grasp configurations, namely tip and key-pinch. Due to an incomplete knowledge of the musculoskeletal system involved in grasp, functional outcomes of certain types of such surgeries are not highly predictable. Since the models developed to-date contain various simplifications that in certain cases prevent the surgeon from making optimal choices, a study is currently being undertaken to define a more complete neuro-biomechanical model of force production by the forefinger and thumb. The reader is referred to [1, 2] for a discussion of the scientific aspects of this study; this paper will discuss only certain methodological issues involving the use of a robot manipulator. Simply using a pinch force meter was not adequate as we sought to measure finger forces in postures and directions not commonly used in simple grasps. This led to a more complete model of finger force production.

Central to the methodology of this study is the need to perform numerous intramuscular electromyographic (EMG) and fingertip force measurements while the fingers are placed in precise configurations relative to the hand. After a series of initial experiments using manually adjusted fixtures, it was decided to use an industrial manipulator to achieve *flexible fixturing*,. This approach reduced set-up and measurement time sufficiently to make the collection of EMG signals possible.

EXPERIMENTAL SET-UP

Each subject signed the consent form approved by the Stanford University Panel on Human Subjects in Medical Research. The subject's dominant forearm was comfortably strapped into a padded, table-top mounted cradle, with the hand's thumb and palm gripping a vertical Ø 20 mm dowel. The extended forefinger was custom-fitted with a thimble that carries 5 orthogonally placed Ø 5 mm brass balls (see figure 1). Before the first series of trials, the experimenter commanded the robot to move a small metal pressure-plate sequentially to 15 pre-defined locations in space: 5 spots (+X,-X,+Y,-Z,+Z) for each of 3 finger flex postures. At each location, the experimenter adjusted the default plate position with the robot teach pendant, if necessary, so that the finger stayed in the correct posture and applied a force on the pressure plate in the proper direction, i.e., normal to the plate. The 8 test subjects in this study had forefingers that varied in length from 9 to 12 cm, requiring robot locations to be adjusted approximately ±20 mm from the default positions. The new positions were saved for use in the actual trials.

The robot pressure plate was mounted on a 6-axis force/torque sensor (Assurance Technologies Model Gamma 130/10), which in turn was attached to the end-effector flange of the Stäubli-Unimation PUMA-260 robot (figure 2). The pressure plate was fabricated in aluminum to have a low coefficient of friction with the brass thimble balls:

this assured that subjects applied forces that were predominantly normal to the pressure plate. Forces directed more than 16° from the normal would have caused the balls to slide; fingertip rotation would only have twisted the finger (corrected by the subject), but could not induce a torque on the plate. The forces and torques were recorded at 200 Hz. All 3 force components were recorded to verify that the forces were indeed close to normal. Subjects exhibited an average tilt of 4.7° ± 2.20°.

In the first series of trials (no EMGs), the robot moved in random order to each of the 15 recorded postures. Subjects were shown the normal force level trace on a computer screen programmed to resemble a digital oscilloscope. They were asked (a) to press as hard as possible (max attained = F_m) for 2 sec while maintaining the posture; (b) using a horizontal reference line at the level of F_m, generate a force even greater than F_m; (c) relax, retract forefinger, and wait for the robot to move to the next randomized posture.

Before the second series of trials, subjects had a fine-wire electrode temporarily inserted into each of the 7 muscles involved in index finger motion (4 in the forearm, 3 in the hand). They were then asked to repeat the protocol of the first

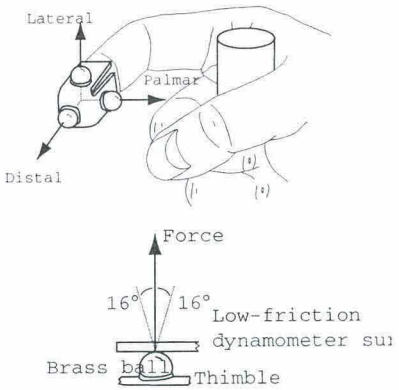

Figure 1. Hand position, showing the stabilizing dowel and fingertip thimble. The 3 sets of orthogonal directions correspond to the local reference frame: Lateral = +X, Distal = +Y, Palmar = +Z. The friction cone illustration details the contact between the pressure plate surface and one of the brass balls on the thimble.

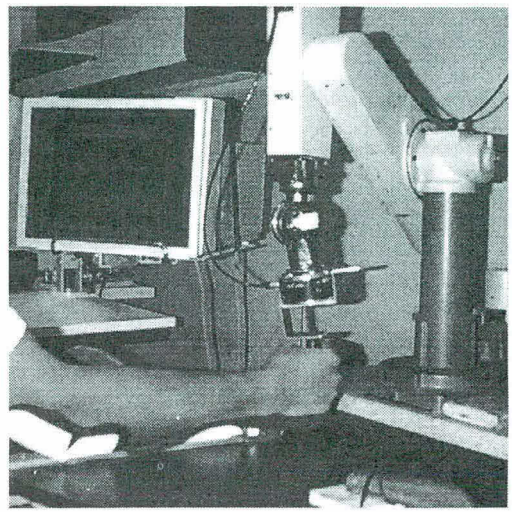

Figure 2. Photo of the experimental set-up, showing the test subject's forearm, the cradle, the PUMA-260 robot, pressure plate and force sensor. On the left is the screen used to provide visual feedback of forces to the subject.

series, in a newly randomized order. Due to the fact that the robot had stored all 15 locations, subjects could progress without delay through them, minimizing subject discomfort and the possibility of electrode malfunction.

RESULTS AND DISCUSSION

For these experiments, the total session time needed to be kept to a minimum due to the discomfort level of test subjects and the required number of trials. Session 1 took under 2 hours to complete. A typical breakdown (verified by analysis of the videotape recorded of all sessions) was: 30 minutes for instruction to the subject, 30 minutes to adjust and store the 15 customized robot positions, then 45-60 minutes for the 15 trials. The average of 3 to 4 minutes per trial included one minute for the robot relocation time, 2 minutes for the force measurements, and a variable amount of time for the subject to relax between trials. None of the subjects expressed discomfort or felt unsafe with the robot, predominantly due to arm's small size and slow, repeatable, smooth trajectories that it was programmed to follow.

The second session also took approximately 2 hours, typically 60 minutes for electrode placement

by a licensed professional, 45 minutes for the 15 trials, and 15 minutes for electrode removal. Note that the experimental portion of Session 2 was substantially shorter than Session 1 because the adjusted robot locations had been stored in Session 1 and were subsequently reused. Coupled with the semi-automation of the data collection and storage, the experimenter could focus on initiating each of the trials and supervising their proper completion.

In the preliminary experiments preceding that described above, the trials were done with hard fixturing to mount the pressure plate and force sensor in the appropriate locations, using vices, clamps, micrometers, etc. The adjustment process took an average of 5 minutes per position, and had to be performed for each posture in each session. The process was considered so cumbersome that EMG recordings were not considered appropriate. The set-up was therefore appropriate for force measurement proof-of-concept experiments only. Indeed, the use of the robot (a) made EMG recording reasonable, and (b) allowed a large number of trials to be performed, leading to a substantially richer data set and a consequently more accurate and robust mathematical model of forefinger force production in all directions and in many postures.

The data acquisition computer and the robot controller were linked so that the experimenter could, from several windows on one console, command the next robot location, create a new data file for the force data, synchronize the collection of the force and EMG data (stored on separate computers), and manage the display to the test subject. The automation of many of these steps helped streamline the procedure and reduce the potential of data management errors.

CONCLUSIONS

The experimental procedure has been refined for a second set of sessions focusing on thumb motion. The interface between the data collection computer and the robot controller has been refined so that the experimenter can automatically progress through the different locations, rather than manually stepping commanding the sequences. The role of the robot will not change.

Following this modeling phase, the robot is projected to be used in the clinic to diagnose particular hand force pathologies, to measure the functional gains following tendon transfer surgeries, and to allow recovering patients to perform therapist-supervised, robot-guided hand exercises. The force sensors will allow real-time display of performance and archiving of performance data to chart rehabilitative progress.

The use of robots in industry is referred to as "flexible automation". In other application areas, such as undersea, space, chemical assaying and rehabilitation, the reprogrammable and interactive nature of robots and telemanipulators provides advantages over hard automation. This paper has described the advantage of the use of robots in human subject experiments to maximize the fidelity of the biomechanical measurements through customization of the procedure for each individual test subject.

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Development of a New *M*otorised *U*pper *L*imb *O*rthotic *S*ystem (MULOS)

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ABSTRACT

This paper describes the development of a new motorised upper limb orthotic system. This new device with five powered degrees of freedom will work in assistive, exercise and continuous passive modes. This project, which started with a functional specification drawn up with the help of many potential Users and professionals, has proceeded through the design stage and a prototype is now ready for clinical testing.

BACKGROUND

MULOS is a 3 year project funded through the EU TIDE initiative and involves 5 partners in 3 European countries. The project is concerned with the development of modular orthotic units which will be used by people with impaired upper limb function. The system will take the form of a 5 degree of freedom powered upper limb orthosis and is designed to work in 3 different modalities; assistive, exercise and continuous passive motion (CPM). As an assistive device the orthosis can be used to move the User's arm to the required position providing improved function. As an exercise or CPM device, the orthosis can be used in the clinic or at home, assisting in the rehabilitation of the arm and shoulder complex.

STATEMENT of the PROBLEM

Comprehensive literature reviews and feedback from Users and Professionals has shown that there are few useful upper limb orthoses, either powered or non-powered, currently available anywhere in the world. Indeed, there have been very few reports of attempts to develop an upper limb assistive system. Furthermore, so far as we can determine, there has been no system, even conceived which can operate in exercise and CPM modes as well as assistive, of an exoskeletal orthosis, with 3 powered as originally envisaged for MULOS.

Previous attempts to produce assistive upper limb devices were generally unsuccessful, due to the complexity and bulk of the designs leading to high cost and difficulty of use (Davalli, 1993). More recent devices have also suffered from similar problems although some attempts have been made to remedy this (Romilly, 1994).

The most common Exercise devices are large, immobile structures intended for the use in the gym by able-bodied people. Some attempts have been made to extend this technology to disabled people, but the resulting devices are still large, Clinic based machines (Dixon, 1995). Commercial CPM devices also suffer from this problem and tend to be limited in their functionality.

RATIONALE

In order to fill this large demand in the market, the MULOS consortium has proposed a new upper limb orthotic system. Comprehensive reviews of information and data available in the literature, along with the views of health care Professionals and Users have been used to formulate the functional and technical requirements of a powered upper limb orthosis.

The system will provide, assistive, exercise and CPM functions and will be designed in a modular nature allowing shoulder and elbow modules to be used separately or together. In this way it is hoped that the system will have a wide appeal to many user groups, allowing a higher volume and lower cost product than has been possible in the past.

DESIGN

Major design considerations of the orthosis have been function, safety and cosmesis. A wheelchair based prototype design having 3 degrees of freedom at the shoulder and 2 at the

elbow has now been manufactured and is ready for testing. Figure 1 shows the prototype attached to a wheelchair.

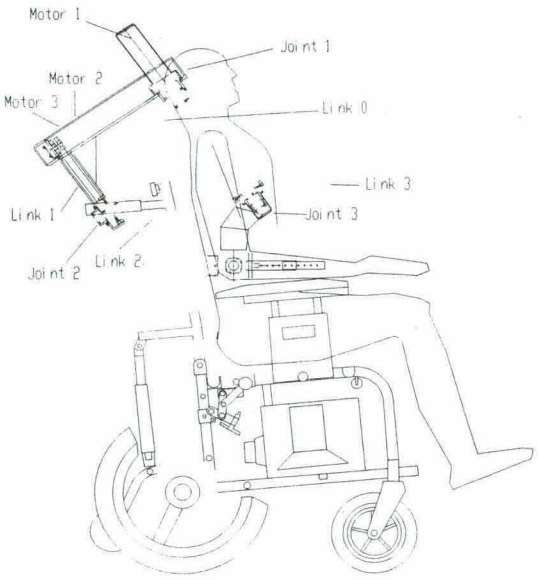

Figure 1 Assembly of the Prototype Orthosis

The joints of the human shoulder form an extremely complex structure (Pronk, 1991) providing the upper arm with a large range of movement. If any orthotic device is to be successful, there is a need for a mechanism which, while occupying the minimum space, possesses the same workspace as the shoulder joint and will allow the arm and orthosis to move freely in concert. To this end, a three degree of freedom serial mechanism has been designed, consisting of three revolute joints having concurrent axes. This mechanism provides a complete kinematic synthesis of a ball and socket joint and thus provides shoulder flexion/extension, abduction/adduction and internal/external rotation.

The elbow module consists of a powered revolute joint whose axis coincides with that of the true joint providing elbow flexion, and a separate module to allow pronation / supination of the wrist.

All the degrees of freedom are driven by D.C. electric motors utilizing a 24V power source (2 wheelchair batteries). Motors of this type are relatively cheap, provide good power to weight ratios and are easily controlled using standard techniques.

This particular application of robotic technology is highly safety critical and a number of safety features have been incorporated into the design. A sophisticated watchdog system continually monitors the control software, and all joints have adjustable mechanical stops and limit cut off switches to ensure that a required range of movement is not exceeded. Clutch mechanisms are incorporated into all power trains and in the case of spasm of the User's arm muscles, the appropriate drive will disengage and the system automatically shut down.

DEVELOPMENT

An important part of the project has been the dynamic simulation of early prototypes using the very latest CAD techniques. Figure 2 shows the model of the arm and orthosis that has been generated using a 3D dynamic analysis package. This software has been used to investigate the power requirements of the orthosis and also to study the overall system kinematics.

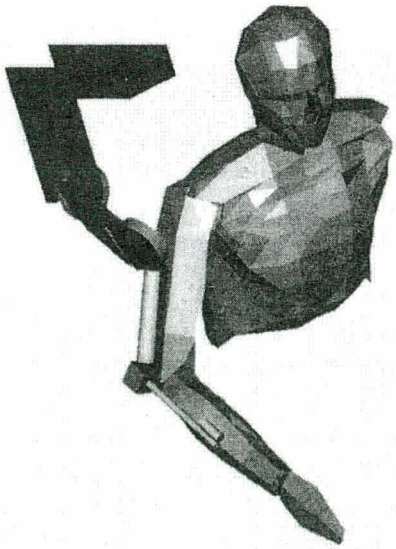

Figure 2 Computer Model of the Orthosis

An intermediate deliverable of the project has been a novel 4 degree of freedom joystick and test software. This system has been used to evaluate the ability of potential Users to operate a multiple degree of freedom manipulator using a 4 degree of freedom joystick or other suitable input device. Potential Users have tested the system and demonstrated the feasibility of using a multiple degree of freedom joystick as a control device for MULOS.

EVALUATION

The project is now entering an important stage with the manufacture of powered, working prototypes complete. When these prototypes have been mechanically and electrically tested to ensure complete User safety, they will be passed on to the clinical partner for testing by real users. Figure 3 shows an early prototype being tested by an able bodied volunteer.



Figure 3 Early Prototype Testing

DISCUSSION

The development of a prototype 5 degree of freedom, powered upper limb orthotic system is now reaching completion, ready for further testing by potential Users. The prototype incorporates many safety features including a sophisticated electronic system watchdog and mechanical drive system clutches and power drive decoupling devices.

An input device with the potential to drive the system has also been manufactured and tested by interested Users.

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CONTROL OF AN UPPER LIMB ORTHOTIC EXERCISE SYSTEM

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ABSTRACT

A control system has been developed for using a motorised upper limb orthotic system as an exercise machine. The exercise system has four modes; two for user exercise (percentage resist and percentage assist) and two for strength profile acquisition (resistive torque and assistive torque tests). The control software has been completed and tested on a laboratory rig.

BACKGROUND

The development of a Motorised Upper Limb Orthotic System (MULOS) is a project funded by the Technology Initiative for Disabled and Elderly (TIDE) programme of the Commission of European Communities. The system is a five degree of freedom orthosis, consisting of three shoulder joints, an elbow joint, and a wrist (pronation/supination) joint. The joints are powered by dc motors and are computer controlled. The final system will be used in any one of three modes; assistive (to compensate for loss of muscle action), exercise (for active movement to improve muscle tone) and continuous passive motion (for prevention of joint contractures and reduction of oedema).

STATEMENT of the PROBLEM

The assistive mode was considered the most important mode, and hence it was taken as the design priority. The task for exercise mode was to design a control system that could be used to adapt the chosen design without increasing its cost and complexity.

RATIONALE

Whilst exercise machines are fairly common, they are generally large machines for able-bodied people. A survey of patents showed some exercise machines aimed at disabled users, but they are still large, immobile devices (Dixon, 1985, Westing, 1991). A survey of potential users carried out for the MULOS project suggested that there was a need for a lightweight, low-torque device for disabled and elderly people. Suggested users for a MULOS exercise device are people recovering from arm injuries or neurological impairments. Devices have been suggested in the past for stroke patient rehabilitation (Lee, 1990, White, 1993).

DESIGN

The design of MULOS is a partially exoskeletal device with the arm supported at the elbow. Exercise mode is intended to be used on any of the MULOS joints apart from the wrist. All the joints are powered by dc servomotors, and they feature relatively reversible transmission, allowing the user to move the joints and work against the motors. DC servomotors have a linear relationship between torque and current, so by controlling the motor's current it is possible to control its torque. This allows the device to be used as a simple exercise machine, without the need for complex force or torque sensing methods. For safety reasons all the joints incorporate a clutch, which will not allow pre-set maximum torques (e.g. 7 Nm at the elbow) to be exceeded.

Initially, the exercise mode system has been designed to provide single joint exercise for simplicity.

Control Strategies

The control strategies of the system are based on the principle of recording a torque versus position profile for the joint, then outputting a torque value corresponding to the current joint position. The four modes are described below;

1 Percentage Resist Exercise Mode

In this, current is output in such a direction as to oppose movement of the joint. The resistive level is selected by the user/therapist and represents a percentage of the level recorded in the profile. This is intended to be the main operational mode, because exercising at less than maximum torque is considered to be of greatest benefit to elderly and disabled users.

2 Percentage Assist Exercise Mode

Current is output in such a direction as to aid movement of the joint. Again, the assistive level is selected by the user/therapist and it represents a percentage of the level needed to move the joint. This can be seen as halfway between resistive exercise and continuous passive motion (where the user makes no attempt to move the joint).

3 Resistive Torque - Profile Acquisition

The user moves the joint from one end of its range of motion to the other, and a profile is recorded of the torque required to resist the movement throughout the range.

4 Assistive Torque - Profile Acquisition

The user is instructed to keep the joint passive, and a profile is recorded of the torque required to move the joint from one end of its range of motion to the other.

DEVELOPMENT

Work proceeded on the control system whilst mechanical design and manufacture of the orthosis was in progress. For this reason a simplified test rig was built for exercise mode software, in which the joint is replaced by a torque arm connected to the output shaft of a servomotor. As in the final MULOS joints, position feedback is provided by an optical encoder.

Control System

The control hardware is based on that developed for the MULOS project, and is outlined in Figure 1. The amplifier is a pulse width modulation amplifier used in current mode, i.e. the motor current is proportional to the amplifier input. The control system is completed by an axis control board in a Pentium PC. These will be replaced by PC-104 boards in the final MULOS system, giving a smaller architecture capable of being mounted in a wheelchair.

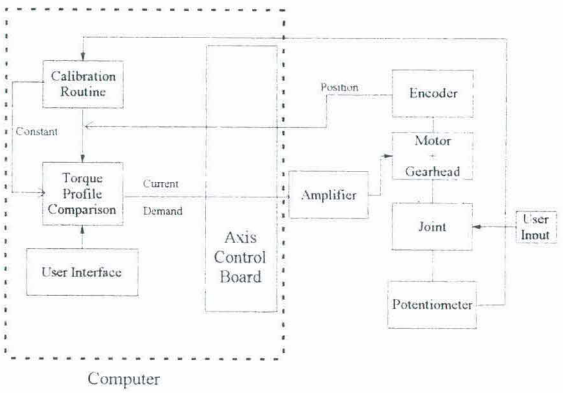

Figure 1. Control System

Software has been written in C++. The torque profiles obtained are stored as files. During the program these files are read in to linked lists, which are used to find the appropriate current value. A calibration constant relates the encoder position to the actual position, obtained from the potentiometer. To account for gravitational effects and differing muscle strength, torque profiles are obtained for both directions of joint movement.

As the MULOS architecture will be embedded in the system, it was necessary to

create an additional interface for exercise mode, currently this is a lap-top PC. This communicates with the controller via a serial link On this, a Graphical User Interface has been implemented. This allows selection of joint, mode and range of motion, and provides displays of users' strength in terms of torque tests.

In order to improve the feedback to the user, it was necessary to calibrate the system so that a relationship is known between the torque at the joint and the motor amplifier input. A simple calibration program was written. This records the amplifier input required to hold various weights on the torque arm. Results of torque against amplifier input were plotted and gave a linear relationship, which was used to obtain a system torque constant.

EVALUATION

The four modes have been implemented successfully and tested on the exercise mode rig. As the integration of the control architecture with the initial MULOS prototype nears completion, it should soon be possible to evaluate the exercise mode control software on the real joints. The linear relationship obtained by the calibration confirms that the amplifier input can be used to control the joint torque.

DISCUSSION

The control system proved successful as a low torque exercise machine, though testing is still required on the full MULOS at the time of writing. A possible future improvement would be to allow the exercising of more than one joint at a time. Another area for future development concerns making the device more adaptable to changing user strength. One way of doing this could be to monitor the cycle speed and adjust the exercise level to compensate for changes in it.

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PERFORMANCE ASSESSMENT OF A HEAD-CONTROLLED REHABILITATION TELEROBOTIC SYSTEM WITH FORCE REFLECTION

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ABSTRACT

This paper presents an experimental evaluation of a head-controlled telerobotic system that is designed for use by persons with disabilities such as quadriplegia. Experiments were carried out performing a set of routine tasks using the system with and without environmental force feedback, as well as two passive headstick systems employed for comparison. Results indicate that the telerobotic system with force-feedback is comparable to a passive headstick, and outperforms the system with no force feedback.

INTRODUCTION

Enhanced sensory feedback, in particular, force reflection has been studied in a teleoperation setting to better control remote robots [1]. It has also been investigated in the field of prosthetics by means of extended physiological proprioception (EPP) [2]. EPP underlies the development of the system used in this paper. The system contains a master/slave robot pair (Fig. 1) to allow a person with cervical spinal cord injury to control a robot and receive interactive force information.

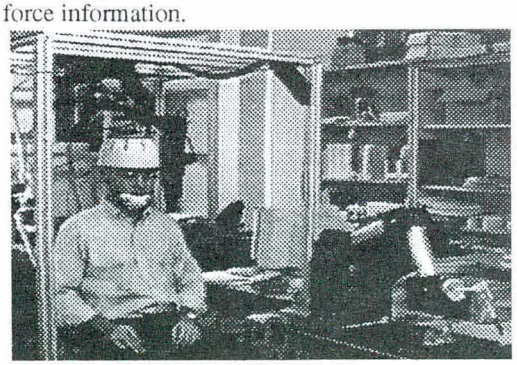

Figure 1 The configuration of the head-controlled telerobotic system.

The master device is a PerForce six DOF handstick which has been modified to facilitate head control via a helmet. The slave unit is a six DOF Zebra ZERO robot arm. The PerForce unit is a back-drivable manipulation device that is capable of giving the user force reflection sensation. The Zebra ZERO has a force sensor at its wrist that is able to measure contacting force when the end-effector encounters obstacles. The current system is configured to send the head position information from the master to the slave and receive force information from the slave. Details on the system design and the control scheme can be found in [3,4,5].

EXTERIMENT DESIGN

Experiments that assess the performance of the teleoperated system and compare it to two headstick systems have been conducted. One headstick system uses the ADL/Shooting Star measurement device with a two feet long carbon fiber stick, whereas the other uses the PerForce manipulator attached with a helmet and the same fiber stick. The former gives unencumbered headstick performance, while the latter allows for a fair comparison between the teleoperated system and the headstick, by factoring out the weight of the PerForce device. The headstick with the ADL offers the gold standard with which performance is measured. Three sets of experiments are used to evaluate performance: (1) Fitts' movement, (2) page turning, and (3) drawing. Six lab staff members participated in the experiments: two females and four males. At this stage only non-disabled subjects were used.

Fitts' movement experiment

Disk-shaped targets with sizes of 1", 2" and 3" in diameter are used in this experiment. A pair of equally sized targets are first placed 6", then 12" apart on a wooden board that stands vertically in front of the subject. The center of the board is approximately at the subject's eye level.

There are a total of 6 trials for each subject. The

subject is asked to touch the two targets with the tip of the headstick or the end effector of the slave robot by moving up and down at a comfortable pace. Each trial consists of 10 round-trip touching trajectories.

Page-turning experiment

For this experiment, a large book was placed in front of the subjects at an angle of 20-degree with respect to the horizontal plane, in a way that allowed the upper half of the book to remain within the workspace of the headstick tip or the slave end effector. The subjects were provided with sufficient training time to learn a good page turning strategy and were asked to use the same strategy throughout the trials. The subjects were asked to turn 5 consecutive pages of the book. The experiment was repeated 6 times.

Line-drawing experiment

For this experiment a large board was placed in front of the subjects at an angle of 20-degree with respect to the horizontal plane. A piece of drawing paper was attached to the board. It was ensured that the drawing paper was within the workspace volume of both, the head-stick tip and the robot arm tip. Diagonal lines were pre-drawn on the paper and the subjects were asked to trace the lines as best as they could. Both the headstick and the robot tip had a marker attached to the tip.

RESULTS

Fitts' law experiment

The conventional Fitts' law paradigm [7] is employed in this paper. Table 1 lists the linear regression parameters and the R-squared statistic for each testing condition. It shows that teleorobotic system with force reflection has the highest bits per second rate. The performance of the four systems can be seen as regression lines in Figure 2. As predicted, the ADL outperforms the PerForce, and the tele-system with force-reflection outperforms that without force-reflection.

Table 1: Fitts' Law information

	Bits/S	Intercept	R square
ADL	2.639	0.0407ms	0.963
PerForce	2.732	0.2961ms	0.962
Tele w/o F	3.086	0.2246ms	0.876
Tele w/ F	3.378	0.2254ms	0.965

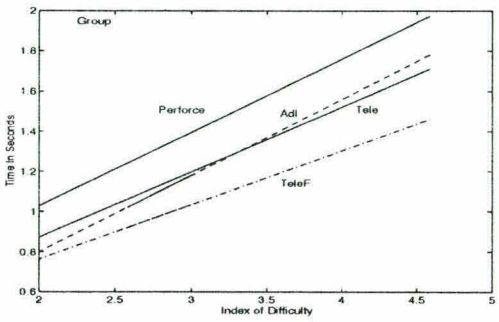

Figure 2 Fitts' law performance for different systems, mean of all subjects.

Page turning

The criteria considered in assessing the performance of the page turning task in this paper is the average completion time in seconds. Figure 3 shows the group statistics using the boxplot. Not surprisingly, the ADL performs better than all the other three devices with the possible reason of easy to operate by the user. The performance of the teleoperation with force reflection is comparable to that without force reflection largely because a big portion of the time in page turning is spent in the free space where force reflection yields no benefit.

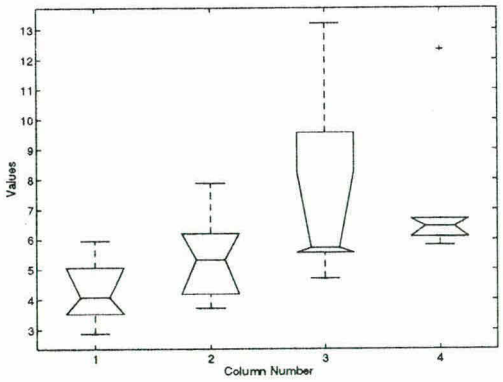

Figure 3 Page turning completion time, mean of all subjects; 1: ADL, 2: PerForce; 3: Tele w/o force, 4: Tele w/ force.

Drawing

Currently, two performance measures are used to evaluate the systems in drawing experiment. The first one is the linearity that is indicated by taking the mean squared error between the actual line and

the ideal straight line. The smaller the value, the better the performance. Table 2 lists the mean value, as well as the deviation and median, of the mean squared error for a total 168 drawings for each configuration.

Table 2: Mean squared line errors

	Mean	STD	Median
ADL	0.0268	0.0432	0.0106
PerForce	0.0197	0.0385	0.0055
Tele w/o F	0.0592	0.1028	0.0186
Tele w/ F	0.0303	0.0550	0.0091

The second measure is the ensemble averaged force exerted on the paper. The results are plotted in Figure 4. Teleoperation with force feedback produces significantly less force on the paper than one without force feedback while producing a smaller error.

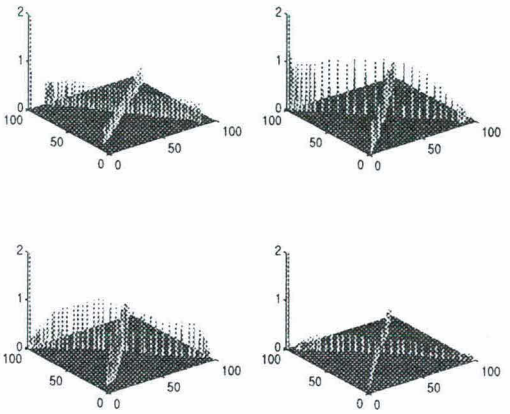

Figure 4 **Ensemble averaged force profile upper-left: ADL; upper-right: PerForce; lower-left: Teleoperation w/o force reflection; lower-right: Teleoperation w/ force reflection**

CONCLUSIONS

In this paper, we presented the performance evaluation of the head-controlled telerobotic system that has been implemented at the ASEL. The experiments support the hypothesis that there is a performance difference based on the mechanical properties of the devices such as mass, and based on the availability of extra information such as force reflection to the user. Notice in Fitts' movement experiment and the drawing experiment that force reflection in teleoperation can elevate the performance level with respect to the system without force reflection. In fact, from these experiments, we conclude that for tasks that involve motion and touching the teleoperated system with force reflection gives the best performance with respect to the other options.

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STANDARDIZED ASSESSMENT TESTS FOR THE HUMAN ROBOT SYSTEM

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ABSTRACT

This paper discusses the use of common standardized assessment tasks from the occupational therapy field to evaluate human performance augmented by a rehabilitation robot. This approach may potentially provide a method to assess individuals and compare them to the norms of disabled and nondisabled individuals who have performed the assessment task. This paper will discuss the different assessment tasks investigated as well as the results obtained to date.

INTRODUCTION

At the current time, there exist no standardized assessment tests in rehabilitation that may be used to determine the effective performance of a human augmented by an assistive robot. There are many different assessment tests currently used in occupational therapy to test an individual's manipulation abilities. Although adding a robot to the assessment is changing the task, a general comparison can be made. Also, a baseline of data can be found for this type of accommodation so other tests can be performed.

There are dozens of assessment tests used by occupational therapists to find the manipulation abilities of their clients. Some of these tests can be very easily adapted to robotics. Although there are many different robots, robotic drivers, and input devices making all of the robotic accommodations different, a baseline of data can be taken to find the area at which robotics can perform.This information can then be used to better identify the appropriate applications for robotic implementation.

Using this information, judgements can be made as to what types of occupations can be found using the human/robot team. The Revised Handbook for Analyzing Jobs (RHAJ)[1] can be used as a source of defining job requirements. The RHAJ defines jobs by education level, physical demands, training needed, and environmental conditions to name a few. The Dictionary of Occupational Titles [2] which contains over 12,000 defined jobs that can then be viewed to find the types of jobs the human/robotic team can handle physically by reviewing the definitions of the particular job that is being investigated.

PREVIOUS ASSESSMENT

Few examples of quantitative assessment of the human/robot system exist. IRQAT [3] used a peg and hole task to test manipulation as part of a pilot study. The results were promising but it is not a common test used in occupational therapy with a known level of achievement.

Other studies have been performed to evaluate the ability of a robot to take the place of an attendant for a period of time. Other experiments took actual work situations and tested an individual who was already familiar with the job as demonstrated in the DeVAR project at the VA Center in Palo Alto, California. [4] Both of these comparisons are very useful for the particular situations, but neither directly indicate human/robot performance nor translate easily to other systems.

ASEL ROBOTIC SYSTEM

The current vocational robotic workstation under development at ASEL may help expand the employment opportunities for people with

manipulation disabilities in many different vocational environments. The components of this system include a PC running under Windows, an UMI-RTX manipulator controlled by a window based robot language, Windows access devices, such as Intellikeys and WiViK, and task specific objects. Because the system runs in a Windows environment, existing off-the-shelf Windows access devices may be used to allow the system to be accessible by individuals with a wide range of disabilities.

The robotic program that is currently being used is Cambridge University Robot Language (CURL)[5]. It runs under a Windows environment and provides three different levels of control for the robot: direct control of each joint on the robot, line based command control, and multiline procedural control. Because all of this is done in the windows environment, they can be accessed with many of the current alternate methods of windows interaction. Figure 1 shows the set up for all of the tests.

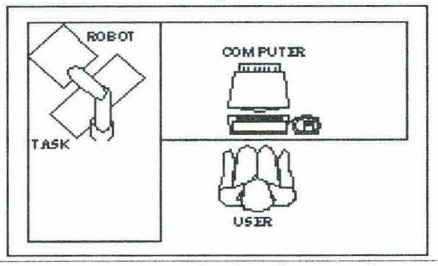

Figure 1: Human/Robot System Setup

OCCUPATIONAL THERAPY ASSESSMENT TESTS

There are many different assessment tests that have been established in occupational therapy to determine an individual's manual dexterity. Many of these assessment tasks have norms that have been found using both able bodied individuals as well as individuals with disabilities to give a basis of comparison.

Two assessment tasks were selected to evaluate their potential for measuring human/robot performance. The tests were chosen using the following criteria:

- object size 1 to 3.5 inches
- one-handed task
- within working envelope 20 to 27" radius
- common use within research and therapy
- structured task
- low cost

Jebsen Hand Test:

The Jebsen Hand Test [3, 6] was designed in 1969 and consists of many house hold items such as soup and coffee cans, paper clips, and kidney beans. With these items, seven different tests are performed to determine finger dexterity, gross arm movement, and strength. The seven tasks are as follows:

- writing a short sentence (2A)
- turning 3x5 cards(2B)
- Picking up small objects, placing in can(2C)
- stacking checkers(2D)
- simulated feeding with spoon and beans(2E)
- grasping large light objects(2F)
- grasping large heavy objects (2F)

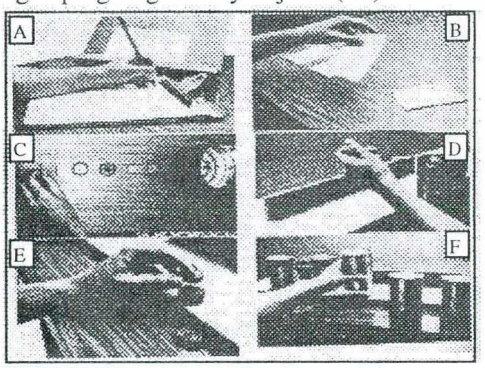

Figure 2:Jebsen Hand Test [6]

This test has norms from 360 normal subjects who are tested at each of the subtests. Many of the Jebsen Hand Test subtests may be appropriate to assess using robotics. The simulated writing test is the only inappropriate subtest for robotics.

Minnesota Rate of Manipulation Test:

Another set of tests that examine level of manual dexterity is the Minnesota Manual Dexterity Tests (MMDT) sometime known as the Minnesota Rate of Manipulation Tests (MRMT) [7, 8]. Currently at ASEL, the

STANDARDIZED ASSESSMENT

MRMT is being actively explored. There are 60 checkers and 120 holes that are used for an assortment of placing and turning tasks. Five separate tasks are tested.

- Placing Test (3A)
- Turning Test (3B)
- Displacing Test (4C)
- One -Hand Turning and Placing Test (3A)
- Two -Hand Turning and Placing Test (3A)

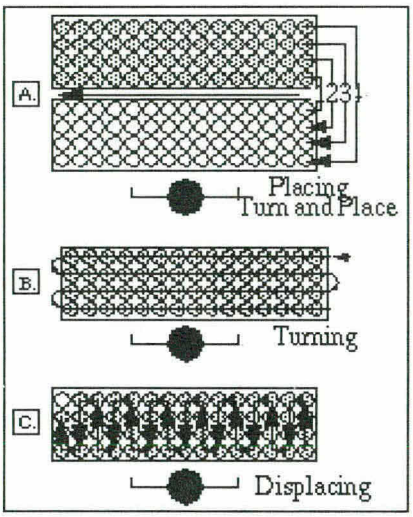

Figure 3:MRMT Setup

A direct comparison cannot be made with the two handed turning and placing test because only one manipulator will be used at this point. The average norm for the Turning test is 155 seconds for 3 tests. It takes the robotic workstation 1500 seconds to complete one full board. This is 29 times slower than the norm. The other three tests gave similar results.

FUTURE WORK

Users will be trained on the system and timed on the different assessment tasks. These results will be compared to the baseline results of the robot only and to published norms for average users and users with disabilities as well as with other robotic workstations. The results can also be used as a way of measuring the training of individuals using the devices. Finally, the abilities found using the robotic workstation can be compared with job requirements to find a good match of person and job.

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INITIAL EVALUATION OF THE MIDDLESEX REHABILITATION ROBOTIC ARM

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ABSTRACT

A prototype of the Middlesex University Rehabilitation Robotic Arm has recently been completed. An evaluation of the arm was undertaken by an individual with spinal cord injury, to provide subjective feedback for use in future design and modification stages. An adaptable user interface has been developed allowing for arm control via a combination of different input and feedback devices. Initially a voice recognition system and a purpose built head-gesture recognition system were used. Specific aspects of the arm's appearance were identified for improvement. The user interface was regarded as being too complex, and ways in which it could be simplified were explored. The performance of the arm in terms of flexibility, speed, accuracy and smoothness of movement, was regarded as acceptable for the tasks undertaken.

BACKGROUND

A project has been undertaken at Middlesex University to develop a wheelchair-mounted robotic arm to assist people with physical disabilities in activities of daily living (Prior, 1993). Initial design requirements were derived from evaluations of previous robotic systems (Danielsson & Holmberg 1994; Hillman & Jepson 1992; Topping 1995), and an extensive user survey (Prior 1990). This resulted in the development of a purpose-built arm employing a novel eight-axis kinematic configuration.

A Task Analysis Process was used in the development of a modular user interface. A number of input and feedback devices may be selected and combined according to the user's functional ability. Furthermore, the system complexity, in terms of the modes of control provided, may also be individually configured.

Input devices currently supported include a commercial voice recognition system, and a purpose-built head-gesture recognition system. The latter employs low-cost electrolytic tilt sensors mounted on a baseball cap, the output signals of which are classified by an Artificial Neural Network.

Development and refinement of the robotic system is an ongoing process. An initial evaluation was undertaken by an individual with spinal cord injury, to highlight and prioritize the elements of the system that require improvement, and to help plan more extensive and informed user evaluations.

RESEARCH QUESTIONS

A quantitative assessment of technical design specifications such as reach, speed, payload and accuracy had previously been performed (Parsons, 1996). This allowed the current evaluation to concentrate on predominately subjective user related issues, i.e. for a single subject, how well had the principle design objectives been met ? These being : appearance, safety and functionality.

An assessment of the interface's usability was made, with reference to its contents, structure and the speed with which the interface can be navigated under the control of voice, head-gesture, and a combination of the two.

METHOD

A questionnaire addressing the design objectives was developed, and formed the basis of a semi-structured interview. Initially, open

ended responses by the subject were encouraged, followed by a summary using a Likert-type five point scale. Although often restrictive in terms of descriptive potential, Likert scales were used as an attempt at providing a degree of consistency between the current and future evaluations.

Ideally, the evaluation would have involved undertaking each user task identified and prioritized in the user survey. The arm's flexibility is partially achieved through an interchangeable end-effector, and at the time of evaluation, only one gripper attachment had been completed. Tasks were therefore designed around reaching and gripping medium sized objects around the home, such as a cup.

The tasks were performed to allow the user to assess levels of usability. After an initial period of familiarization, various measurements were recorded while tasks were undertaken using voice control, head-gesture control, and a combination of the two. Measurements recorded were : overall task completion time, error frequency and error recovery time. The evaluation was performed over a period of two days.

RESULTS

A short summary of the evaluation results is provided below.

Appearance

With the exception of one joint, the current size of the arm was regarded as acceptable. The principal reason given for this was the existence of an adequately compact home position for use when the arm is at rest.

An exposed motor, and electrical leads, were regarded as having a dramatically negative effect on appearance.

The fact that an anthropomorphic design has not been adopted, particularly for the end-effector, was regarded as positive, the subject suggested that a high-tech (as opposed to human-like) appearance is preferable.

Quality of movement

For the tasks performed, smoothness of movement and perceived accuracy were regarded as entirely acceptable. However, because of the acoustic noise made by two of the axes, the subject was given the impression that the arm was about to fail. This was mainly due to the fact that the noise made was not constant.

The arm's maximum speed, provided in accordance with the original specifications (0.2 m/s), was regarded as excessive. The subject suggested that safety would be the significant factor here : task completion time is not a serious issue for those that have previously had little independence.

User Interface

Initial impressions of the menu based user interface were that it was far too complicated. Menu options were identified that were regarded as excessive, particularly the number of speed settings, and the number of pre-taught positions available. The comment was made that providing the user with too many options and too many modes of control, gives the impression that the system itself is not sufficiently 'intelligent'.

Tasks that were heavily dependent on menu navigation were completed using voice recognition in approximately half the time that the gesture recognition system took. This was in spite of the fact that failure to recognize voice was ten times more frequent than failure to recognize gesture (11% of the voice issued commands needed repeating at least once, in a quiet laboratory environment).

Initially the voice recognition system was deemed preferable, as the commands themselves were being vocalized, rather than performing an abstract gesture. However, after a period of familiarization (two hours), the gesture recognition system was regarded as being superior. The reasons given for this were that recognition failures were less frequent, and

that the system could be operated in a more discreet fashion. The user was influenced in this decision by being informed that the vocabulary for the voice system has been shown to need re-enrolling through time to cope with changes in the users voice.

The impact of the simultaneous use of two input devices on task completion time appeared ambiguous, as the user apparently randomly switched between modes of communication. This indicated that a more prolonged period of evaluation would be required if consistent patterns of use were to be established. However, error recovery time significantly improved (67%) as the user was able to appropriately switch input modality. The subject suggested that whatever the preferred mode of communication, there would be an increased sense of safety if a secondary mode were present.

DISCUSSION

The evaluation allowed for a number of issues to be highlighted and prioritized for future modifications. The size of the arm's largest axis may be reduced by repositioning two of the motors. This would result in slightly shifting the arm's center of gravity from its base, towards the end-effector. This may have a negative effect on control, however, this may be compensated for by reducing the maximum possible speed of the arm.

The unacceptable level of noise may be addressed by exploring the use of different gear and shaft materials.

Work remains to be done in simplifying the user interface, and building 'intelligence' into the system where appropriate.

Although originally skeptical, the subject concluded that the arm could adequately perform the tasks undertaken. Further trials and appropriate modifications will determine whether this conclusion may be extended to the full range of user tasks, and for a significant number of potential users. The use of gesture as a mode of communication has been shown to be appropriate, as has the significance of developing an adaptable user interface.

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PRELIMINARY INVESTIGATION OF A SEMI-AUTONOMOUS ROBOTIC WHEELCHAIR DIRECTED THROUGH ELECTRODES

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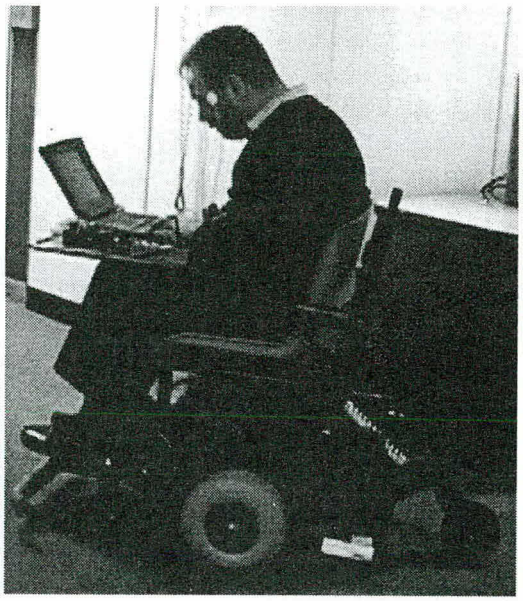
ABSTRACT

Many people with disabilities do not have the dexterity necessary to control a joystick on an electric wheelchair. Our system allows a semi-autonomous robotic wheelchair to be commanded by head and eye movement using electrodes placed around the eyes. Once the user issues a high level command such as "forward," the wheelchair system will perform the command while avoiding obstacles and taking care of any necessary driving adjustments. Since our system will automatically avoid obstacles and make motor corrections, less effort is required by the user to drive the system. We present preliminary results on an experimental system that combines the Wheelesley robotic wheelchair with the EagleEyes system for controlling a computer through electrodes.

INTRODUCTION

In recent years, researchers have started to experiment with putting computer control and sensors on an electric wheelchair (see, for example, Gomi and Ide 1996). We have developed a semi-autonomous computer controlled wheelchair that provides driving assistance by taking over low-level control. Our system provides a new method for driving a wheelchair through the use of electrodes (Figure 1). This system is intended to allow people who do not have the dexterity necessary to drive a joystick controlled system to move around the world.



There are two levels of control in our system: high-level directional commands and low-level computer-controlled routines. The person using the system has the highest level of control. The user's head and eye movements are translated to screen position using the electrode system. The command at the calculated position is then sent to the robotic wheelchair. Once given a command by the user, the computer acts to keep the wheelchair out of trouble using the sensor readings. For example, if the user instructs the chair to go forward, the chair will carry out the command by taking over

control until another command is issued. The chair will not allow the user to run into walls or other obstacles. If the chair is completely blocked in front, it will stop and wait for another command from the user. If it is drifting to the right, it will correct itself and move to the left. This allows the user to expend less effort when driving the chair than a person issuing all of the necessary motor commands. It can also help to mediate for people who have trouble with fine motor control but who have the ability to issue high-level commands.

Our system is composed of two parts. The Wheelesley robotic wheelchair system provides the low-level system that avoids obstacles and makes driving corrections and the high-level interface between the user and the wheelchair system. The EagleEyes system allows the user to control the Wheelesley system with eye movements.

THE WHEELESLEY ROBOT

Wheelesley (Yanco et al., 1995), a robotic wheelchair system, allows the user to tell the robot where to move in gross terms and will then carry out that navigational task using common sense constraints such as collision avoidance. The hardware was built by the KISS Institute for Practical Robotics. For sensing the environment, the robot has 12 infrared sensors, 4 ultrasonic range sensors, 2 shaft encoders and an instrumented front bumper.

Wheelesley has a user interface that runs on a Macintosh Powerbook. This interface takes commands from the user (forward, right, left, back and stop) and sets the computer controlled wheelchair in motion. The wheelchair uses its sensors to avoid obstacles and to maintain proper heading in accordance with the user's commands.

EAGLE EYES

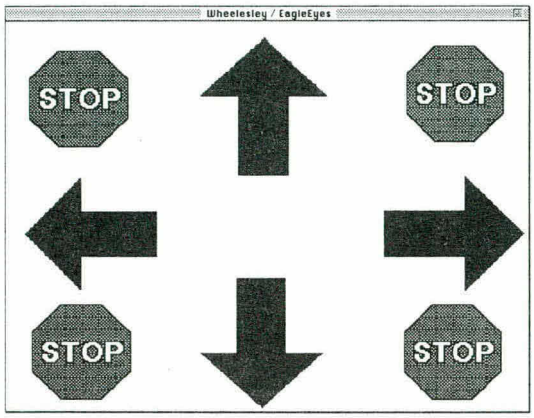
EagleEyes (Gips, Olivieri, & Tecce 1993) is a technology that allows a person to control the computer through five electrodes placed on the head. Electrodes are placed above and below an eye and to the left and right of the eyes. A fifth electrode is placed on the user's forehead or ear to serve as a ground. The electrodes measure the EOG (electro-oculographic potential), which corresponds to the angle of the eyes in the head. The leads from these electrodes are connected to two differential electrophysiological amplifiers. The amplifier outputs are connected to a signal acquisition system for the Macintosh.

Custom software interprets the two signals and translates them into cursor (mouse pointer) coordinates on the computer screen. The difference between the voltages of the electrodes above and below the eye is used to control the vertical position of the cursor. The voltage difference of the electrodes to the left and right of the eyes controls the horizontal position of the cursor. If the user holds the cursor in a small region for a short period of time the software issues a mouse click.

Children with profound disabilities have been using EagleEyes for the past 18 months as a way of enabling them to control the computer and communicate (Gips et al., 1996).

DESIGN OF THE INTERFACE

The user interface screen (Figure 2) has been designed to accommodate the needs of the EagleEyes system. Large buttons are easier to use with an electrode system than small ones. We have four large direction arrows and four large stop buttons. We provide four stop buttons so that the user will be near a stop button regardless of where the cursor is placed on the screen.



DISCUSSION

Since the signal measured by EagleEyes corresponds to the angle of the eye in the head, the user can control the robot through eye movements. For example, look to the right to make the robot move to the right or look up to make the robot move forward. To issue a command, the user needs to hold gaze at the same spot for a fraction of a second to cause the mouse to click. This allows the user to look around without issuing commands to the chair. We envision a system where the user would not need to look at the computer screen to drive the wheelchair.

In our initial driving experiments on the system, the user has been able to control the Wheelesley robotic wheelchair system using the EagleEyes electrodes system. We are experimenting with variations in the interface and high level control actions.

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DEVELOPMENT AND EVALUATION OF VOICE CONTROL FOR A SMART WHEELCHAIR

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ABSTRACT

The NavChair Assistive Wheelchair Navigation System (Levine et al, 1990) is being developed to reduce the cognitive and physical requirements of operating a power wheelchair. This paper describes the development and evaluation of voice control for the NavChair.

BACKGROUND

The variation in functional abilities presented by power wheelchair users is clearly illusrated by the vast array of wheelchair controllers that are available. However, even though it has proven useful for operating other assistive technologies like computers and environmental control systems, voice control has yet to become a viable wheelchair control method.

Voice control is an attractive option for several reasons. Voice control systems can be used by any individual capable of consistent and distinguishable vocalizations, so voice control is potentially appropriate for a large number of wheelchair users. Voice control would also reduce the physical requirements of operating a wheelchair. Finally, by eliminating the need to move one or more extremities to control the chair, it should assist the wheelchair operator in maintaining proper positioning within his or her seating system.

Unfortunately, voice control has proven difficult to implement within a standard power wheelchair. One difficulty is the very real possibility that a voice input system may fail to recognize a user's voice. Another wheelchair voice control system (Amori, 1992) attacked this problem by limiting the amount of time that any command could move the chair, reasoning that momentary commands were less likely to produce collisions than latched commands. One drawback of this approach is the fact that even short-lived commands can cause collisions in a crowded area.

Another problem is the limited rate by which information can be transmitted by voice. An experienced voice recognition user can enter between 30 and 50 words a minute (Kambeyanda et al, 1996). In practice, this makes voice input useful for general directional commands for operating a wheelchair in open spaces but inadequate for rapid correctional maneuvers in crowded environments.

The challenge, then, is to implement a voice interface for a wheelchair that assures the safety of the wheelchair rider, remains unobtrusive, and is easy to learn. Safety requires that the voice control system must anticipate that commands may be misinterpreted or ignored and be impervious to extraneous noise. Unobtrusive means that the voice interface must not require multiple corrective inputs from the user and must not use long or complex commands. To ease learning, the voice interface should consist of a small number of commands which are consistent and intuitive.

The voice control system described in this paper was implemented within The NavChair Assistive Wheelchair Navigation System. The NavChair is being developed to provide mobility to those individuals who would otherwise find it difficult or impossible to operate a power wheelchair. The NavChair was chosen for this project because the navigation assistance it provides to the user makes it possible to ensure the user's safety while limiting the amount of interaction required between the user and the wheelchair. The NavChair's navigation assistance allows the wheelchair operator to supply gross directional commands while the NavChair itself makes the numerous small corrective maneuvers actually needed to reach the target. Most importantly, the NavChair's obstacle avoidance capability means that misinterpreted or ignored commands won't cause a collision.

IMPLEMENTATION

The NavChair prototype is based on a Lancer power wheelchair [1] augmented with an IBM-compatible 33MHz 80486-based computer and an array of 12 sonar sensors (Jaros, et al., 1993). During operation, the NavChair system interrupts the connection between the wheelchair's joystick and wheel motor controllers. The user's indicated path of travel

and the wheelchair's immediate environment are used to determine the control signals sent to the wheelchair motors, and hence, the direction and velocity of the wheelchair.

The NavChair's voice control facility is based on the Verbex SpeechCommander [2], a continuous-speech voice recognition system that relays user commands to the NavChair via the computer's serial port. Prior to operation, users train the SpeechCommander to identify a small set of commands, a process which is typically accomplished in less than ten minutes. During operation, the user speaks commands into a microphone. The sound signal is identified as one of the pre-trained commands by the SpeechCommander, which then transmits a computer code associated with that command to the NavChair's computer. The NavChair's computer matches the signal from the SpeechCommander to a specific joystick command which is then used to steer the chair.

Experimental Methods

Six able-bodied subjects (five male, one female), ranging in age from 22 to 27, were asked to perform a series of navigation tasks using the NavChair. During the experiment subjects were asked to perform the three tasks, shown in Figure 1. Each task was first performed four times with navigation assistance active (condition WNA) and then four times without navigation assistance (condition NNA). Table 1 lists the voice commands that were available to subjects during the experiment. After the experiment was finished, subjects were asked to complete a questionnaire rating operation under WNA and NNA from one (worst) to ten (best).

Command	Explanation
Stop	Chair halts immediately
Go Forward/Backward	Chair moves directly forward/backward
Rotate Right/Left	Chair rotates in place
Hard Right/Left	Chair turns 20 degrees then continues moving forward/backward
Soft Right/Left	Chair turns 10 degrees then continues moving forward/backward

Table 1. Voice Commands Available During Experiment

During each trial the performance measures listed in Table 2 were recorded. Most measures are self-explanatory, except jerkiness, which is a quantitative measure of ride comfort measured as the root-mean square average of the linear (forward jerk) and angular (steer jerk) motor commands over 10 MHz. Data was compared between conditions using a repeated measures ANOVA for each experimental measure. A significant difference was defined as one whose p-value was less than .05.

Results

Statistically significant differences are shown in Table 2 in **bold**. No performance measure had a significant effect for trial. WNA received an average ranking of 8.17 (out of ten) from subjects while NNA received an average ranking of 4.67, a difference which was statistically significant. No subject failed to successfully complete any of the tasks on any of the trials under either condition.

Measure	Method	Task 1	Task 2	Task 3
Avg Time (sec)	WNA	11.00	**57.91**	18.10
	NNA	9.84	**37.55**	22.94
Avg Speed (mm/sec)	WNA	469.58	186.44	506.08
	NNA	537.2	269.22	452.87
Forward Jerk	WNA	0.47	**0.33**	0.38
	NNA	0.34	**0.52**	0.28
Steer Jerk	WNA	**1.06**	**0.62**	**0.85**
	NNA	**3.82**	**2.09**	**1.70**
Avg. Minimum Clearance (mm)	WNA	566.23	622.00	447.08
	NNA	544.75	624.2	423.60
Front Collisions	WNA	0.00	**0.00**	0.00
	NNA	0.08	**0.33**	0.13
Back Collisions	WNA	0.00	0.13	0.00
	NNA	0.00	0.08	0.00
Side Collisions	WNA	0.00	**0.00**	0.00
	NNA	0.00	**0.5**	0.29

Table 2. Experimental Results. Significant differences shown in **bold**.

The only significant difference between NNA and WNA in terms of average time or speed occurred during the Door Passage task for average time. This was caused by navigation assistance stopping the chair as it approached the door and forcing the user to back up to reposition the chair. This slowed completion of the task but also reduced the number of collisions that occurred while passing through the doorway. Although the WNA condition generally caused the NavChair to move slower and take more time to complete tasks, on the allowed the chair to maintain a greater average speed and complete the task in less time.

Navigation assistance also contributed to making the ride more comfortable. There was a large and significant difference in the amount of steer jerk between the two conditions for all three tasks. The only time a significant difference was noted for forward jerk (in the Door Passage task) was when WNA caused less forward jerk than NNA. Navigation assistance lead to slightly more forward jerk in the other tasks but the difference was not significant.

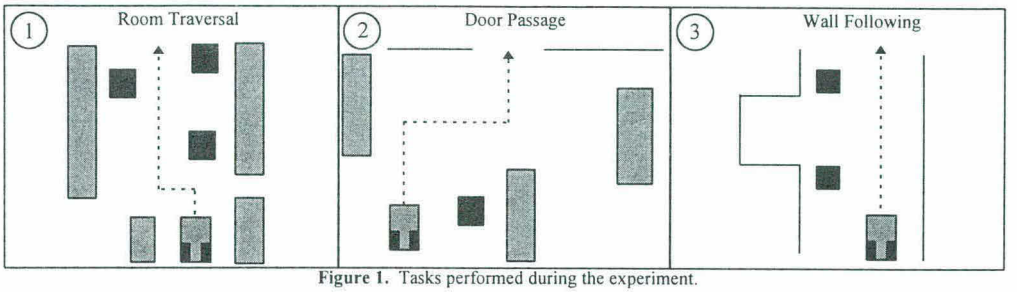

Figure 1. Tasks performed during the experiment.

Condition WNA was noticeably safer than condition NNA in terms of collisions and average clearance. Significant differences were observed between conditions for front and side collisions during the Door Passage task. In general, WNA kept a greater minimum distance from obstacles and had fewer collisions.

DISCUSSION

Based on user's subjective ratings alone, navigation assistance is clearly preferred when using voice control. Navigation assistance decreased the likelihood of a collision and reduced the amount of steer jerk. Collisions when there was no navigation assistance were caused by the voice recognition system's inability to correctly recognize a command or subjects' inability to make rapid, compensatory inputs when navigating in confined areas. Navigation assistance allowed the NavChair to immediately compensate for misinterpreted commands. Navigation assistance also allowed the NavChair to automatically perform the small adjustments in speed and direction necessary to successfully pass through closely spaced obstacles, such as two doorposts. The approach that most users took to steering through doorways when navigation assistance was not active was to line the chair up with the door and drive straight at it hoping to get through with, at most, one corrective maneuver.

CONCLUSION

It is certainly possible to implement voice control within a wheelchair that does not provide navigation assistance. With sufficient training and technology misrecognitions can be reduced (though probably not eliminated). An interface could also be developed that allowed users to make variable degree turns, which would probably reduce the amount of jerkiness experienced by users. However, as the complexity of the voice interface increased, the number of subjects for whom it was appropriate would decrease. Additionally, more complex commands would likely decrease the number of commands that could be given in a fixed amount of time.

Navigation assistance represents a viable design alternative which allows the voice interface to be simplified and helps to maintain the safety of the operator and the wheelchair. More importantly, we believe the results we observed apply equally well to other discrete wheelchair control methods. A set of switches is functionally equivalent to the set of voice commands used by subjects during this experiment, and it is likely that users of these wheelchair control methods would receive similar benefits from navigation assistance.

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A METHOD FOR QUANTITATIVE USER EVALUATION IN CASE OF ASSISTIVE ROBOT MANIPULATION

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ABSTRACT

The present study describes a new method under development for the quantitative analysis of Manus robot manipulation by people with severe disabilities. The analysis of the man/machine interaction is recorded via M3S (Multiple-Master-Multiple-Slave) communication bus. A spy software permit to identify the current messages on the bus. Thus each command action is detected on line and the associated task performed by the robot is stored. A 3D recording method of the hand movement on the input device and the trajectories of the arm end-effector is used to analyze the transfer function between the human hand and the robot gripper motion. This approach will permit to quantify the reaching and grasping strategies with the Manus and to point out the difficulties encountered during the learning phase. A study of the working space of the hand and the Manus end-effector will allow us to specify the motor capabilities of each end-user and to get some guidelines about the design of the input device.

KEYWORDS

Man/Machine Interaction, Motor Control, Quantitative Evaluation

INTRODUCTION

This project consist of analyzing the different features which could influence the man/machine interaction in the case of disabled user, in particular for the command of a Manus manipulator. These factors are linked to the handicapped users with their specific needs and to other technological factors as the command interface, the transmission protocol of the data and the nature of the end-effector. The evaluation of these factors will favor the use of assistive technology by an individual and will guide future technological development. The means used are based on quantitative analysis methods of the man/machine interaction that we propose to develop. It consists on the comparison between the user action on the input device (i.e. a joystick) and the result obtained by a controlled system, as an arm robot, during an action toward a target.

The use of precise observation methods, inspired from recent research work on motor control physiology, will permit to analyze the way a disabled user acts on the available commands to use technological aids. Preliminary results obtained by A. Roby-Brami [4] on the computer mouse permit to validate this approach.

3D MOVEMENT RECORDING

The perspective of our project is to use 3D movement analysis methods to facilitate the adaptation and the learning of technological aids in particular robotics arms.

The movement are recoıded with a Spatial Tracking System (STS Fastrak). This system is based on the use of electromagnetic sensors (Polhemus) which allow to measure on line the position (X, Y, Z) and the Orientation (Yaw, Pitch, Roll) of each sensor in an hemispheric area of about 1.5 meters in diameter.

Actually the software developed in the lab permit to:
- record the position of the working point (i.e. the motion of the hand, or the motion of the end-effector of the Manus robot).
- provide an audio feedback which helps the user to know if his action is closer or not from the target.
- measure the upper limb joint configuration (software developed in collaboration with E.V. Biryukova of the university of Moscow [1].

In practice, this 3D recording tool will be used to study the man/machine interaction at three levels:
- To well define the motor capabilities of disabled users: measurement of the working space and measurement of the joint limitation of the movement.
- to quantify the actions: a sensor is then fixed on the gripper of the robot and another one on the object which represents the target. The analysis of the trajectories allows to measure the duration of the task to be processed and the number of commands executed and to detect the command errors (missing the target, wrong direction, etc.). This type of method will probably improve the ergonomic analysis of the interaction.
- to favor the learning of new commands by enriching the working environment by audio feedback. We have noticed during preliminary observations that the main difficulty faced when using a robot was to center the end-effector according to the target. The STS on line recording will permit to get a continuous sound which varies with the centering of the gripper according to the target.

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The command and processing signals will be recorded on line each time it will be possible depending on the technical aids used. This will be done thanks to the use of M3S communication bus which is a standard of interfaces command developed at a European level. It permits to have access to the data sent from the command device to the peripherals. We plan to develop this recording function to complete the information obtained by the 3D Analysis motion toward a study of the man/machine interaction.

M3S COMMUNICATION BUS

The M3S standard of communication is born through a European consortium (project FOCUS-TIDE). The aim was to design a concept of communication bus to favor modularity, safety and mobility.

M3S (fig. 1) is based on the industrial bus CAN (Controller Area Network).

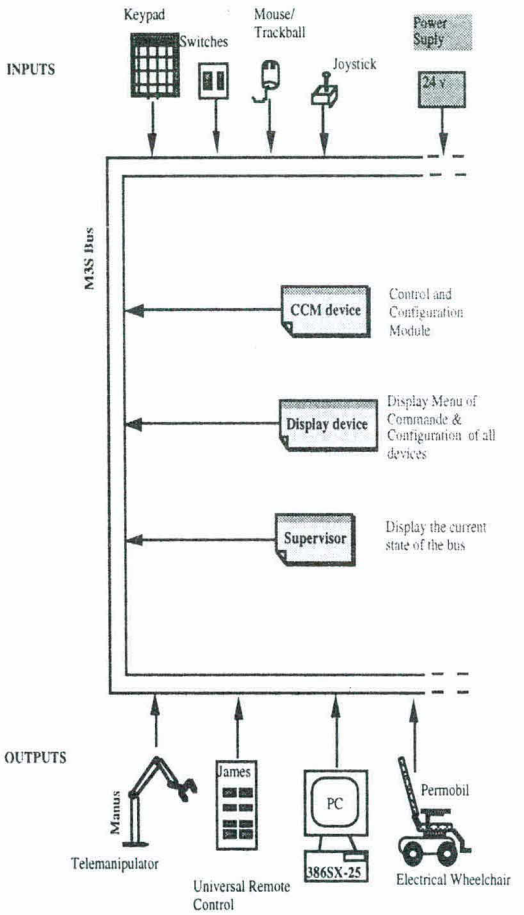


Figure 1: M3S (Multiple-Masters-Multiple-Slaves) Communication Bus
European TIDE Project - DGXIII

Actually a final version of M3S protocol is exploited by different companies and laboratories (TNO, Permobil, FST, etc.) to design new prototypes. A starter development kit, commercialized by TNO in Netherlands, permits to develop new applications.

The main advantages of M3S is that it is mounted on electrical wheelchairs and that it favors the integration of the inputs interfaces, only one input (ex. joystick, keypad, scanboard) is able to command different assistive devices (Manus robot, electrical wheelchair, James environmental control). The CCM module controls the devices connected to the bus and allows the user to swap between the inputs/outputs devices. A PC CAN spy software detects the messages emitted by the CCM and by each device. Each message is interpreted by a supervisor, under development, and stored as ASCII files. The supervisor will permit to measure the time elapsed between each data. This will permit to evaluate a precise delay between the command and the resulted action.

HUMAN HAND MOVEMENT ANALYSIS

Five quadriplegic patients of the Rehabilitation Hospital of Garches have participated in this experimentation. One STS sensor was fixed on the back of the hand to measure the working space of the hand and another one on the shoulder to measure the displacement of the body (fig. 2). The patients was asked to move their hand with a maximum amplitude following particular directions. Two types of experiences was performed: one using a working plan to get the user capabilities on a plan and another set of task without any support to get 3D working space.

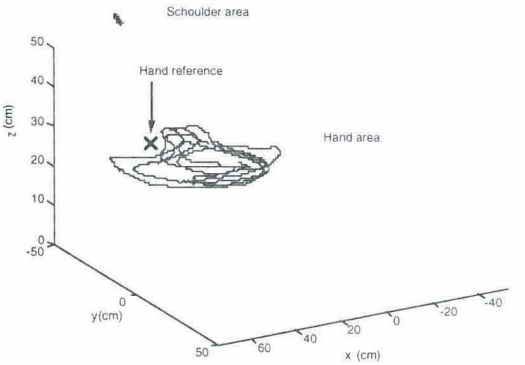


Figure 2: Working Space of the Hand and Shoulder Positio

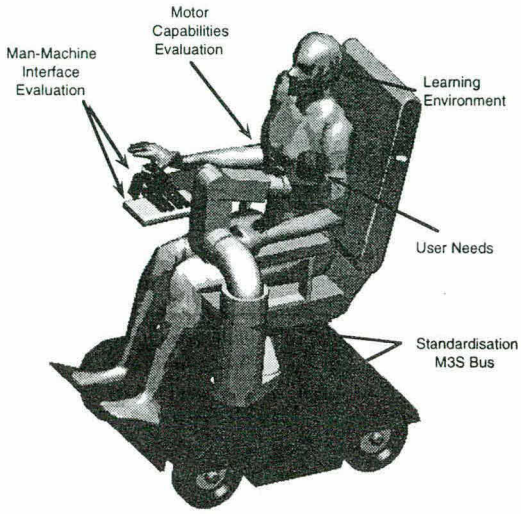
MANUS ROBOTICS ARM

Manus robot is manufactured by Exact Dynamics company in Netherlands. It's a six degrees of freedom robotics arm mounted on an electrical wheelchair (fig.3). At the extremity of the arm is fixed a symmetrical motorized gripper with a maximum load of 1.5 kg.

We have fixed an STS sensor on the gripper taking into account the electromagnetic perturbation due to the metallic structure of the arm. The aim of the experimentation was to measure the working space of the Manus by the use of a calibrated work plan.

A second sensor was used to designate the target. According to the module of the vector between the two sensors, we vary the frequency of a sound generated by

a Soundblaster stereo card. Also the amplitude of the right and the left channels are operated separately according to the position of the gripper from the target. The perspective of audioguiding is to improve the learning of complex motor commands in the context of rehabilitation and assistive robotics devices.



Manus Mounted Wheelchair Robot

DISCUSSION

The trajectories of the hand movement obtained with the participation of quadriplegic users shows that often the patient moves his body in the same direction (right, left, forward and backward) as his hand when performing a reaching task. Figure 2 shows the working space of a patient when using a mechanical support for his arm. A same experimentation with the same patient and without the mechanical support showed a smaller working space. It's important to note that the reaching space is not the same as the prehension space which necessitate more precise movement. An analysis of the prehension space is done in the rehabilitation hospital of Garches with the help of several disabled patients.

CONCLUSION

Actually the main problem of assistive technology is the lack of a method to analyze precisely the user needs. The evaluation of technological aids is fully dependent on: the system provided, the motor and cognitive capabilities of each user, the context of the evaluation (on site or at home) and some other factors. The problem that we have encountered during the experimentation's realized with the collaboration of disabled user of the hospital of Garches was situated at the level of the man/machine interface. The necessity to work toward a quantitative method seem to be the best way to evaluate assistive functions instead of the evaluation of the products. for example the analysis of the task 'taking object from the floor using robots', the quantitative method will answers such questions: How long does it take to perform this task? What is the frequency of appearance of this functions? What is the strategy used? etc.

"The Engineers has to accept that the value of their work has not to be in the technology they develop, but in the application the disabled people do" [2]

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THE RAPID PROTOYPING OF CUSTOMIZED MOTORIZED WHEELCHAIR TRAYS

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ABSTRACT

This paper presents the design of a customizable wheelchair tray. This device includes movable and motorized parts which provide manipulation assistance. The design steps in creating this novel tray and the use of rapid manufacturing techniques are described. An essential issue in this project is to evaluate the application of rapid prototyping, such as Virtual Prototyping, Computer Aided Design and Manufacturing technologies to the design of rehabilitation devices.

BACKGROUND

The overall goal of this project is to evaluate the application of rapid prototyping technologies to the design of customizable rehabilitation devices. This approach may reduce product cost and increase quality and also help meet the widely varying needs of consumers with disabilities, in terms of the user's body geometry, degree of disability and activities [1].

The project includes several aspects: Virtual Prototyping, Computer Aided Design and Manufacturing, and design case studies.
- Virtual Prototyping is the use of computer animation to simulate the device in its working environment without creating a physical prototype.
- Computer aided manufacturing is the use of computer software to design, plan and carry out the manufacture of devices. Most of the manufacturing processes can be performed by CNC machine, which can be entirely controlled by this kind of software.
- Design case studies are being used to show the application of these manufacturing techniques to a real customizable product and the evaluation of these methods upon concrete results.

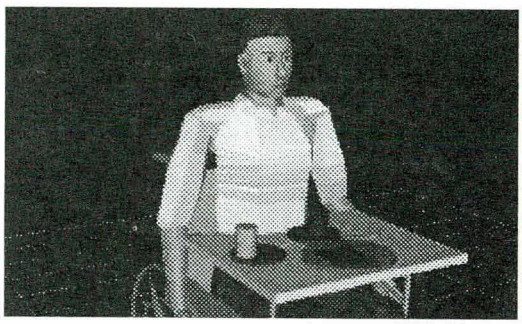
STATEMENT OF THE PROBLEM

As one of the design case studies we have been focusing on different kinds of wheelchair trays. The idea is to assist a wheelchair user who has a manipulation disability with moving several objects on the wheelchair tray. For that purpose the wheelchair tray may include motorized parts that can move or reorient an object. Wheelchair mounted robots are available and designed to serve a similar purpose. Those devices, however, are very expensive and complicated. We preferred to consider one-to-three degrees of freedom devices aimed to perform a specific kind of task. Such a device has the potential to be more affordable and reliable.

The first step in this project was to select a design for the wheelchair tray in collaboration with a group of consumers. A wide range of alternative designs was submitted to the consumers. In order to make sure that the consumers would understand the design description, we used two approaches to present our ideas.
Foam core models were fabricated. These representations were quite straight forward because the users could hold them and operate them. On the other hand it required a long time to put them together and they were not very easy to transport from one place to another.
Virtual prototypes were created. The tray models were created with ProEngineer™ CAD software. Then they were ported into JACK™ as shown on Figure 1. JACK™ is a Human Behavior simulation package which allow one to animate articulated figures and visualize the scene in 3 Dimensions [2]. Finally an animation of the device while working was recorded on a video tape. This prototyping method is fast so it is easy to create many different design simulations. The result was very positive too. These 3D animations provided a very clear idea of how the device could look like while being used and were acceptable to consumers.

All possible degrees of freedom were considered during this design selection phase: horizontal, vertical, and back-and-forth translations, rotations about those 3 axis. The number, size and path of the sub-entities was also a variable as shown on Figure 2. The feedback from the consumers showed that the simpler devices were preferred because they are easy to operate since they have a limited number of inputs. Finally, two designs were selected: the rotating plate and the reading tray.

The rotating plate consists of a circular plate inserted in the tray. Its rotation is performed by pushing either of the two input buttons. The user's tools and objects rest on the plate. Whenever he/she wants to reach one of them, he/she operates one button until the desired object comes in front of him/her. The available working space is then enlarged. The reading tray features a tilting board. By operating the system's actuator, the board lifts up and reorients the book towards the user. Several consumers with spinal cord injuries had remarked that they may not be able to read a text that rests horizontally on their wheelchair tray because inclining the head forward may cause fatigue.



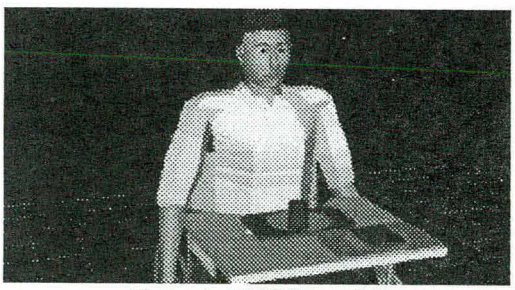


Figure 1: JACK™ models

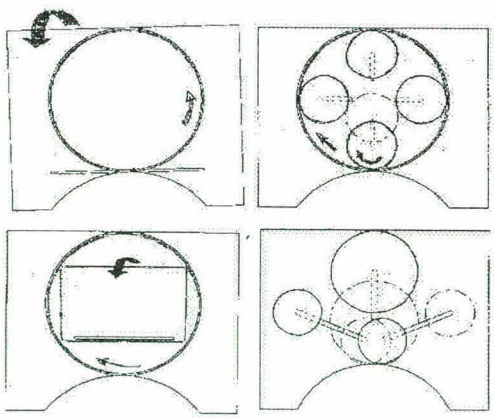


Figure2: Other example of tray designs

PRELIMINARY DESIGN

The turning plate has a very simple design. Power transmission from the motor to the rotating plate is provided by a friction wheel. This system is cheap and safe.

The reading tray shown in Figure 2 is composed of 2 main parts. The basic tray has a semi-circular cut at the user placement and a rectangular slot in the front right. A rectangular board can be inserted into this first part and rotated around one of its edges. A lever powered by a small DC motor hangs on the tray bottom. Power transmission from the motor shaft to the lever is provided by a worm gear. Consequently, the system stays in position without consuming any energy.

The input device is a box featuring two push buttons. Operating one of those buttons causes the board to lift up while pushing the other button causes the board to go back down. One limit switch stops the board up-motion when this one reaches an angle of roughly 45° to prevent the book from falling if the user keeps pushing the control button. Another limit switch stops the down-motion beyond the horizontal position for the same reason.

All the parts were designed with the CAD package Pro-Engineer™, and relations between interconnecting parts dimensions were defined. This makes the dimension modification process easy. Some dimensions may be customized to the current customer: For example the tray dimensions may be adapted according to the wheelchair geometry. The attaching clips may be selected and placed in relation to the armrests configuration. Body cut dimensions must fit the customer stoutness. The tilting board may be placed either on the left side or on the right side. Each of those dimensions are driven by a specific parameter in the ProEngineer™ Assembly model.

DESIGN PROCESS

Feedback from the consumers group on the working prototypes has been positive. Current developments are now focusing on the manufacturing process for a customized model.
As mentioned above some features of the tray can be customized to an individual user, while some parts can be obtained off the shelf. The motors and other mechanical parts need not be customized, while the tray options, dimensions, and shapes may be adjusted. Customizing the generic model for an individual is

made rapid and efficient thanks to the design flexibility of ProEngineer™, as well as virtual prototyping. This design process has not been further evaluated so far, but it is being processed.
The CAD model of the tray can be easily imported from ProEngineer™ into JACK™ environment as an Inventor file, and animated on the wheelchair the correct position. By visualizing interactively the scene in 3D the designer can check how the tray fits and make any necessary adjustments. The CAD model can be consequently adjusted, and imported again into JACK™ environment for evaluation. The loop might be repeated several times until the device fits perfectly. This process is much faster than when using an ordinary prototyping method [2].

When a CAD model of the customized product is obtained, the effective manufacturing of the parts can be fully automated. Indeed the CAD file is converted to Machine Command Code by Pro-Manufacturing, and the parts can be automatically fabricated.

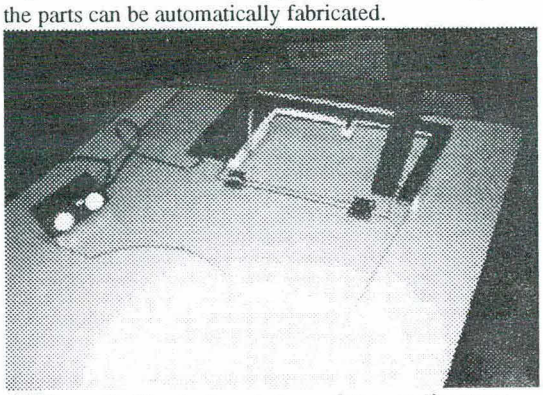


Figure 2: Physical prototype of the reading tray

CONCLUSION

This design has shown that Virtual Prototyping is a useful product evaluation tool for the designer. A great amount of time and material is saved using this technique versus physical prototyping. It showed also how Rapid Prototyping tools such as CAD and CAM packages, as well as CNC machines are helpful to manufacture customized rehabilitation devices.
The evaluation can be improved by creating a model of the individual in JACK™. For that purpose the personal geometric datas such as size, torso circumference, arms length are acquired and used to modify JACK™ human model [3].
The enthusiastic feedback from the consumers showed also that this novel idea of the motorized wheelchair tray is worthwhile because it is useful and simple, and helps increase independance.

JACK™ is a registered trademark of the University of Pennsylvania
ProEngineer™ is a registered trademark of Parametric Technologies Corporation

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SIG-14
Job Accommodation

THE USE OF A CUSTOMIZED PORTABLE PLATFORM TO MAKE WORKSTATIONS ACCESSIBLE IN A VOCATIONAL TRAINING SETTING: A CASE STUDY

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ABSTRACT

This case study demonstrates how assistive technology can effectively support the individualized goals and objectives of a vocational training program. The customized portable platform described in this case study was developed for Tommy T., a 17 year old with dwarfism. This device was developed by a multi-disciplinary team which included a physical therapist, a rehab. engineer, an orthotist, an occupational therapist and an O.V.R. Counselor. It was developed so that Tommy could access and receive training on the various machines in his Vo-Tech's Metal Machine Shop. The customized portable platform enabled Tommy to overcome the challenges and obstacles that he faced because of his disability, and to achieve success in the classroom.

BACKGROUND

Tommy has a history of dwarfism and is only 38" tall. He also has congenitally absent knee joints and progressively deteriorating hip joints. Tommy is able to walk moderate distances independently without assistive devices. He walks with a waddling-type gait because of hip weakness and he does have limited endurance. He has good upper extremity function and coordination. The Hiram G. Andrews Center for Assistive and Rehabilitative Technology team first became aware of Tommy in September of 1995. At that time Tommy's OVR counselor made a referral to our CART team for the purpose of making assistive technology recommendations concerning Tommy's safety and machine equipment access in his Vo-Tech's Metal Machine Shop. At that time, Tommy had just begun his first year of vocational technical training in the Metal Machine Shop. The Metal Machine Shop vocational program that Tommy had entered required that he receive training and develop competency on 9 separate machines over the next 4 years. These machines included a metal lathe, a vertical milling machine, a horizontal milling machine, a vertical bandsaw, a metal grinder, an abrasive cutoff saw and a metal cutter. Because of his short stature, Tommy could only effectively access and receive training on 5 pieces of this equipment without making accommodations. The pieces of equipment that he was unable to access included the metal lathe, the vertical milling machine, the horizontal milling machine and vertical bandsaw. The challenge facing the CART team was to make appropriate accommodation recommendations that would enable Tommy to effectively and safely access these remaining 4 pieces of equipment. It was also critical that any recommended changes to accommodate Tommy would not cause any interference for the other students in the classroom.

METHOD

The first thing that the CART team did when it received the assistive technology referral on Tommy was to request a video of him in the Metal Machine Shop classroom. The video helped the CART team to accurately identify several major problems that Tommy was experiencing in the classroom environment. The video showed that Tommy had begun using a 3-step stepstool to stand on while he was training on the higher pieces of equipment This method of accessing the higher equipment was potentially an unsafe activity because Tommy had to lean forward and to the sides to operate the various equipment and he was at risk for losing his balance and falling into the dangerous moving parts of the equipment. He was also at risk of falling because of the small standing surface of the stepstool. Even with the use of the stepstool, Tommy was unable to access an adjustment nut on the vertical milling

machine and he could not access a 5" adjustment wheel on the horizontal milling machine. The amount of work that Tommy was able to produce in a given period of time was not acceptable because he had to spend so much time repositioning his stool, climbing up and down it and getting necessary project materials.

After reviewing the video the CART team had several lengthy brainstorming sessions to identify solutions for the access problems that were preventing Tommy from achieving success in his vocational training program. Several recommendations for possible accommodations in the classroom were considered initially before an acceptable solution was finally identified.

The first recommendation was to customize a power scooter with a seat elevator and have Tommy stand on the seat with a cage built around him and the joystick control customized so that he could access it. This recommendation was eliminated because we felt that moving and working from a power chair in a Metal Machine Shop around metal machine shop equipment would present an increased safety risk.

A second recommendation that was considered was to use a commercially available portable electrically elevating platform. This recommendation was eliminated because the platform was too bulky and large to fit around the various equipment in the classroom and Tommy would have needed assistance in moving it from workstation to workstation.

Another suggestion was to build separate platforms at the 4 machines that Tommy was unable to access. This recommendation was also eliminated because these platforms would prevent the other students in the classroom from accessing the machines effectively.

The recommendation that was finally agreed on by the CART team was to have a portable platform custom built for Tommy's use. Specifications and information on the fabrication of the portable platform was provided to Tommy's Vo-Tech instructor, Mr. Williams. Since they had appropriate facilities at the Vo-Tech, fabrication of the portable platform was done there. The CART team projected that Tommy had the potential to effectively access the majority of the operations on the 4 higher machines from a portable platform.

RESULTS

After the portable platform was fabricated the Physical Therapist and Rehab. Engineer did an onsite assessment of Tommy. The instructors and students did a good job of fabricating the recommended portable platform. The platform is 36" long by 21" wide by 21" high and it has two 8" steps attached to it and it also has four retractable swivel casters on the base. It also has 20" high 3/4" diameter metal pipe railings on the 2 sides and on the end. (See Diagram)

By the time the onsite assessment was made Tommy had the opportunity to use the platform for several weeks. Tommy and his instructor were very pleased with Tommy's improved equipment access, improved safety and improved independent usage of the various machines. During our onsite assessment Tommy demonstrated his usage of all the different machines in the metal machine shop classroom. With the use of his portable platform Tommy was able to safely, independently and effectively carry out most of the operations of the four higher pieces of equipment. The only operations that he could not carry out independently were accessing the adjustment nut on the top of the vertical milling machine and the 5" adjustment wheel on the horizontal milling machine. Accessing the adjustment nut was accomplished by providing him with a customized offset wrench which allowed him to reach and adjust the adjustment nut. Accessing the 5" adjustment wheel was accomplished by modifying the wheel and increasing its diameter from 5" to 10" which permitted him to be able to reach and turn it. Tommy had no difficulty moving his portable platform from machine to machine and the lower storage shelf was very effective for

transporting materials. Tommy was not at any higher safety risk than normal and he no longer required a student to spot him when working on the different machines. Although he still had to occasionally get up and down on the platform and move it while at a specific machine, Tommy was now able to work at an acceptable speed. Tommy demonstrated his ability to work at the lower pieces of equipment in the machine shop and he had no difficulty accessing them without the need for accommodations.

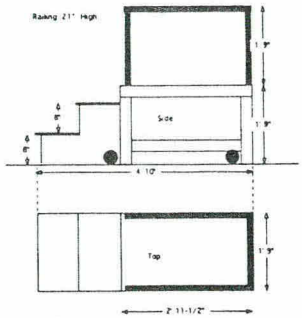

Diagram of Portable Platform

DISCUSSION

Since providing Tommy with a portable platform and the other training site accommodations, he has made steady progress in his technical training and he is successfully achieving the individualized training goals and objectives that had been set for him. This is the first time in his academic career that Tommy has achieved academic success. Until this past year Tommy had a history of behavior problems in school. He was uncooperative and poorly motivated. He is now described as being pleasant, motivated, well-behaved and cooperative. Both Tommy and his instructors credit appropriate assistive technology for his change in attitude and for his current success in school. He now has good potential to become a highly skilled machinist and to lead a productive and fulfilling life. Appropriate assistive technology interventions were able to be provided for Tommy because of effective communication, innovation and team work between the CART team, the OVR counselor and the Vo-Tech staff.

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EFFECTS OF SPLIT KEYBOARD USE ON CUMULATIVE TRAUMA DISORDERS

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ABSTRACT

Repetitive keyboard use has been linked to the development of cumulative trauma disorders (CTDs). Because of this link and the growth of CTDs, various keyboard modifications have been proposed. Current research is limited on what keyboard designs are the most appropriate for reducing or preventing CTDs. This paper looks at the existing research surrounding one of these designs, the split keyboard, and whether its use substantiated. We concluded that although split keyboards show some benefits in preventing CTDs they cannot be considered a "cure all." Factors, such as force and repetition have a large impact on the occurrence of CTDs, for which the split keyboard does not compensate.

BACKGROUND

With the 1872 invention of the manual typewriter, the main concern for designers was to slow the user and prevent the jamming of typewriter keys. The computer keyboard, modeled directly after the manual typewriter keyboard, has come under fire as a reason for many keyboard related health problems. Operator stress problems related to CTDs include carpal tunnel syndrome, tendinitis, epicondylitis, and others (1).

CTDs of the upper extremities have increased dramatically and account for more than 50% of all work related injuries (2). Repetitive, forceful motions of the hands and wrists have been widely accepted as a leading cause of CTDs (3).

Although all of these cases cannot be attributed to keyboard use, many of the major keyboard makers, such as Apple, IBM, Compaq, Atex, and Unisys, have recently been sued by individuals claiming that keyboards are the main cause of their injuries and illnesses (4). Poor posture coupled with additional force and repetition has been shown to greatly increase the chances of a CTD (5). Modifications to the standard computer keyboard have been suggested as ways to reduce CTDs, including the rearrangement of the keys and separating the keyboard into sections. Because of the possible connection to CTDs, many companies are designing alternative split keyboards that claim to enable the user to keep the wrist in a more anatomically correct posture, decreasing pressure inside the wrist.

Limited research has been targeted towards the effects of a split keyboard design on the reduction or prevention of CTDs. Reasons that a review of this research is needed are three-fold. First, information is scarce. Second, consumers need to be informed on the effectiveness of split keyboard designs and third, information is needed to improve the understanding of possible accommodations for individuals with CTDs.

RESEARCH QUESTION

Does existing research support the hypothesis that split keyboard design is effective in reducing or preventing CTDs?

METHOD

A search of existing research was completed. Seven studies were reviewed and their results reported. A determination was then made on whether existing research supports the hypothesis that split keyboard design is effective in reducing or preventing CTDs.

RESULTS

In depth research on Klockenberg's 1926 idea of splitting the keyboard in half and tilting

each part in a declining manner to reduce muscle tension is limited (6). Research began in 1972 when Kroemer summarized a number of studies that investigated possible biomechanical improvements to keyboards. One improvement, the splitting of the keyboard, concurred with Klockenberg's earlier idea. Kreomer's investigation highlighted that the standard keyboard required the user to pronate the hands to their anatomical limit, resulting in constant tension, muscle strain, and fatigue. He cited 1964 and 1965 experiments where he looked at alternative keyboard arrangements. Kroemer found the standard horizontal arrangement caused the greatest muscle strain and fatigue. He found no substantial results regarding the centerpiece angle but did determine that separation of keyboard sections should be considered (6).

Chen et. al evaluated four computer keyboards by looking at a quantitative analysis of wrist posture and typing performance and on subjective analyses of operator comfort (7). Eleven volunteer subjects performed typing tests on each keyboard consisting of four five minute typing sessions alternating with a one minute break. The evaluations resulted in all three split design keyboards receiving equal or better ratings than the flat keyboard. Smaller wrist extensions in all three alternative keyboards were observed suggesting that properly designed alternative keyboards may improve posture.

Gerard et. al completed an ergonomic study evaluation of the Kinesis Ergonomic Computer keyboard (8). The Kinesis was designed by the Kinesis Corporation to reduce physiological stress and features a QWERTY layout with split design and tilted concave keys. Six female subjects participated in the study. Data showed that the Kinesis required less typing force than the standard keyboard and reduced muscular activity required for typing. The Kinesis also required less activity to maintain the resting posture than needed for the standard keyboard. Findings suggested that the Kinesis may reduce operator stress related to keyboard entry.

In 1994, Sommerich presented a study that looked at carpal tunnel pressure and how it is affected by wrist posture. For the study, she used four subjects that had no hand or wrist problems within the past year. Sommerich used a fiberoptic pressure transducer to measure carpal tunnel pressure and a goniometer to measure wrist posture (9). Subjects performed typing tasks on a standard keyboard and on an Apple split keyboard. Sommerich found that carpal tunnel pressures were reduced using the split design and suggested that there were advantages to the use of a split keyboard design.

The National Institute for Occupational Safety and Health (NIOSH) released partial results of a study on alternative keyboards. The study looked at four keyboards: one standard flat, two adjustable split and one fixed split. Results showed no significant differences between the standard and split keyboards in error rate, comfort or fatigue. However, two split keyboards, one adjustable set at 45 degrees and the fixed split, showed decreased productivity (10).

A November 1994 CTD News article regarding a report by James R. Lewis from IBM stated that Lewis reviewed much of the current literature on split keyboards and found none supported the use of split design keyboards to correct or prevent CTDs. Lewis reviewed studies involving the Mykey, Kinesis, Health Care, IBM, Marquards, and Apple keyboards. The article did state that their use show some positive effects on reducing carpal tunnel pressure (10).

Hedge and Powers performed a video analysis on hand and wrist postures used by subjects typing on a standard keyboard (11). The study compared the use of a standard keyboard on a flat surface with the same keyboard using full motion arm supports and the same keyboard using a negatively sloped keyboard support. The study found that placing a regular keyboard on a negatively sloped support should lessen the risks of developing a CTD. Even though Hedge and

Powers did not directly investigate split keyboards, they were able to suggest that vertical extension and flexion of the wrist appear to show a much greater risk for developing a CTD than ulnar and radial movements.

DISCUSSION

A literary review of current research on the effectiveness of a split keyboard in preventing CTDs, as compared to a standard keyboard, shows that it may reduce some of the discomfort and possible symptoms related to the occurrence of CTDs. However, even though the research shows that there are benefits, it does not indicate that a split keyboard will eliminate CTDs. Neither does it show that a split keyboard produces a *significant* impact on the prevention of CTDs. This conclusion could be due to factors other than posture influencing their occurrence.

Besides posture, force and repetition have been described as two primary causal factors. Secondary factors such as wrist size, gender, chronic disease, and acute trauma have also been suggested as possible causes (12). Furthermore, a split keyboard design only addresses the pronation and ulnar deviations of the wrist, not taking into account wrist flexion or extension. Therefore, it is our conclusion that even though a split keyboard may be beneficial in the prevention of CTDs, it should not be looked upon as a "cure all." The decision to use a split keyboard should not be considered without also addressing the effect that other factors, such as repetition and force, have on the user. Further study is needed to determine the true impact of these other factors.

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THE ROLE OF AN INDIVIDUAL IN ACCOMODATION

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ABSTRACT

Effective worksite design increases productivity. In order to develop better designs, the direct involvement of the end user of the worksite is considered essential. The assessment of each individual's unique capabilities and preferences is necessary. The present study examines the accuracy of prediction and perception of performance on a simple manual task. The study also examines the difference between persons with and without disabilities in prediction and perception accuracy. The results indicated that individuals are not good estimators of their performance but do improve with experience. It was also found that there are no differences between persons with and without disabilities in prediction and perception accuracy.

BACKGROUND

Participatory worksite design is the process in which workers are involved in the design process itself. Important informations relating to the individual's abilities and preferences, which cannot be accessed otherwise, are achieved by this. Individuals are more likely to accept design modifications or alternatives in which they are directly involved in the design process. This participatory worksite design is particularly true with the accomodation provided under American Disability Act (1).

Wolf (1992) indicated that individual's prefernces are affected by their experience. Bailey (1993) indicates that performance and perceptions are two different aspects and for better designs these should be considered seperately. Kweon, Schegel and Purswell (1992) in their study to assess stereotypical strength for automobile power window controls found that preference was related more to familiarity than the ease of use.

RESEARCH QUESTION(S)

The following questions arise in participatory worksite design.

1. Can individuals provide good estimates of the effect of design alternatives on their performance?
2. Do individuals improve their perception accuracy with experience with alternatives?
3. Is there a difference between with and without disabilities?
4. What are the factors affecting the errors in performance prediction?

METHOD

Subjects:

There were 40 subjects, 20 without disability and 20 with a disability(cerebral palsy).

Equipment:

Components from the Available Motions Inventory (AMI), a physical ability evaluation system of the upper extremity for light manual tasks, was used.

Tasks:

Simple rotatory task with four different positions and three different handles

Positions: Normal working positions with biomechanically different functions.

Handles: Rotatory handles with different inputs and similar in output
Hand Preference: Dominant hand

Procedure:
Each subject was familiarized with the experiment. Then each was asked to predict their performance in 12 alternative positions and handle combinations. A score of 10 was given to the alternative(s) which the subject felt they could rotate the fastest and 0 to the slowest. Then each subject was asked to rotate the device as fast as possible for 10 seconds. After performing the task, each subject was again asked to rate each alternative. The performance scores were normalized using the following equation to produce a scale with the same units as the task ratings.

$$NS = \left[\left(X_{ij} - S_{\min}\right) / \left(S_{\max} - S_{\min}\right)\right] * 10 \quad (1)$$

NS = Normalized Score
X_{ij} = Actual performance for a specific task
$S_{\min}$ = The lowest score of six tasks for a subject
$S_{\max}$ = The highest score of six tasks for a subject

RESULTS

Statistical analysis was conducted to compare prediction and perception ratings with actual performance for persons with and without disabilities. An ANOVA was conducted to identify the factors affecting the prediction and perception errors.

Prediction and perception accuracy
Individuals with and without disabilities were not able to predict and perceive accurately. Figures 1 and 2 are the scatter plots of actual performance versus prediction for both groups. For both groups the prediction accuracy was low with r-square values as 0.0799 (with disability) and .2827 (without disability). It is obvious from the scatter plots that individuals often predicted low and performed high or vice versa.

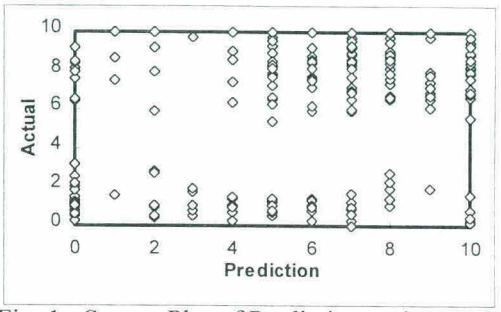

Fig. 1: Scatter Plot of Prediction and Actual Scores for People With Disabilities

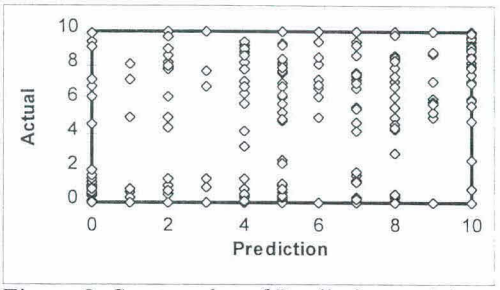

Figure 2: Scatter plot of Prediction and Actual Scores for People Without Disabilities

The accuracy of perception after the experience improved and the r -square values were .03105 and .5572 respectively.

Level of difficulty
Individuals were generally able to identify the task difficulty. This behaviour was analysed using a contigency table for each group. Predictions and perceptions were assumed to be accurate if predictions/perceptions were above an individual's mean and performance was above the mean, or when predictions/ perceptions were below the mean and performance was below the mean. Inviduals with a disabiliy were able to correctly identify 62% of the tasks alternatives where as individuals without disability were able to

identify 69%. This accuracy improved to 78% and 87% respectively after the experience. The results are shown in the following tables.

Table 1: Task difficulty identification in " %" for both groups with and without experience

	Prediction		Perception	
Performance	Good	Not Good	Good	Not Good
With disability				
Good	35.83	22.5	47.5	10.83
Not Good	15.42	26.25	10.83	30.83
Without disability				
Good	44.17	20.83	55.42	9.58
Not Good	10.42	24.58	3.75	31.25

Effect of Disability

A nested ANOVA was conducted to determine whether disability status had a significant effect on prediction/perception accuracy. It showed that there was no significant difference between groups in errors in prediction or perception of task performance.

Error

ANOVAs of prediction and perception errors were conducted for each group. The factors considered were position (4), handles (3) and their interaction. The results of the ANOVAs are tabulated below for both the samples.

Table 2: Significant factors with probabilities for both groups with and without experience

		Significant		
	Experience	Device	Positions	Interacti-ons
With Disability	No	<.0001	.0001	NS
	Yes	.0001	.0228	NS
Without Disability	No	<.0001	.0002	NS
	Yes	<.0001	NS	NS

The results of the ANOVA indicate that the individuals make errors in understanding the task alternatives and that devices or positions have independent effects.

DISCUSSION

Prediction of performance is not accurate. The accuracy is improved with experience. Errors in performance prediction and perception are not affected by disabling conditions. In participatory worksite accomodation the individual plays a vital role but their judgement concerning the effectiveness of alternatives should be objectively verified.

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AWARENESS OF HAND PERFORMANCE: DO I NEED AN ACCOMMODATION?

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ABSTRACT

This paper examines the accuracy of performance predictions made by persons with and persons without disabilities on a simple assembly task. Persons with disabilities are often expected to identify situations which may require an accommodation for them. A sub-test of the Available Motions Inventory was used in this study. The results indicate that disability status did not affect the accuracy of performance prediction. Both groups (persons with disabilities and persons without disabilities) did not predict their performance on a simple manual task with reasonable accuracy. Subjects consistently over predicted the ability of their hands and errors were greater for the preferred hand.

BACKGROUND

Estimating one's performance compared to others is the basis for identifying situations in which some accommodations may be required. Some studies have indicated that individuals with physical disabilities rate tasks as being easier than individuals without disabilities while performing at a lower level (Lanciault, 1990; Klein, 1990). The purpose of this paper is to study the accuracy of prediction on a simple manual task by two groups of subjects, persons with disabilities (PWD) and persons without disabilities (PND).

RESEARCH QUESTIONS

This research examines whether people can predict their hands' abilities on a simple assembly task. The research was also designed to determine whether PWD differ from PND in predicting the performance of their hands. One hypothesis is that PWD have a greater awareness of performance because performance is an operating constraint. An alternative hypothesis is that they may be less accurate because they may have had less opportunity to compare their performance with others.

METHODS

Equipment

A sub-test, spacers, of the assembly module of the Available Motions Inventory (AMI) was used in this study. The AMI was developed in 1974 by Rehabilitation Engineering Center at Wichita State University (WSU) to evaluate the upper extremity capabilities of persons with neuromuscular impairments. Its purposes are to provide information relevant to task modifications and to evaluate job-related physical abilities (Malzahn, 1984).

Subjects

There were sixty-five subjects that participated in this study. Forty-five PND were visitors during Engineering Open House 1996 at WSU, and twenty PWD were residents from the Timbers, a residential facility sponsored by Cerebral Palsy Research Foundation of Kansas for adults with physical or neurological disabilities.

Procedures

1. The subjects were first familiarized with the assembly task (spacers).

2. The subjects then predicted their hands' performance (preferred and non-preferred hands) on the assembly task in percentile compared to the performance to the total population of hands. For example, if the subject said 85% for their right hand, that meant that they could perform this assembly task as fast as 85 % of the general population.
3. One spacer at a time was taken by one hand from a spacer bin, and placed on a station plate. The spacer bin was located at the side of the hand being assessed and within the reach of the subject. The station plate had ten upright bolts attached to it in two parallel columns of five.
4. The observed time was converted into a population percentile using data from 100 adults without disabilities, 50 males and 50 females.

RESULTS

Comparative Statistics

The means and standard deviations of prediction and performance percentiles for preferred and non-preferred hands of PWD and PND are shown in the Table 1. A paired t-Test was used to determine whether the predictions were different from the actual performances. Then, an ANOVA table and Tukey-Kramer HSD Test were used to analyze factors that affecting prediction errors.

Table 1: The means and standard deviations of prediction and performance percentiles

	Mean (Std Dev) %ile	
Predictions & Performance	**PWD**	**PND**
Prediction P	39 (36)	66 (14)
Performance P	9 (22)	49 (28)
Prediction NP	13 (22)	48 (16)
Performance NP	6 (22)	42 (29)

* NP = Non-preferred hand, and P= Preferred hand

Paired t-test

The scatter plots of performance and prediction percentiles by preferred and non-preferred hands are shown in Figures 1 and 2. P values (< 0.01 for non-preferred hand and < 0.0001 for preferred hand) from Paired t-Tests show that performance and prediction for both hands are significantly different.

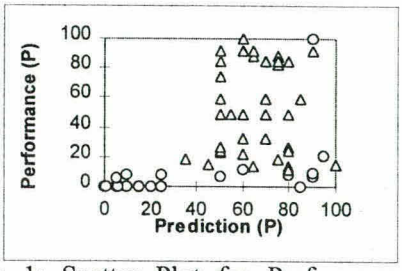

Figure 1: Scatter Plot for Performance and Prediction of Preferred Hand (O = PWD, Δ = PND)

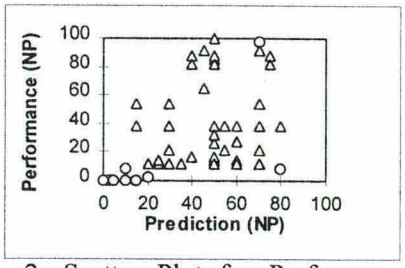

Figure 2: Scatter Plot for Performance and Prediction of Non-Preferred Hand (O = PWD, Δ = PND)

ANOVA Table

Prediction error (Predicted percentile - Performance percentile) was the response variable in the ANOVA analysis. The factors considered were subject, disability status (PWD, PND) was nested within subject, and hand (preferred, non-preferred). The results of ANOVA are shown in Table 2. The results indicate that only hand (preferred or non-preferred) significantly affected the prediction error. Disability status did not have a significant effect on the accuracy of prediction.

Table 2: Result of ANOVA

Source	DF	SSE	F	Prob
Subject [Disability]	2	3850	2.235	0.1112
Disability	1	1580	1.835	0.178
Hand	1	7652	8.885	***0.0035***
Disability* Hand	1	1012	1.175	0.2804

Tukey-Kramer HSD Test

Figure 3 shows the result of a Tukey-Kramer HSD Test that examining the effect of hand preference on prediction error. The prediction error of the preferred hand was significantly greater than the non-preferred hand. Subjects over estimated the performance of their non-preferred hand by 6.59%, and preferred hand 20.89%.

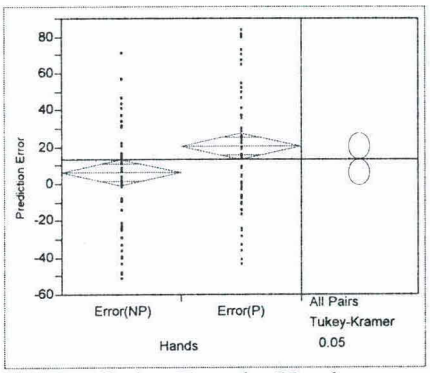

Figure 3: Prediction Error by Hand

DISCUSSION

The accuracy of predictions for both PWD and PND was not good for this assembly task. Disability status did not have an effect on prediction accuracy. Simply asking an individual if they can perform a task at a reasonable level may not be an effective means of identifying opportunities for improvement through task accommodation. Only when persons with disabilities indicated that they were unable to perform the task at all (0 percentile prediction) was there an indication that they felt that something could be improved.

Individuals rarely have the opportunity to gauge their performance on simple tasks directly compared to a larger population and yet it is this kind of information needed to determine whether a task needs to be altered to produce competitive performance levels.

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A READING CAROUSEL FOR PERSONS WITH QUADRIPLEGIA AND PARAPLEGIA

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ABSTRACT

The ability to consult several books or documents simultaneously without outside assistance is a need more and more often expressed by people who have quadriplegia. This situation is related to the fact that an increasing percentage of them go back to school and enter the labor market. The reading aids which are now available do not fulfill their need since they only give access to a single book at a time. To fulfill this need; we have developed a reading carousel that provides access to six books at a time and which can be utilised with the sole use of a mouthstick. A clinical evaluation of this reading-aid will soon be carried-out with two groups of clients; the one who has quadriplegia and the one who has paraplegia.

BACKGROUND

A mock-up and simplified version of the reading carousel was fabricated in response to a request made in the early 1980's by a student with a high-level quadriplegia. The student desired a specialised and adjustable reading table, which, with the aid of a mouthstick, would enable him to consult several books at a time without assistance. After analysis of the design, it was apparent that a specialised table has two main drawbacks : first; the user needs to continually move and precisely position his wheelchair in front of each book and second; the several books require a large surface area. To overcome these drawbacks; a reading carousel prototype was fabricated and given to this student for evaluation. Unfortunatly we lost contact with him for the next five years as he went abroad to study. When he returned, we learned that despite some design weaknesses, he has continuously used the unit during his absence. Since the interest and need for this type of equipement remains high, we have addressed the design weaknesses in this prototype and, while retaining the original concept we present here a second prototype with ergonometric and functional improvements. These changes have been undertaken following an analysis of the specific characteristics of the various types of the reading material found in modern texts. This has permitted more precise specification of geometrical, ergonomical and functional parameters of our design. The present version, ready for clinical tests, integrates all these modifications including some adjustable ergonomic and functional parameters which can be set to maximize the comfort of the individual.

DESIGN PROCESS AND DESCRIPTION OF THE READING-AID

To optimize the design and to evaluate more precisely the level of constraint pertaining to each possible design approach, we have undertaken an analysis of both the geometric and functional characteristics of the reading material which are well-known for their great variability. The geometric characteristics are generally expressed terms of:

- The format, for which each dimension varies greatly.
- The type of covering material and its size relative to the size of the pages.

•The type of page material, its thickness and the binding method used.

•The print type and size and its relative legibility.

The functional characteristics of the reading material are essentially related to the instability of the pages which, in turn, varies in function of:
•The page material, its thickness and the type of binding used.
•The book opening angle.
•Where the book is opened; considering that the instability is maximal at both the begining and the end of the book.
Another important characteristic concerns the asymmetric position of the book axis with respect to the book-holder axis. This asymmetry increases with the thickness of the book and becomes maximal to the left for the first page and maximal to the right for the last page. While this characteristic does not affect directly the stability of the pages it affects the efficiency and design of the stabilisation system.

The characteristics of the reading material together with the anthropometric and ergonometric data have influenced the design of the optimal geometry of the book-holders. The relevant factors are the maximum dimension of the books to be consulted, the inclination of the book-holders with respect to the rotating base of the carousel and the angular opening of the panels that support each side of the book. The six book-holders are arranged in tiers of three and disposed every 120 degrees around a common axis of rotation (see fig. 1). Each book-holder consists of two panels with an angle of 125 degrees between them, an angle that has been found empirically to enhance the stability of the pages without affecting their legibility. The dimensions of the book-holders are slightly bigger for the second stage; they have been designed to accept a book-lenght of up to 12 inches. Anthropometric and ergonometric considerations prompted a design whereby the inclination of the book-holders on each of the two stages has been made adjustable with respect to the rotating base. This approach offers the possibility to further optimize the reading angles by providing an ajustment for individual comfort. The rotation of the carousel is now motorised ; this permits each books to move back and forth in front of the user. This rotation is controlled from sensitive touch-switches which can be easily operated by the mouthstick. The motor mecanism offers also the possibility to stop and prevent rotation while turning the pages with a mouthstick.

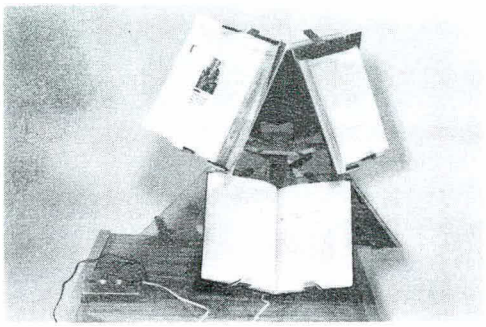

Figure 1:
New version of the reading carousel

The great variability of the book format, the relative dimensions of the cover to the pages and the texture of the pages provide a range of functional characteristics of the reading material which represent a design challenge for stabilizing the book with its pages in the open position. This challenge is further increased by the necessity to avoid obscuring the reading material or hindering the ability of the user to turn the pages with the mouthstick. As a

consequence, the design of a simple, efficient and easily adjusted stabilisation system has required several stages of experimentation. The system produced, is composed of two distinct mechanical assemblies which are mounted on the book-holder panels. The base assembly first retains the book in place and together with the adjustable and spring-loaded upper assembly stabilizes the pages by applying a constant force against them.

CLINICAL EVALUATION

A one-year clinical evaluation will be carried out in 1997. This evaluation will first concern the people having quadriplegia and aftewards those having paraplegia and for whom a simplified version may be developed. During this year each evaluator will use the reading carousel in a real life situation for a period of two months. At the end of this period, a questionnaire will be used to determine :

- The level of muscular fatigue produced by setting the adjustable geometric parameters and illumation conditions.
- The level of functional difficulty experienced while using the mouthstick. These difficulties may be related to the position of various supporting elements that interfere with the manipulation of books or pages. The function of the various technical components will be assessed for their accessibility and ease of manipulation. Both will be defined as a function of their geometric variables.
- The level of satisfaction together with the efficiency of the reading apparatus to meet the functional objectives of the user.

DISCUSSION

A reading carousel with a capacity of six books has been developed to answer a need indentified by people with quadriplegia. Currently this need is not being fulfilled by available reading-aid equipement. Although the preliminary results obtained with the mock-up version are encouraging, a comprehensive clinical assessment with a broader group of users is needed to verify the design and functional characteristics of the new version. The results of this evaluation will be used to further optimize the design and to promote the technological transfert process.

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ELECTROMECHANICAL COUNTER

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ABSTRACT

The assignment was design and development of a counter to support vocational training of three consumers at the Calumet Center, Montgomery County OH, Department of Mental Retardation and Developmental Disabilities (MR/DD). Each has severe developmental difficulties, but they are capable of learning manual tasks. The intent of the Electro-Mechanical counter is to permit consumer count of completed tasks, such as component assembly or packaging. The Center staff required periodic interface with the consumer, especially presetting and resetting of the counter, while also conducting a "quality control" check on the consumer's activities/ products. Delivery demonstrations to the customer and consumers at MC MR/DD included functionality and compliance with requirements, as well as operational verification for utility by the consumers. The Electromechanical Counter, Battery Recharger, and Instruction Book were deliverables.

BACKGROUND

The statement received from the Calumet Center was used to derive the consumer needs. The consumers disabilities are related to mental retardation and developmental delay that limit their cognitive and physical abilities. They have varying difficulties in learning, following instructions, and attention span. Two consumers sit normally in a chair, and the other uses a wheelchair and positioning support. However all sit up at a worktable and do "hands-on" work, and they have mental and physical abilities necessary to use this device.

Consumers' cognitive impairment is the predominant justification for this product. The consumers are deficient in retaining sufficient information to recognize and then identify completion of multiple work units. Adapting their physical abilities required a consumer-counter interface with easy reach and convenient operation. Experiments with consumers were conducted to obtain sufficient physiological data; range of motion, strength, and reach. Also, the three consumers are basically non-verbal but able to communicate with the project designer in limited fashion.

OBJECTIVE

Mechanical counters can be used by consumers to track the number of completed items in a training workshop environment. They are mechanically activated switches, susceptible to bounce, for advancing the numerical counter. These counters only provide visual numeric feedback, and counter reset is quite delicate using a knurled knob. Also, safety of operation by MR/DD consumers is both cause for concern and a designer liability. The consumers' severe developmental disabilities cause accompanying physical and mental limitations, and unwittingly or knowingly they could inappropriately operate the device. The consumers have cognitive limitations; thus EM Counter operating instructions and required knowledge for use should be elementary.

The consumers can only operate the device while sitting at a workstation or table. Because of assembly or piece-part work, consumer's workspace limits placement of human interface devices. Manipulation by hand is the viable consumer input mode. Finally, the operating environment at Calumet Center is broadly defined for the EM Counter; therefore the device must be able to operate under certain extreme conditions. This especially applies to handling and storage, contamination from body fluids or environment particulate (dust), and withstanding of physical shock and drop.

Major objectives for the new electromechanical counter were design, development and fabrication with the following features: mechanization of the Consumer switch such that multiple consumer tactile bounces are only counted once, preset ceiling of 5 count before reset, activation of attention-getters when the preset count is reached, and a method to permit staff to respond to the attention getters and reset the counter at zero.

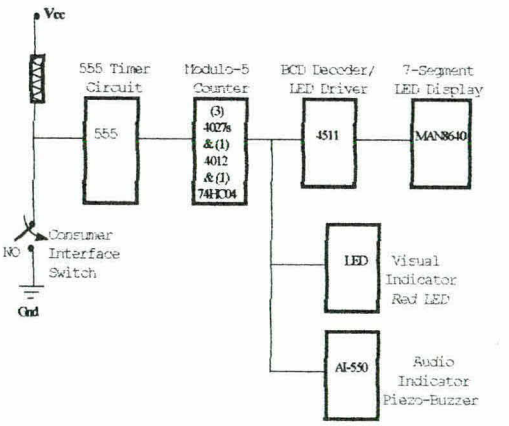
METHOD

The final system design uses sequential logic based on flip-flops, and a Light Emitting Diode display to show each increment in count. Consumer interface uses the AbleNet "Big Red" switch. Staff interface is a RESET switch and a LED display showing count status. Drawings, schematics, parts list and cost summary documentation are available to show the costs, including fabrication and assembly, of less than $325.

APPROACH

The EM counter components are illustrated in the system block diagram of Figure 1. The design of the EM Counter system uses commercially available components. The Consumer Interface Switch is the consumer's means to input a 'unit count' by activating the 555 Timer Circuit which delivers a dc voltage to the Modulo-5 Counter. The counter displays the number of 'unit-count' inputs through the Binary To Decimal Decoder/LED Driver onto a Seven-Segment Light Emitting Diode (LED) Display. It also stores the inputs until five inputs are "counted", then turning on the staff attention-getters. The 555 timer/consumer interface switch function is to prevent recognition of a second consumer switch activation for a specified time, 1 to 10 seconds depending on the selected value of the input resistor. This inhibits unintended counts through the consumer switch caused by muscle tremor, spasticity, or switch bounce.

FIGURE 1
ELECTROMECHANICAL COUNTER SYSTEM DESIGN



RESULTS

Safety issues are addressed by limiting the consumer interface to the, Abledata's "Big Red", a switch owned and used by the Calumet Center for other uses. The remainder of the EM Counter is completely housed in a single unit. When in use, this unit would normally be placed out of reach of consumer's at work. The consumer interface switch is connected to the EM counter by a long wire. Secondly, electrical power is a safe 6 volt dc precluding shock

hazards, and energy capacity of the alkaline batteries is well below biological danger levels of electricity. The comsumer can operate this device by hand while sitting or standing within reach of the consumer interface switch. However, any switching modality by consumers would likely be an adequate counter input. The only intrusion on the consumer's workspace is the Big Red switch's 'footprint', 5 inch diameter circle with a height of 1 and 1/2 inches. The anticipated worktable environment at Calumet Center appears to offer a fairly benign operating environment for the EM Counter. The storage environment will be in staff office cabinets with similar devices to limit EM counter exposure to consumers, except under supervision of staff. Battery recharging is done after consumer hours.

DISCUSSION

The Electromechanical Counter's use at Calumet Center of MC MR/DD is possible by any consumer that has need a training need whereby a pre-set count is useful. Consumers who have severe developmental disabilities were accounted for in this design. Specific Needs/requirements were determined by agreement between the program specialists at Calumet Center and the design Rehabilitation Engineer. These requirements bounded the EM Counter design and assembly. Final selection of components were constrained by costs and the budget of $300, and constraints were necessary during assembly and fabrication in order to keeep the counter affordable. The EM Counter design and assembly satisfies "specific needs", and the product is being applied for MR/DD consumers.

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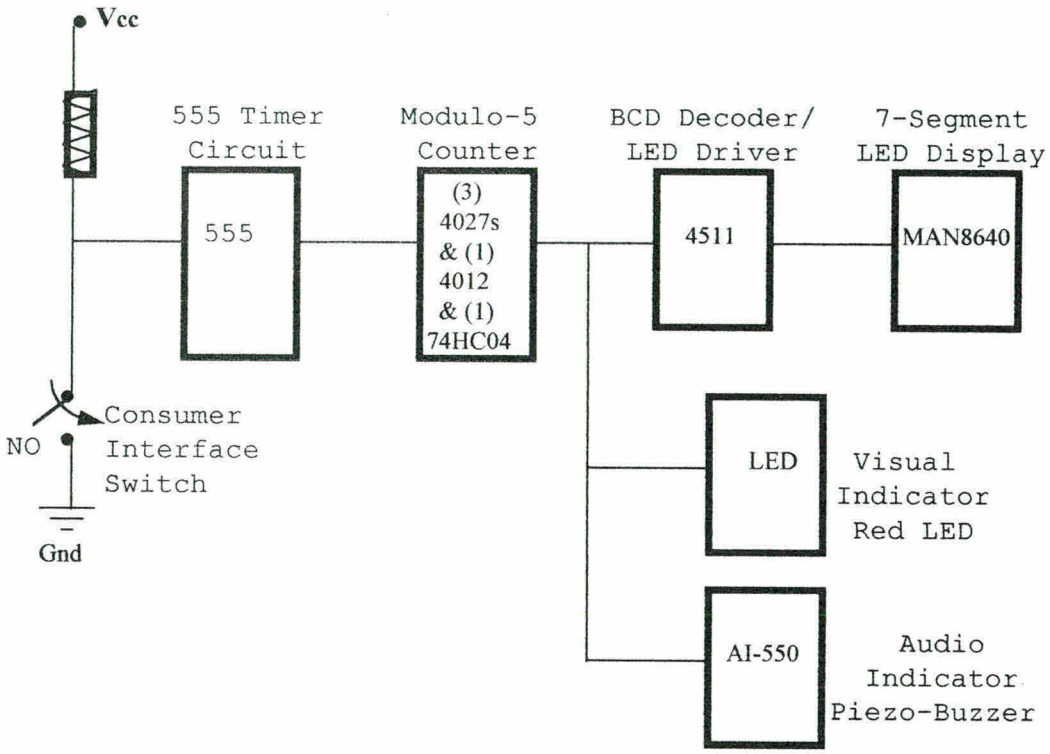
FIGURE 1
ELECTROMECHANICAL COUNTER SYSTEM DESIGN



EWICK, 03-09-96

DESIGN OF A LETTER LABELER

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ABSTRACT

Teaching students with disabilities how to integrate into society's work force is one of the goals at the Rosedale School in Austin, Texas. One way in which this is done is by doing the job of labeling letters for outside organizations. This not only brings money into Rosedale but teaches the students a valuable skill which can be taken with them to job sites. A modular device was designed to assist with this task. Due to the different levels of abilities of the students which may use this device, modules of either peeling labels or placing labels onto envelopes can be removed or added for the highest level of learning possible for the student.

BACKGROUND

The Rosedale School which operates in Austin, Texas is a member of the Austin Independent School District (AISD) and is a school where independence is taught to students with disabilities. One way this is done is through performing jobs at school and outside in the community. These tasks not only increase the self-esteem of the students performing them, but also teach the students how to perform everyday tasks by themselves.

Labeling letters is a common task both inside and outside of Rosedale. The students usually label pamphlets for different organizations at approximately 200,000 a year, while at Rosedale. Students label more letters than that each year at different locations where they hold jobs [1].

The current method to labeling letters is that a teacher will remove the label from the backing and place it into a student's hand. Then the teacher will actually take the student's hand and place the label on the letter. This method is known as the "hand-over-hand" method and is very tedious and time-consuming. Since Rosedale does so many of these letters each year, there was a great need for a device to assist them. Rosedale also gets paid for this labeling task and if this process could be sped up, more letters could be done each year bringing in more money.

Also the teachers at Rosedale expressed concern over using the students as "tools" in this process [1]. They not only wanted the job to get done but wanted the student to learn from the repetitive nature of the motion; to learn through cause-and-effect. Economic rewards are not the only reason Rosedale does this labeling. Teaching the students a skill such as this which they could use elsewhere and earn their own money is another. By giving students this skill, they can become more included in the work force of today's society.

STATEMENT OF THE PROBLEM

The goals of the design team was to design a device which would label a variety of sized envelopes with a variety of sized labels. Many of the students who label letters have different levels of abilities. Because the teachers at Rosedale want to include as many students in the process as possible, the device needed to be modular and adjustable to different student's needs.

DESIGN METHODOLOGY

The designing of this device followed the documented methodology outlined in Ulrich and Eppinger [2]. By following this design process the team hoped not only to create a device which worked but also one with features which the customer wanted and would therefore use often. One of the main design restraints placed on the team was that Rosedale wished to reproduce this device for use with more students, so most of it needed to be made from wood since Rosedale has woodworking facilities on their grounds.

The first step of the methodology calls for gathering customer needs through interviews. A total of ten interviews were held. Four of them were conventional interviews with supervisors and teachers, and the remaining six were

observational interviews of students while they used the "hand-over-hand" method of labeling. The customer needs gathered from these interviews, both expressed and latent, were then transformed into engineering requirements using the Quality Functional Deployment (QFD) method [2].

The methodology then calls for these engineering requirements to be analyzed to see which ones should be concentrated on achieving and which one should be labeled as secondary. Once this is completed the overall design is broken down into simpler parts and concept solutions for each different feature is produced. From these concept solutions, complete designs are made, embodiment is done on this final design and ultimately prototypes are built [2].

Before concept generation can begin, the team decided to break the complex task of peeling labels from the backing and placing them onto envelopes into smaller more manageable functions. The first division was obviously into the two separate functions of peeling and placing the labels. By doing this a third problem arose, of a structural nature, of how to place the two modulars together. After this was done, concepts were created for each function and the team went through the concept generation phase. Once there was confirmation that this peeling function was possible through the construction of a proof-of-concept model, the embodiment phase was entered.

The embodiment phase was the most difficult part of the design since critical decisions needed to be made at this point. Decisions on how to complete each task using the simplest of designs but also reaching as many customer needs as possible, had to be made. The peeling function had to obviously peel labels from the backing but also had to accommodate all formats of labels which Rosedale might use, e.g. sheets, rolls, etc. The placing function also had to accommodate all different sized "envelopes", from 8.5"x11" sheets to 3"x9" pamphlets. And the structural function had to hold both peeling and placing modules together properly.

DEVELOPMENT

After the customer needs were categorized into related sections, analyzed and finally truly understood by the team; and after concept generation was completed and solutions to the different problems faced in the design were formed, an alpha prototype was constructed. This prototype did not work properly but did illustrate to the team many critical aspects of the design. The first problem which was faced was the tolerance problem. When the labels were removed from the backing the envelopes needed to be in a position as close to the peeled label as possible. This was more difficult than the team expected due to lack of experience working with wood.

Another major problem with the alpha prototype was the size. When Rosedale was revisited after the alpha was constructed it was learned that the prototype would not fit onto the trays in front of most student's wheelchairs. Since most of students whom will be using the device make use of wheelchairs, this needed to be fixed before the beta prototype was constructed. Through talking with the teachers at Rosedale the idea was come up with to use flexible cable to control the energy input. This way even if the assembled device was too large to fit onto a wheelchair tray, the flexible cable would allow the input to be placed in front of a student no matter how far away they sat.

There were also some problems with the plate which held the envelopes in place. The springs were buckling when they were at their extended length. This problem was solved easily enough but would not have been noticed if the alpha had not been constructed.

After most of the problems were resolved and redesigned, a beta prototype was constructed. It was decided to use three rollers to tension the labels as the backing is feed through a 180° turn to peel the labels. Two rollers are attached to the flexible cable which connects to a lever. When a student moves the lever, the rollers rotate in opposite direction, pulling the labels backwards through the 180° turn. This angle is what peels the label from the backing. The third roller tensions the labels at the beginning of the turn which removes them from the backing more easily.

A removable plate with adjustable holders, to accommodate different sized envelopes, and a removable pressing plate, to affix the labels to

the envelopes, is used to place the labels. As mentioned before, all of the students using this device have different levels of abilities and the pressing plate was made removal for this reason. If a student is capable of pressing down on the label, securing it to the envelope, this plate is not needed. If that ability is not present in the student, the plate can be added and a simple downwards force on the handle will affix the label for the student. A simple structure allows for the insertion and removal of the placing modular to the peeling modular with accuracy for correction placement of the label. This feature was also done for adjustment due to different users. If a student just needs the label peeled for them but can place it on the envelope themselves, the whole placing module can be removed. If it is needed, it can be added and fits securely into position to allow for the proper placement of the label.

DESIGN EVALUATION

Although many different types of labelers are available on the commercial market, they are very expensive and do not teach the user as is wished with this device. Most of these labelers are continuous, meaning that once they are loaded and turned on, they peel and label a whole stack of envelopes at a time. The device outlined here is discrete, for each input for the user, one envelope gets labeled. This discrete motion gives the student that cause and effect learning technique which the teachers at Rosedale are looking for.

This labeler is also modular, which was very important to the customer. When teaching people with disabilities, the abilities which they have should not be suppressed just because that is what the device calls for. If the ability to pick up a label and place it onto an envelope is present then just turning a lever and having the process done is not teaching that students anything. By designing this device as modular as it is, hopefully every student who uses it, will be able to use their abilities to the fullest extent and learn from the process.

CONCLUSIONS

The purpose of this device was to design a tool to assist people with disabilities in labeling letters. It needed to accommodate different sized envelopes and different sizes and formats of labels. The purpose of this was to increase the user's self-esteem and teach them a skill which could be taken with them to job sites. By making the device modular and therefore adjustable to different levels of abilities, the users of this device should be able to get the most out of it and learn the skill which it was intended to teach.

The device as it is now is fully manual but if so desired a future project could be to automate it. The flexible cable and lever assembly could be removed and a step motor added instead. This would complicate the design a little due to some added electronics but might make the device more useable to more students then it already is.

All but the pulling rollers on top of the device are made from wood and can be reproduced at the Rosedale School. These rollers can be made from PVC piping but it is difficult, so they are made from metal and can be made easily at any machine shop. It is low-cost, easy to manufacture and easy to use. Most of the customer needs gathered in the interviews were met and the device is considered a success.

ACKNOWLEDGMENTS

The team would like to thank many people without whom this project would never have been done. To Dr. Kris Wood, Dr. Rich Crawford, and all the faculty assigned to ME392M, who supervised and advised the team throughout the design. And to the students, supervisors and especially the students at Rosedale, who granted us interviews and put up with our endless questions.

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EVALUATION OF BIOFEEDBACK DEVICE IN REDUCING PAIN AND IMPROVING FUNCTION OF INDIVIDUALS WITH LOW BACK PAIN

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ABSTRACT

Seventeen persons with mechanical low-back-pain were recruited to participate in a study comparing feedback vs. corset wear to control trunk angle. The experimental design is based on the concept that the mechanical load associated with trunk inclination (due to either lumbar or hip motion) is a contributing factor in causing or worsening mechanical low back pain, and that trunk inclination reduction will result in low back pain reduction. Results suggest that feedback is as good or better than corsets at helping the user maintain a more neutral posture with less total exposure to extreme flexion angles.

BACKGROUND

Corsets of various design are commonly prescribed for the clinical treatment of mechanical low back pain. This practice continues despite limited knowledge of both their efficacy and their mode of action. Modes of action that have been suggested include increased intra-abdominal pressure or restriction of lumbar motion, either by introducing mechanical resistance or by providing proprioceptive feedback to the user. We hypothesize another mode of action: reduction of trunk inclination away from vertical, which reduces back muscle (erector spinae) force and thereby reduces low back pain. This project is designed to test this hypothesis. In this study, the use of biofeedback to control trunk position is compared with a corset in a full crossover design to determine their effect on back pain and function in individuals with low back pain.

RESEARCH QUESTIONS

Specific Aims

1. To provide a clinical measure of the effect of limiting trunk motion through the use of feedback on patients with low back pain.
2. To compare these results to those obtained through the use of a corset and no corset.

Hypotheses

1 The use of feedback compared to no corset is associated with: less low back pain, greater trunk function, less trunk inclination exposure.
2. The use of a corset compared to no corset is the same as the above.
3. The use of feedback compared to a corset is also the same a in (1) with the addition of: greater wear acceptability.
4. Correlation between trunk inclination exposure, the amount of low back pain, and trunk function will be strong regardless of the corset type.

METHOD

A multifunction device that serves as both a trunk inclination monitor and a data logger has been designed and constructed. It consists of a pool type electrolytic tilt sensor linked with a high storage capacity, low power consumption data logger. It also contains a small vibrator, similar to those found in pagers, that when turned on will provide an alert to the subject when she/he exceeds a pre-set trunk inclination angle.

The device components are integrated into a small (55 x 70 x 18mm), lightweight (50 grams) package designed to be worn on the chest using

a custom harness.

The two axis tilt sensor has a functional range of approximately 120 degrees in both flexion and lateral bend, a response time of approximately 200 ms, and is reasonably stable over time. The data logger has 64K of memory. Inclinometer data is sampled at 2 Hz and, to conserve memory, this data is binned in approximate 2 degree increments in 1 hour segments. With this data management design, there is sufficient memory for about 10 days of continuous data collection. Software control provides for user determined sampling parameters as well as for setting angle thresholds for turning the feedback system on and off.

Research Volunteers:

To date, seventeen subjects have been recruited, 9 female (mean age=50.4 range=20.2-71.7; mean height = 63.9, range = 61.5-67; mean weight = 164, range = 15-189) and 8 male (mean age = 46.6, range = 30.3-68.5; mean height = 67.8, range = 56.5-71; mean weight = 197.5, range = 152-255). Entry criteria for this study were:

1. Diagnosis of mechanical low back-pain: i.e. pain generally improved with recumbency and made worse with activity.
2. The time of the onset of pain greater than 6 weeks but less than 12 months at enrollment.
3. Symptoms do not include any radiculopathy or pain below the knee
4. Age 18 or more.

Study Design

The objective of this study is to compare the effectiveness of each of 3 treatments for mechanical low back-pain. Each treatment was evaluated on several outcome measures including self-report of pain, functional questionnaire scores (Rowland-Morris, and Oswestry) and finger-to-floor measures. Independent variables are the type of treatment and the measured trunk-inclination exposure over time. The experimental design is a complete cross-over randomized trial with each participant tested in each of the 3 conditions, each condition for a 1 week period. Baseline data was taken at commencement. Follow-up data was taken at each cross-over point (after weeks 1, 2 and 3). The test conditions were:

- Corset: Traditional cloth corset + inclination monitor/data logger
- Feedback: Feedback + inclination monitor/ data logger
- Control: Inclination monitor/data logger only.

RESULTS

Daily Trunk Angle Distributions

Figure 1 shows a typical daily trunk inclination pattern for each day in a one week period for the corset condition for one representative subject. Note the daily similarity of the trunk activity distributions.

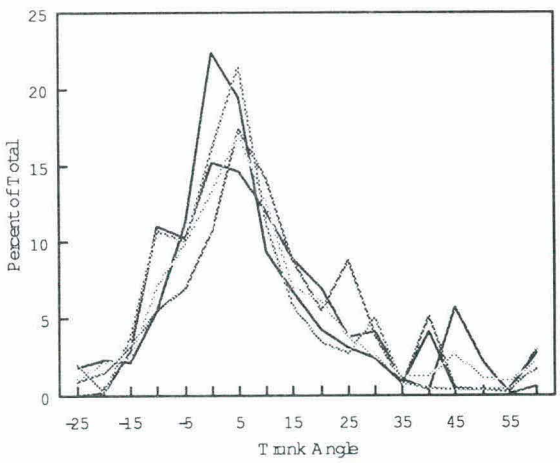

Figure 1. Daily trunk activity for one subject. Each line represents cumulative data for a single day.

Figure 2 shows similar data averaged across the test period. In both figures, note the exposure above 25 degrees.

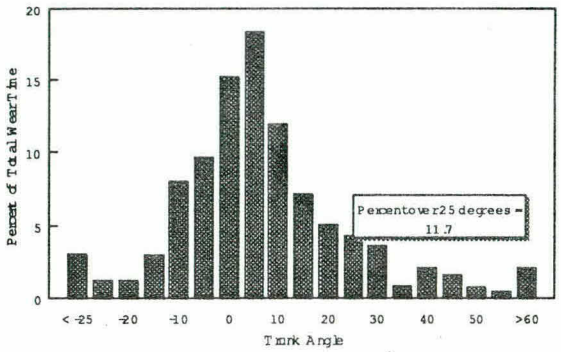

Figure 2. Shows the total weekly trunk activity for one test condition (Corset).

Weekly Inclination Exposure

The following tables show week long cumulative exposure for each test condition. Table 1 shows the mean integrated trunk angle for each test condition. Table 2 shows the total exposure to flexion angles greater than 25 degrees as a percent of total trunk activity.

Treatment	Trunk Angle	STD
Control	3.81	4.4
Corset	5.7	4.9
Feedback	1.09	5.1

Table 1. Mean weekly trunk flexion exposure, in degrees.

Treatment	Exposure to >25 degrees	STD
Control	10.9	6.2
Corset	9.4	4.5
Feedback	5.1	4.9

Table 2. Mean weekly trunk flexion exposure to >25 degrees flexion, as percent of total activity.

Visual Analog Pain Scores

Table 3 shows the mean across subjects of the daily Visual Analog Scores (VAS) for each test condition.

Treatment	VAS Score	STD
Control	5.0	2.5
Corset	4.9	2.4
Feedback	5.3	2.5

Table 3. Mean of daily Visual Analog Scores for each test condition.

DISCUSSION

The data collected to date demonstrate that the use of feedback is somewhat better at minimizing total inclination exposure as well as minimizing exposure to extreme flexion angles, defined as greater than 25 degrees. While there were no apparent differences in the amount of pain reported for each of the treatment conditions, there was a favorable trend over time and feedback use for longer than only 1 week may have a greater effect. The preliminary result of trunk inclination reduction is encouraging for further study, now in progress.

ACKNOWLEDGMENTS

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EVALUATING THE EFFECT OF CONTINUOUS PASSIVE LUMBAR MOTION ON LOW BACK PAIN AMONG TRUCK DRIVERS

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ABSTRACT

The purpose of the study is to evaluate the efficacy of continuous passive motion in reducing back pain among long-distance truck drivers. It is believed that continuous lumbar motion will reduce the severity of low back pain and reduce the likelihood of injury due to the effects of prolonged static postures. Results indicate that that there are no significant differences in the primary outcome measures when using the Continuous Passive Motion (CPM) compared to a similar device without CPM.

BACKGROUND

Those who maintain static postures over long periods are more prone to low back pain than those whose occupational environment allows them to change positions (Magora,1972). Drivers who operate a motor vehicle for four hours or more a day have a risk of disc herniation three times higher than the average (Kelsey,1975). Truck drivers are one of the occupational groups with the highest rates of low back pain; a 12-month low back pain prevalence of 6.7%. Although seated comfort and body posture are greatly affected by chair contouring and padding, Chaffin and Anderson (1984) suggest that the most important considerations in seating are adequate back support and allowance for movement or postural change. Optimal seating would allow a relaxed but supported, posture and would not only allow but promote lumbar motion. Reinecke et al. (1985) demonstrated that sedentary static postures are correlated with back discomfort. Bendix (1987), who investigated the effect of motion on seating comfort, also concluded that discomfort correlates with the amount of movement or changes in posture.

When one maintains static seated postures, ligaments and tendons can be under tension. If fiber tension is maintained, the ligament will "creep" , increasing it's length (McGill). After being stretched the fiber will require a relaxed period to allow it to return to it's original length. Relaxed fibers may reduce stability of the joint segments, which may contribute to the stress placed upon that joint during movements which would not normally be harmful. For example, the reduced stability resulting from soft tissue elongation due to driving for several hours may put a driver at increased risk for injury when he/she unloads the truck during a cargo delivery. Joint stability may be maintained by frequent changes of posture; however a motor vehicle may find this difficult or inconvenient. It is therefore suggested that providing continuous motion of the lumbar spine may be beneficial in alleviating some of the potential problems associated with prolonged sitting. A device, developed and tested at this institution provides continuous passive motion of the lumbar spine. The device fits into the user's seat and can be adapted to office or vehicle seating. Laboratory testing has verified that the device induces continuous motion of the lumbar spine (Hazard, 1995).

RESEARCH QUESTION(S)

Does the use of continuous passive motion have an effect on the level and duration of low back pain when used by long distance truck drivers who have a previous history of low back pain?

METHOD

Research Volunteers:

Ninety persons have been recruited into the study. (Male: n=88, mean age=41.2, std=9.6; mean height=70.2 inches, std=3.0; mean weight=203lbs, std=34.0. Female: n=2, mean age=37.5, mean height=66 inches; mean weight=197.5 lbs). To date, 49 subjects have completed the study, 12 are currently enrolled and 29 dropped out before completing the study.

The study design was a randomly assigned crossover using two devices: a Continuous Passive Motion device, and a device of similar design but without lumbar motion. Subjects were assigned to one of the devices for a period of six months, followed by six months use of the other device. Participants were long distance truck drivers, long distance defined as driving a minimum of three hours per work day, and who reported a previous episode of low back pain. Drivers were invited to participate in the study through various means including notices distributed in pay envelopes and posters placed in trucking terminals. The drivers mailed pre-printed post cards to the researchers, who then contacted the drivers by telephone or by mail. Volunteers completed an approved informed consent. Participation in the study required completing monthly questionnaires on the presence and intensity of pain, discomfort, duration of pain (in days) and lost work time due to back pain (in days).

RESULTS

Table 1 shows the response data for 6 of the questions from the monthly questionnaire. All responses were scaled from 0 to 10; 0 indicating that none of the variable in question was present and 10 indicating that the greatest amount possible was present. The questions were as follows:

1. During the past week, how often have you had back pain or discomfort?
2. During the past week, how often did you experience back pain or discomfort while driving?
3. During the past week, indicate the effect your back pain had on our ability to perform your usual daily activities (dressing, lifting, walking, sleeping, etc).
4. During the past week, how much has your back pain affected your ability to do your job?
5. During the past week, indicate the effect your back pain had on your ability to perform other activities (social/recreation, sports, traveling, sex, etc)?
6. Describe how much back pain you had while driving for your most recent work day.

In the table Active refers to the device providing CPM while inactive refers to the inactive device. The Diff variable refers to the difference Inactive-Active. Sequence refers to the order of treatment, A is the active continuous passive motion device first in sequence, treatment I is the inactive device first. The reported values are baseline corrected, i.e. the value prior to commencement of the study is subtracted from subsequent data points. Negative numbers indicate a relative decrease in the score, positive numbers indicate an relative increase in the score.

TABLE 1.

		Active		Inactive		Diff	
Ques-tion #	Sequence	Mean	STD	Mean	STD	Mean	STD
1	A	-1.0	3.3	-1.1	3.7	-0.1	1.8
	I	-2.1	2.8	-1.3	3.2		
2	A	-1.2	4.0	-1.5	3.9	-0.2	1.9
	I	-2.5	2.9	-1.3	3.4		
3	A	--0.7	2.7	-0.7	2.5	-0.3	1.6
	I	-0.8	3.0	-1.0	3.1		
4	A	-0.3	2.1	0.4	2.6	-0.3*	1.2
	I	-0.5	2.0	-0.5	2.1		
5	A	0.0	2.5	-0.2	2.5	0.2	1.4
	I	-0.4	2.5	-0.8	2.6		
6	A	-0.4	2.9	-0.3	2.6	-0.3	1.3
	I	-0.4	2.1	-0.7	1.6		

DISCUSSION

The results indicate that with the exception of question #4, there were no significant differences in the primary outcome measures between the active CPM backrest and the inactive backrest. However both devices showed positive and similar results for several of the outcome measures. Drivers reported a decrease in the frequency of pain or discomfort when using either device. This data deviates somewhat from the results of an exit questionnaire where at the end of the study participants were asked to rate the effectiveness of each of the devices. In this questionnaire, 61% of the respondents indicated that the CPM device made their back feel much better, compared to 15% for the inactive device. An additional 23% said that the CPM made their back somewhat better, compared to 53% for the inactive device. The participants comprising the test group in this study represent a small percentage of the total of population of drivers who were approached to participate. It is possible therefore that a selection bias may exist. This should also be considered when discussing the generalizability of the results from this group.

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DD & NeuroPage®/ VIRTUAL SUPEREGO PARTNERING IN WORKPLACE

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ABSTRACT

A case study of a developmentally disabled worker identified a practical application of the Virtual Superego/NeuroPage. Work environment, work requirements and worker's performance were analyzed under conditions with and without use of this device. Work-related prompts were sent via wireless communication and paging network. We found that after seven weeks of use, the Virtual Superego/NeuroPage, beyond a reasonable doubt, assisted a maintenance worker in retaining his job. Future studies involving more candidates are under way to further investigate the optimum time for partnering this adaptive device to impact on performance.

BACKGROUND

Historically, pagers have transmitted numerical digits and were associated primarily with doctors and other professionals. The NeuroPage utilized in this project is system developed and defined as a cognitive prosthesis (Hersh and Treadgold, 1994). They used four traumatic brain injured (TBI) individuals and found that three subjects in the NeuroPage condition showed one hundred percent compliance with self-initiated attendance. Wilson demonstrated that out of fifteen TBI individuals, with only fifteen weeks of using the NeuroPage, some were able to acquire the necessary skills to do their tasks independently thereafter (Wilson, 1996). Performance problems were defined as situations in which the person knows what to do but requires additional support to perform the tasks (Wacker, 1993).

We chose a developmentally disabled (DD)[1] worker with a learning disability, who had demonstrated work performance difficulties. He was previously discharged from two different job sites and was on the verge of losing his present job. By partnering this DD worker with the NeuroPage , we provided him with the additional support necessary to more quickly achieve work stabilization and to enhance his ability to perform a variety of tasks.

OBJECTIVE

To demonstrate a pragmatic match between a worker at risk of losing his job and the use of the NeuroPage within the natural work environment.

METHOD/APPROACH

Subject

Domingo is in his early thirties (his identity has been changed to protect his privacy). He has a DD, an adjustment disorder and a learning disability. Intellectually, he functions in the low average range; he is only able to read at the fifth-grade level. Functionally, he demonstrates memory dysfunction in the mild to moderate range. He enjoys working with electronic gadgets and often seeks prestige and recognition.

Apparatus

We used the current open-loop NeuroPage system, which uses advanced wireless communication to display both text and numbers on a tiny LCD pager's screen. Specialized software allows a central PC to send messages via a modem and a paging network. After being trained and becoming proficient with the proper use of this alphanumeric pager, Domingo was given the NeuroPage to carry with him daily.

Procedure

Similar daily logs, specifically developed for this case study, were used by the job coach to record data during both baseline and NeuroPage conditions. During the first fifteen working days, the baseline data of Domingo's actual work performance was collected, including the number of tasks he accomplished and the type of interventions provided. During the next thirty-five working days, while Domingo was in the

NeuroPage condition, task-specific reminders were sent, on a given date and at a given time, to display both cues and prompts in written message form. Again, data of Domingo's actual work performance was collected. Cues to be transmitted were carefully chosen by analyzing and prioritizing the essential daily tasks and the time in which they were expected to be performed. This was done in partnership between the job coach, work supervisor and Domingo. Care was taken to use only the most relevant cues necessary to his work success. The cues were written as reminders or as prompts, using the subject's own preferred wording to facilitate the user-friendly aspect of the NeuroPage. The team approach model was found to be most productive here.

RESULTS

We followed Domingo for a total of fifty working days, or ten working weeks.

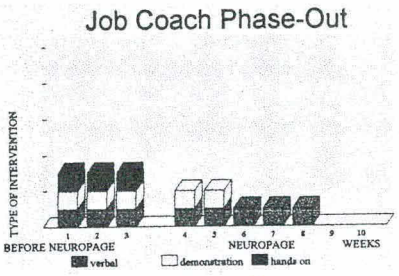

Figure A

Before NeuroPage, Domingo required all types of verbal prompts, hands on assistance and demonstration in an intensive intervention by his job coach. He failed to self-initiate work activities, forgot his work routine and resented staff interventions. His employer rated his work performance as unacceptable, and he was put on notice. He was once again at risk of losing his job. Then, for the next thirty-five working days, we used the NeuroPage. It transmitted no more than seven to ten task specific reminders daily. Domingo received structured prompts during working hours. As Figure A shows, it took eight weeks of coaching for the job coach to be phased out. During the ninth and tenth weeks of monitoring his performance, no further job coaching intervention was provided. Thus, twenty-five days subsequent to the introduction of the NeuroPage, Domingo made a successful adjustment to his work-site requirements according to the rating by his employer.

This is an especially remarkable development because as a maintenance worker for the past two years, Domingo was placed at three different job sites.

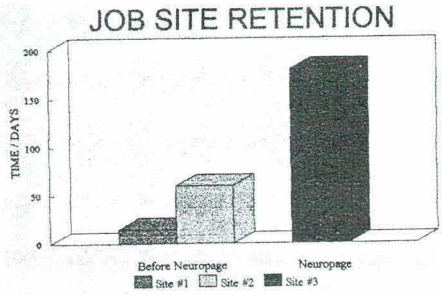

Figure B

As Figure B shows, at job site #1 and #2, when he was not using the NeuroPage, Domingo successfully worked for only fifteen and sixty days respectively. Currently, at job site #3, using the NeuroPage, he has been working over one hundred eighty days. Domingo is still successfully employed. After ten months of working and using the NeuroPage, he achieved a three hundred percent increase in working days.

DISCUSSION

Like Evans, who questioned why the NeuroPage was so effective, we asked what makes it so powerful and potentially so useful (Evans, 1996). A possible explanation can be found by borrowing from Freudian literature. Whereas Evans offers some neuropsychological answers to his question, we propose the hypothesis that the NeuroPage virtually embodies some intrapsychic mechanisms, much like what Freud was referring to when he postulated the Superego, as it assists the individual in his functioning. Freud suggested that one of the intricate mechanisms of the Superego is that it observes, judges, approves or punishes conduct. The Superego also involves emotional

identification with the love object and its concomitant emotional conflicts. In this context the virtual Superego is a reliable and trustworthy fund of processes, commands and performance cues from authority figures. These are instructions a person appears to integrate during his/her training much as a child integrates his/her parent's commands during early development and socialization.

People are not born with either a Supergo or a NeuroPage. At first the NeuroPage is used as an object that provides acknowledgment and greetings. Then, like a trusted friend, it provides prompts in a reliable form. As it delivers written cues and messages that reinforce the person's performance, it also evokes emotional reactions as identification with its familiar messages and recognition appears to take place. Thus, unlike a passive prosthesis, the NeuroPage functions like a Virtual Superego with its associated benefits.

Conclusions

The Virtual Superego/NeuroPage was found to have a role in stabilizing a DD worker at risk. This is so not only because it reminds him of the tasks he is expected to complete but also because it functions as an integral part of his intrapsychic mechanisms. The NeuroPage may be the Virtual Superego that provides DD workers with the necessary edge to succeed in competitive employment.

Further studies are under way to investigate the most effective method of partnering with the NeuroPage at the workplace.

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Footnotes

[1] Developmental Disability (DD) means a disability of a person which is attributable to mental retardation, cerebral palsy, epilepsy, neurological impairment or autism; or any other condition of a person found to be closely related to mental retardation because such condition results in similar impairment of general intellectual functioning or adaptive behavior similar to that of mentally retarded persons or requires treatment and services similar to those required for such persons; or dyslexia; and originates before such person attains the age of twenty-two; has continued or can be expected to continue indefinitely and constitutes a substantial handicap to such person's ability to function normally in society.

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SIG-16
Gerontology

THE UNIVERSITY AT BUFFALO RERC-AGING RESEARCH FINDINGS FROM THE FIRST FIVE YEARS

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ABSTRACT
This paper provides an overview of the research of the Rehabilitation Engineering Research Center (RERC) on Aging from 1991 to 1996. Studies focusing on older persons with disabilities included an examination of problems in the assistive technology marketplace, a longitudinal needs assessment, studies of the home environment, identification of devices most problematic for elders, and a controlled clinical trial of an intensive approach to assistive technology service delivery. Results and their implications for practice and policy are discussed.

Consumer Assessments Study (CAS): The RERC-Aging conducted a longitudinal research study over the past 5 years, called the *Consumer Assessments Study* (CAS), to identify the assistive technology (AT) and home environment needs of home-based older persons with disabilities. Over 500 frail elders were interviewed in their home, with follow-up assessments each year. While the sample is drawn from Western New York, a comparison of the CAS with the National Health Interview Survey (1987) and the National Medical Expenditure Survey (1986) demonstrated that the sample is representative of the 8 to 10 percent of the older population with limitations in activities of daily living.[1] Several follow-up studies in specific assistive device areas were conducted following analysis of CAS study results. Work from the CAS resulted in over 30 peer reviewed publications and provided direction for development of assistive devices and information dissemination products. The CAS also played a major role in the development of a practitioner based community assessment instrument.[2]

One CAS report is based on an analysis of differences in AT use among elders with different types of impairments. Recognizing the heterogeneity of the 65+ population in America, the CAS examined differences in assistive device use by older persons with visual, cognitive, and physical impairments.[3] At the time of the first published report on this topic, 157 persons over 60 years of age (M = 75.5 years) were interviewed in their homes. Study participants were assigned to one of seven groups according to types of impairment: minimal, physical, visual, visual and physical, cognitive, cognitive and physical, and cognitive and visual. Group assignments were based on scores from the Sickness Impact Profile (physical), Older Americans Resources and Services Program Multidimensional Functional Assessment Questionnaire (vision), and Mini Mental State Exam (cognitive). Overall, study participants owned a mean of 13.7 devices, used 10.8 devices (79% of the devices they own), and were satisfied with 9.8 devices (91% of the devices they used). There are significant differences among the impairment groups in numbers of devices owned and used, and in satisfaction with devices. Study participants expressed the need for more devices, especially devices for increasing mobility and assisting with balance. Results suggest a stronger role for professional involvement in the assessment of assistive device needs of older persons, and in recommending devices and training persons in their use.

Several of the published papers from the CAS identified problems in service delivery for older persons with disabilities. There are differences in the types of problems depending on the type of device. There are also some more general issues, such as the lack of service provider and consumer information on assistive technology. The CAS, together with several follow-up studies on canes, walkers, wheelchairs, magnifiers, phone features,

and bath devices, provided a base of information on a significant number of service delivery issues.[4, 5, 6, 7, 8] Several papers also focused on persons with specific impairments or chronic diseases, including cognitive impairments; physical impairment; hearing impairment; vision impairment; developmental disabilities; stroke; and arthritis.[9, 10, 11, 12, 13, 14, 15, 16, 17, 18]

The CAS generated information presented by the RERC-Aging in 40 workshops in 24 states across the country and provided direction for the development /modification of assistive technology for older persons with disabilities. The CAS also provided a pool of potential participants for other RERC-Aging projects, including research studies, evaluations of devices, and development of dissemination products, such as videos and booklets (ordering information listed).

Effectiveness of Assistive Technology Devices: and Environmental Interventions in Maintaining Independence in the Home-Based Elderly: A Controlled Clinical Trial (Effectiveness of AT Study): The RERC-Aging, with additional support from the Administration on Aging, is studying the effectiveness of an approach to assistive technology service delivery for older persons with disabilities. This service delivery approach includes an intensive assessment of AT and home modification needs, provides all necessary assistive technology and home modifications, and includes monthly follow-up contacts. Following a group experimental design, outcome measures for this study include independence, cost, incidents relating to safety, and other health and psycho-social measures. The results will be the first capable of addressing the value of assistive technology and environmental interventions to the quality of life for older persons. An earlier paper utilized data from the CAS to establish the relationship between assistive device use and functional status.[19]

Problems in the Marketplace: The CAS demonstrated that persons with disabilities lack up-to-date information on assistive devices, yet are users of AT. Many older persons with disabilities would purchase additional AT devices if they had better information. At the same time companies that market AT cannot easily reach end-users. Using focus groups, this study determined that issues of confidentiality prevent service providers from sharing names and addresses with AT marketers. In response to this finding, the RERC-Aging established Project LINK, which provides information on assistive technology to older persons with disabilities. Project LINK connects (through a confidential mailing service) those who sell products to those who lack information on available products.[17] Project LINK has a growing membership of 15,000 consumers, and has sent 36,657 pieces of information to targeted sub-groups.

Enabling Home Environments: Initially, home environment data was collected and analyzed from the CAS.[20] The Enabling Home Environments project extended the CAS findings. This project identified high-priority problem areas in the homes of older persons with disabilities, and tested concepts for the design of "enabling environments."[21] A computerized home assessment instrument, called the Hyperhome Resource, was developed based on work from this study.

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ALTERNATIVES IN QUANTITATIVE GERIATRIC BALANCE AND MOBILITY ASSESSMENT

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ABSTRACT

This paper reviews new technological advances in quantitative instruments for gait and balance assessment suitable for clinical and research use.

INTRODUCTION

The sense of balance declines with age due to disease and to idiopathic vestibular, proprioceptive and visual losses. It is important to distinguish environmental from intrinsic causes of mobility impairments and consequent falls. A valid assessment tool can be used to examine the cause and likelihood of falling by an individual, and for diagnosis of postural instability in order to administer appropriate therapies or interventions

The elderly are more at risk of falling and may suffer greater injury from a fall than the general population[1,2]. In a prospective study of 336 individuals living in the community, 32% fell in one year, of whom 24% had serious injury and 6% fractures; 10% of falls were during acute illness; 44% were "in the presence of environmental hazards"[3].

PERFORMANCE ASSESSMENT

Performance tests are often administered to measure static and dynamic stability, and gait characteristics[4]. Harada, et al.[5] found that a combination of static balance and gait measures are effective in screening for balance and mobility impairment.

Because of cost and need for special equipment, technology based quantitative assessments are primarily the domain of research scientists. They have been useful in aiding the clinician to understand mechanisms underlying disorders of balance and gait and to monitor changes due to pharmacologic or therapeutic interventions. Challenging tasks, such as tandem stance, reveals strong age related effects that are more easily measured by quantitative assessment (ie, force plate). Since most quantitative measures, with the exception of accelerometry, rely on lab based activities, it is uncertain how these relate to most functional measures[6]. Recent advances in technology has provided a means to overcome some of the drawbacks associated with cost, portabilty, and size of quantitative measurement devices. Listed below are a few examples of assessment devices with such enhanced capabilities.

Sway magnetometry was examined by Fitzgerald, et al.[7] which measures hip movement in the sagittal and coronal planes by magnetic field detectors worn at the waist. Results revealed path length to have the smallest inter-subject variability and was the only technique whose mean Romberg Coefficient (eyes open/closed ratio, equivalent to symmetry in our accelerometry studies) was more than 2 standard deviations from 1.0 (0.74 ±0.11, mean ±S.D.), indicating that this technique showed greatest sensitivity for detecting changes in body sway.

Accelerometry Sabelman et al.[8] built an accelerometry system to quantify trunk and head accelerations during functional movements. Subjects performed 65 tasks including various standing, reaching, walking, and ADL. The system was able to detect age related balance decrements during challenging activities. It also correlated well to functional based qualitative assessments. Recently, accelerometers have been used for body motion analysis [9, 10, 11, 12, 13, 14, 15, 16].

Optical methods directly obtain joint positions by recording motions of joints instrumented with reflective markers. Motus Motion Measurement System (PEAK Performance Technologies, Inc., Englewood, CO) is one such system, 2D or 3D.

Goniometers -- An angle protractor is strapped against a patient's limb, is more reliable than clinical hand-held goniometer measurements[17].

Force plates record ground reaction forces during static or dynamic tasks. BPM (SMS Healthcare, Essex, UK) is a unique portable dual force sensing footplate which provides biofeedback on a computer.

Force sensing mat -- Balance Master (Neurocom International, Clackamas, OR) developed a force sensing mat which provides feedback on a computer for gait assessment or training. Also, a prototype electronic switch array embedded in a portable mat has been developed by Jette[18] for stride length and cadence measurement.

In-shoe measurement systems -- EMED (Novel Gmbh, Munich, Germany), and F-Scan (Tekscan, Inc, Boston, MA) both measure pressure between the foot and the floor as a subject walks. Stride Analyzer (B&L Engineering, Santa Fe Springs, CA) is a footswitch system which measures foot-floor contact. The predominant problem with in-shoe systems is that sensors migrate due to forces on foot during walking[19].

Balance Master Systems (NeuroCom, International, Inc., Clackamas, OR) are elaborate balance measurement systems with computerized force plates to provide a means to measure dynamic as well as static postural stability.

Extra-laboratory gait assessment method (ELGAM), a gait assessment method developed by Cwikel, et al.[20] requires subjects to walk on paper, leaving imprints of their steps. Step measurements are taken, including ability to turn the head while walking, and walking speed, which were found to be associated with social & physical activities.

Rose Musculoskeletal Research Lab, Denver, CO, developed a portable data acquisition system which collects force and tri-axial accelerometric data of lower the lower leg during bicycle pedaling to determine force on the knee[21]. Authors state that this portable system can be combined with lab tests for balance analysis.

CONCLUSION

Wearable self-contained motion sensing apparatus should eliminate possible errors of qualitative judgment during clinical balance assessment, and permit quantitative balance testing in a natural setting outside the laboratory or clinic. Such "technology-based" systems provide critical information in understanding postural control in elderly populations (Alexander, 1996). There is also need for improved follow-up and reinforcement of fall-prevention training to compensate for balance and sensory deficiencies. There is a similar lack of immediate feedback to patients during rehabilitation to overcome balance disorders. As more interventions involving physical training of the elderly are instituted new, simpler methods of evaluating efficacy are needed.

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SIG-17
International Appropriate Technology

A SIMPLE TEMPERATURE SENSOR FOR SPECIAL SEATING

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ABSTRACT

Construction of a simple, low-cost temperature sensor which may provide quantitative data to whether a cushion 'breathes well' is described. Preliminary data comparing an open-cell foam slab cushion and a cushion using grain hull is presented. Significant differences are found which indicate that the sensor may be generally useful in special seating.

BACKGROUND

From everyday experience with ordinary seating, it is well known that vinyl upholstered foam seats are hot and humid in hot weather while woven seats using natural fibers without a cushion are cool.

It is commonly accepted that sweat is a contributing factor to tissue breakdown in special seating. While some types of foam do provide good pressure relief, they are also a good insulator. Vinyl is widely used as a protective skin against moisture and abrasion for foam, especially open-cell varieties. The combination of foam and vinyl provides the most common and practical cushions in special seating. However, in hot weather, these cushions are hot and sweating is inevitable in a very short time. It was found that a cushion using a cotton bag filled with leaves did have pressure relieving properties and it did breath well in hot and humid weather (1). Breathing well means that a user doesn't find the cushion hot nor readily sweat due to the cushion. Qualitative evaluations are direct and appropriate but it is always useful to have a quantitative indicator for how well a cushion breathes.

STATEMENT of the PROBLEM

In the context of appropriate technology, it is desirable to have a simple, low-cost sensor that can provide quantitative information in regard to how well a cushion 'breathes'.

RATIONALE

Temperature measurements in special seating have a very narrow range around 37 °C. It is highly desirable if practical, low-cost instruments can be constructed using readily available parts and require simple or no calibration for repeatable measurements. Thermistors and thermocouples are two traditional sensors for contact temperature measurements. However, low cost thermistors have high device-to-device variations and thermistors have a highly non-linear resistance versus temperature characteristics. Thermocouples are small, repeatable and have a wide measurement range, however they are constructed with rather stiff metal conductors and require special electronics for measuring the minute temperature dependent junction potential. It is unlikely that practical, low-cost temperature measurement devices can be constructed with readily available low cost components using either thermistors or thermocouples as sensors.

The LM35D, a member of the LM35 family, is

a readily available integrated-circuit precision Centigrade temperature sensor at a retail price of a few US dollars. Key specifications appropriate for this application are listed as follows: -

- Calibrated directly in °C with a typical accuracy of within 0.6°C at 25°C.
- Linear +10.0 mV/°C output from 0°C to +100°C with a typical nonlinearity of 0.2°C
- Operates from 4V - 30V with less than 150μA
- Small size (TO-92 plastic package)

From these specifications, it is reasonable to assume that it can be used to construct a practical, low-cost temperature measurement device.

DESIGN

For this application, temperature of a small area rather than at a point is of interest. The LM35D sensor is glued with its flat side to a 13 mm diameter, 0.21 mm thick phosphorous bronze foil (Fig. 1). The foil serves to sense the temperature of a small area and to protect the skin against the rather angular feature of the TO-92 package. 5-minute epoxy is used both to bond the LM35D to the metal disc as well as to make the exposed cable leads water-resistant.

The electronic circuit cannot be simpler (Fig. 2). Four AA-size penlight batteries provide 6 volts to run one or more sensors. 6 volts is high enough to provide a comfortable margin over the minimal 4 volts operating voltage while low enough to minimize the self-heating effect of an active device.

In the temperature region 15-40°C the corresponding output from this sensor is in the region of 150mV to 400mV. This output range can be easily read directly using a low-cost multimeter either of the digital or analog type.

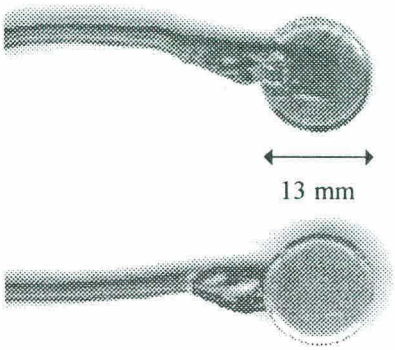

Fig. 1 Front and back views of a 13 mm diameter temperature sensor using the LM35D

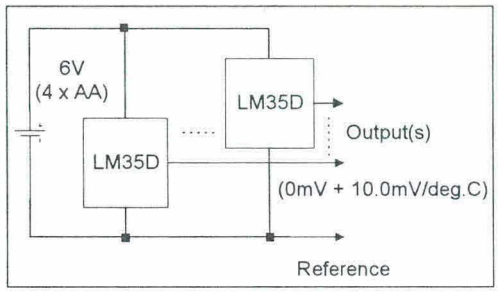

Fig. 2 A multichannel temperature meter

EVALUATION

Two cushions were used in the evaluation. A 57 mm thick open-cell foam slab represented a cushion that did not breath well while a cotton bag stuffed with grain hull represented a cushion that breathed well. The author sat on the foam slab and felt the usual warmth of a common cushion using a good insulator such as foam or polyester fill. The author sat on the cushion stuffed with grain hull and felt that it had a cool feel as that of a woven seat with natural fibers.

Two temperature sensors were used to compare the two cushions. The sensors were attached to the author using skin tape in the standing

position. One sensor (sensor A) was attached immediately under the buttock crest over the hamstring muscle group and the other (sensor B) was attached in the inguinal region just superior to the tendon of the adductor longus. The first location was chosen because this region will be within a large body area in good contact with a cushion in the seated position. The second location was chosen because it was a warm area of the body sensitive to body heat.

At ambient temperature, sensors A and B had only a difference of about 0.2°C (Fig. 3). After attaching the sensors to the body and after about 50 seconds of stable temperature readings were obtained, the author sat on the foam slab for about 450 seconds. Sensor outputs for the total recording time of 500 seconds were shown in Fig. 4. The author then stood up. When the output of the sensors dropped back to a stable level for about 50 seconds, the author sat of the grain hull filled cushion for about 450 seconds. Sensor outputs for the total recording time of 500 seconds were shown in Fig. 5. For sensor A, there was an initial drop in output when the body came in contact with the cushion which was initially at room temperature. For sensor B there was an initial rise only for the foam slab cushion. At the end of the recording period, the temperature difference between the sensors was 2.0°C and 2.4°C for the foam slab and grain hull cushion respectively. The rate of temperature increase of sensor A for the last 250 seconds of the recording period was 0.0032°C/sec and 0.0016°C/sec for the foam slab and grain hull cushion respectively.

DISCUSSION

From the evaluation of the sensor using a subjective warm cushion (foam slab) and a cool cushion (grain hull), small but readily detectable quantitative temperature characteristics were obtained in agreement with these qualitative differences.

This sensor may be useful in providing a quantitative value for the temperature characteristic of a cushion. The author intends to use this sensor for a more comprehensive study using different cushions in the summer when the weather is hot and humid and when any detectable temperature characteristics more meaningful.

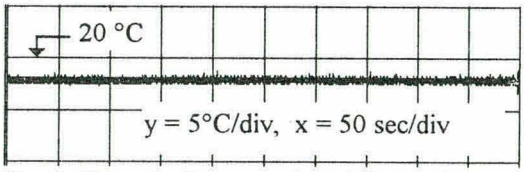

Fig. 3 Output of sensors A and B at ambient temperature

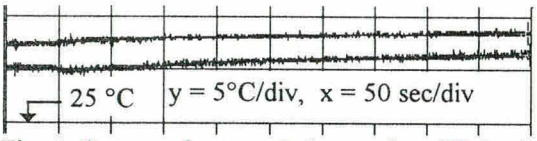

Fig. 4 Output of sensor A (bottom) and B (top) before and after sitting on a foam slab

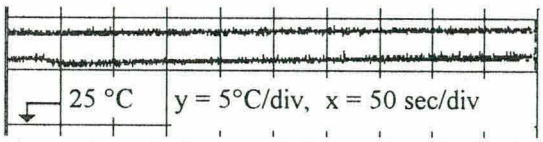

Fig. 5 Output of sensor A (bottom) and B(top) before and after sitting on a grain hull cushion

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WHEELCHAIR CUSHION DESIGNS FOR DEVELOPING COUNTRIES: PROJECT SOREBUTTS

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ABSTRACT
This paper reports on the background to and the results of an international wheelchair cushion design competition. The cushions were to be designed for manufacture and use in developing countries were there are ever-increasing problem due to pressure ulcers. A brief description of the various designs is given and references are cited as to where more detailed information can be found.

BACKGROUND
In 1992 the founding members of RESNA's International Appropriate Technology Special Interest Group (SIG-17) decided to focus on a special project to address concerns related to pressure ulcers (sores) that were reportedly becoming an ever increasing problem in developing countries [1]. The project was named *Project Sorebutts* and addressed both prevention and treatment through three different activities:

The Poster Competition To create an educational poster to make spinal cord injured (SCI) survivors and their caregivers aware of the seriousness of pressure sores and the importance of pressure relief in their prevention.

The Cushion Design Competition To design a wheelchair cushion that is inexpensive, easily made in developing countries, and effective in reducing the pressures on weightbearing areas of the pelvis.

The Spinal Cord Injury Survivors' Manual To produce a manual; which through good graphics, upbeat humor, and practical information; engages the owner in survival strategies. This part of Project Sorebutts is being performed in collaboration with the Wheeled Mobility Center at San Francisco State University [2].

While the development of the SCI Survivors' Manual is still underway, the remaining two parts of the *Project* have produced significant results. Details of the Poster Competition can be found elsewhere [3]. Here we report on the progress in the development of inexpensive yet effective cushions appropriate for use in developing countries. In particular we shall present the results of the Cushion Design Competition that was judged at RESNA's 1996 annual conference. Attention will focus on a description of the various cushions submitted and the judging criteria used.

OBJECTIVE
The objective of the Cushion Design component of the *Project* is two fold. The first is to generate a variety of effective cushions and/or seating designs that would alleviate pressure ulcers. The second is to disseminate information on these designs to developing countries, enabling an appropriate cushion to be chosen for the particular location and required application. Moreover, from the information distributed local crafts-people must be able to manufacture any of the designs deemed to be suitable.

METHOD
In order to meet the first objective listed above, SIG-17 has developed an annual competition, *Project Sorebutts Cushion Design Competition*, with a view to attracting both national and international entrants. In addition to requiring written design and manufacturing instructions, an actual cushion must also be submitted for

evaluation and testing. All entrants would then be judged by a panel of experts, and prize money would be distributed accordingly. While the various entries would be rated by the panel, detailed information on all the submissions will be disseminated to appropriate agencies, published on the world wide web, and sent directly to developing countries.

APPROACH

The judging of the inaugural competition was held at the RESNA's 1996 Annual Conference in Salt Lake City, with detailed rules for the competition having been published a number of months earlier [3,4]. An important component of these rules was a set of drawings that would enable an entrant to build a simple, yet anatomically realistic *Pressure Measurement Dummy* (PMD). This was the same device that would be used by the judges. Detailed assembly drawings of this can be found at the web site [3]. A synopsis of the rules follow:

To design and construct a cushion to fit on or in a wheelchair that has a standard canvas "sling" base and backrest with a seat dimensions of 16" x 16". There were four main judging criteria, each receiving equal weight from the judges. The first was the ability of the device to equalize the pressure acting over the seating area; the second was the cost of the final product; the third was its manufacturability (bearing in mind the availability of local materials and skill levels of the craft persons); and finally there was a category for additional features; such as its fail-safe design, durability and maintenance, ability to be used off the wheelchair, etc.

RESULTS

There were seven cushions in the competition and most were based on a different type of construction. This was particularly welcomed by the organizers because the main purpose of the competition was to generate a pool of unique ideas. A brief description of each of the designs is as follows:

1. A cotton bag was sectioned into three compartments, two of which were filled with beans. Figure 1 shows more details of this design.

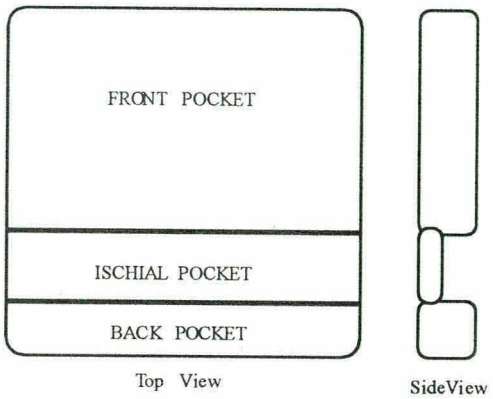

Figure 1. The relative proportions of cushion 1 (16"x16"x3").

2. A 16"x16" frame was constructed from 2"x4" lengths of wood and the space between the frame was spanned by a tensioned weave of cut-up car inner tubes.

3. A three-dimensionally contoured cushioned made from multiple layers of thick fabric sewn together. The contours are chosen to best suit the individual user.

4. This design is perhaps best described as *Roho* like. A base is made from a lattice of leather and then three bicycle inner tubes are woven through this lattice in an ingenious manner. The inner tubes loop-up through the leather lattice producing a 10x10 matrix of rubber 'pods'.

5. Bicycle inner tubes were also used in this design. Here, eight were partially filled with air and air restrictions were created in each tube by tightly tying short lengths of string around the tube every 10cm. All the inner tubes were then formed into a rectangular shape and placed in a cotton bag. Figure 2 shows a photograph of the cushion without its cover in the process of being tested for it pressure distribution capabilities.

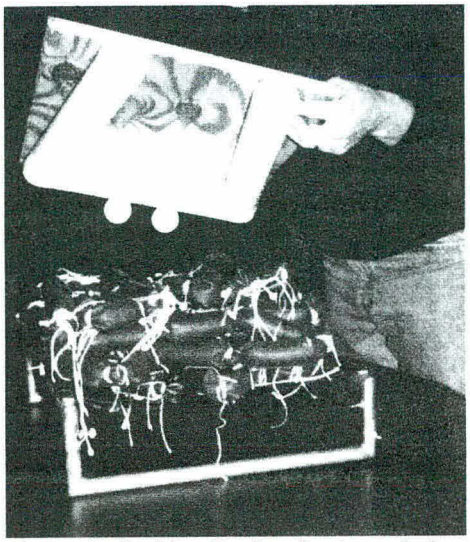

Figure 2. Cushion Design 5 prior to being loaded by the PMD.

6. A partially inflated beach ball was the main component here. It was placed in a loose cotton bag with an additional tightly rolled piece of fabric placed in front of the ball to act as a support for the femurs and 'bucket' the pelvis [1].

7. The final entrant was similar to design 3 in that it was laminated, but the laminations were made from corrugated cardboard. Each lamination was cut and shaped to suit the individual. A three-dimensional, custom shaped product resulted. A 2" layer of foam was then placed on the seating interface.

Specific details of each of these designs can be found at the web site [3] or by contacting the authors of this paper directly.

DISCUSSION

While the judges were asked to look for an overall winner based on the four judging criteria mentioned above, no one cushion emerged ahead in all the four categories. Indeed, it was finally decided to award two first places. Design 1 scored particularly well in the "manufacturability" and the "cost" categories. Design 5, although a little more expensive and harder to construct than the first, performed exceptionally well in the "Pressure" category and was judged to have more "Additional" features.

The competition is to be held again in 1997 with slight modifications to the rules and minor changes being made to the PMD so that it more accurately represents a human in a seating position. The refinements to the PMD are particularly noteworthy because there is currently no simple, standardized way of loading cushions with an anatomically correct load.

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3. http://www.egr.msu.edu/~haddow/sig17

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THE INDEPENDENT LIVING MOVEMENT AND SUSTAINABILITY OF WHEELCHAIR PRODUCTION IN DEVELOPING COUNTRIES

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ABSTRACT

The Independent Living Movement is spreading rapidly throughout the world. Wheelchair riders tend to be its leading activists. Economically viable local workshops and factories which produce durable, high quality, low cost wheelchairs are a key to this success. Yet sustainability of wheelchair production is itself dependent on the sustainability of independent living center-type disability self-help and advocacy organizations. The success of either depends on the success of both.

INTRODUCTION

Among people with disabilities in developing countries, it is the wheelchair riders who tend to spearhead new organizations and ride the crest of the independent living movement wave. Deaf persons, of course, have been marginalized by communication barriers and when organized are usually organized as a separate community. Blind persons, on the other hand, able to communicate with the dominant culture and more mobile than people who need to use a wheelchair, were the first disability group to organize. For decades they have had large and powerful organizations. Although there have recently been more blind persons active in the independent living movement, the traditional blind organizations have generally been unwilling to work with other disability groups for fear of having to share scarce resources. People with mobility impairments who do not need to use a wheelchair, the "walking disabled," have had much less difficulty in integrating into society than those who need a wheelchair due to the lack of wheelchairs and widespread barriers to wheelchair travel.

It is people who need to use a wheelchair who have the most to gain from the independent living movement's success. Living in societies that offer endless barriers to wheelchair travel, they are usually unable to find work and must depend on others in order to participate in most social activities. Not yet organized like the blind, nor cut off by communications barriers like the deaf, wheelchair users are riding to the forefront of the independent living movement.

BACKGROUND

Since 1989 the Wheeled Mobility Center has helped establish workshops and small factories in developing countries where durable, high quality, low cost wheelchairs are built as the first step in promoting the full integration of people with disabilities. From 1993 to 1996 WMC has been actively involved in supporting both wheelchair production and the development of an independent living center in Novosibirsk, Russia. From 1993 to 1995 WMC also supported a major wheelchair production effort in the West Bank and Gaza Strip. An assessment of these two projects highlights the need for a comprehensive program of economic and social development to ensure the viability of wheelchair production.

DISCUSSION

Consumer Feedback

In Novosibirsk, funding from USAID allowed WMC to develop both local wheelchair production and the organizational capacity of a small self-help organization of wheelchair riders. WMC first assisted SibMedDesign (SMD), a small private firm, in designing a wheelchair which can be narrowed while occupied to squeeze through the narrow doorways and elevators common throughout Russia. Local wheelchair riders from the FINIST (Phoenix) Disabled Sports Club actively involved themselves in providing design and fabrication feedback to SMD which has lead to a number of improvements in the comfort, safety, function and aesthetic appeal of the SMD chair. Both wheelchair riders and manufacturers benefitted. The wheelchair riders gained increased mobility and self-esteem while the factory was better able to compete against other wheelchair manufacturers and sell more wheelchairs in other parts of Siberia.

Marketing Through Advocacy and Education

The availability of good quality wheelchairs in Novosibirsk stimulated the first wave of disability activism. New people began to get involved in FINIST, to develop its sports and recreation programs, and to begin to address other areas of concern to people with

disabilities.

One of the first efforts of the wheelchair rider activists was a campaign to convince local government agencies which purchase wheelchairs, such as the Department of Social Protection (DSP), that the SMD wheelchair was superior to wheelchairs built at the state-owned factory near Moscow and to wheelchairs made by a second private factory in Novosibirsk. This pressure was significant because given the relatively low income levels of wheelchair riders in Russia, the absence of a non-profit sector, and the lack of tax incentives for private donations, the government would have to be the main market for SMD wheelchairs.

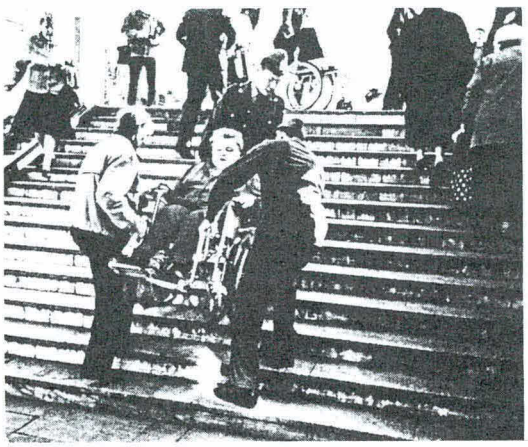
The task of educating DSP officials in Russia was all the more difficult because in Russia the government had produced only two types of wheelchairs, a lever drive chair for outdoor use and a one-size-doesn't-fit-anybody hospital style chair for indoor use. With no real options available, no one knew much about the comparative advantages of various wheelchair features. The government had no reason to seek the input of wheelchair riders, and to make matters worse, government officials usually discounted the opinions of disabled persons. When officials wanted to know about the wheelchairs newly available in Novosibirsk, they asked the non-disabled factory managers.

The new activists used the SMD wheelchair, not only for their own mobility, but also as a vehicle to educate Department of Social Protection officials. They educated DSP officials not only about wheelchair features, but also about the necessity of listening to the disabled consumer. This was the first of many efforts which would raise the status and improve the public image of people with disabilities in Novosibirsk.

The insistence on consumer involvement in government decisions to purchase wheelchairs was also critical to creating a freer, more open market. There were powerful political pressures on local government agencies to purchase government built wheelchairs. Favoritism and political loyalties also had a heavy influence on decisions to purchase inferior quality wheelchairs from the other private factory in Novosibirsk. Consumer involvement through a third party payee arrangement would help make price and quality the determining factors in wheelchair purchasing decisions.

The terms of USAID's funding allowed WMC to be actively involved in supporting the FINIST activists and SMD's marketing efforts. In order to promote better wheelchairs and earn income to sustain itself, FINIST made an agreement to become a sales agent for SMD chairs, and the organization received a commission on all chairs it sold. Soon after signing the agreement, FINIST demonstrated the SMD chairs at a sports competition in a neighboring city and sold 26. A sympathetic official in the Regional DSP learned of the FINIST-SMD agreement and saw it as an opportunity to fund FINIST through the purchase of SMD chairs. (Government funding for FINIST was small and limited to non-salary expenditures). The result was a business-government-NGO triad which benefitted all the parties.

Still, most government officials and a good many disabled persons themselves, with some justification, argued that a better wheelchair did not matter if the architectural infrastructure, including apartments, offices, stores and transportation, was so inaccessible. So WMC, in partnership with wheelchair rider activists, worked to transform FINIST from a disabled sports club into an independent living center, a non-residential service and advocacy organization run by and for people with disabilities. The results have been remarkable.



Soldiers help disabled activist up subway station stairs at demonstration for accessible transportation in Novosibirsk, Russia (Siberia).

In March 1996, FINIST lobbied the Central District Administration (CDA) in Novosibirsk to make curb ramps. By September 1996 over 100 curb ramps had been built in that district and a permanent ramp, designed to international standards, was built into the CDA office. A hospital, whose head doctor also sits on the Novosibirsk city council, has a new wheelchair ramp, making it only the second accessible medical facility in the city. The Special Library for the Blind, a state institution, now has two wheelchair accessible

bathrooms.

In August 1996, activists from the newly formed Novosibirsk Regional Center for Independent Living "FINIST" (NCIL FINIST) received very positive television coverage when they held a demonstration for accessible transportation in the city subway. This and other efforts to educate the media, government officials, and the public have raised the status and improved the image of people with disabilities in Novosibirsk.

NCIL FINIST also established a Disabled Community Health Clinic inside an existing polyclinic in Novosibirsk. Through this project, lead by ARIADNA, the disabled women's sector of NCIL FINIST, disabled persons and medical professionals in Novosibirsk have become familiar with a wide range of rehab supplies and are creating a growing demand for wheelchairs, cushions, catheters and other products for daily living.

The West Bank and Gaza Strip

In a number of important ways, there were similarities between the project in Novosibirsk and the project in the West Bank and Gaza Strip. Both projects were funded at about one million dollars. Both were run under extremely difficult circumstances. The collapse of the Soviet economy and the ongoing conflict in the Middle East had each lead to economic chaos. In both places it was very hard for the shops to get a reliable supply of parts. In both places government or charities, not the disabled individual, had the ability to pay for wheelchairs.

To be sure, there were major political and cultural differences including the great difficulty encountered by Palestinian management in traveling between the two shops in the West Bank and the third shop in Gaza Strip. But the greatest differences lie in WMC's limited role as a business and technology consultant and the absence of a significant role for local wheelchair riders in the West Bank/Gaza Strip project. That project was run through a national committee for rehabilitation that contained very few people with disabilities. In fact, the organizations of people with disabilities in the West Bank and Gaza Strip have been virtually disenfranchised from the project and management does not have a vested interest in the project's long term viability. Two years after the inception of the Novosibirsk project, SMD had sold more than 500 wheelchairs and there was an active and growing organization of people with disabilities. Two years after the inception of the West Bank/Gaza Strip project, no wheelchairs had been sold (although many had been produced) and there was no appreciable strengthening of any disability self-help organization.

CONCLUSION

Because there is a myriad of factors which can affect the success of any business enterprise, more time will be needed before we can draw definitive conclusions. However, WMC's experiences in Novosibirsk and the West Bank/Gaza Strip have reinforced our previous experience that where self help and advocacy organizations of people with disabilities have been actively involved in wheelchair production and marketing, both the business and the NGO are more likely to remain viable.

ACKNOWLEDGMENTS

Funding for the Novosibirsk project has been provided by the United States Agency for International Development (USAID) through World Learning, Inc. Other agencies funded projects with the Novosibirsk Center for Independent Living "FINIST" which dovetailed with WMC's project. These include the Eurasia Foundation, which funded a computer training project through Connect US-Russia of Minneapolis and the National Endowment for the Arts which funded a workshop and performance tour by AXIS Dance Troupe. Funding has also been provided directly to FINIST by the Soros Foundation. Funding for the West Bank/Gaza Strip project was provided by a private donor through the International Labor Organization.



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A LOW COST, LOW SPEED FOAM CUTTER FOR SPECIAL SEATING

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ABSTRACT

Rationale for the need of a low speed cutting tool for soft foam for special seating was explored. A design using a commonly available wire brush was described and evaluated. This prototype cut well and outperformed other cutters for soft foam at low rotary speeds in the range of 1,400 rpm - 3,400 rpm at a feed-rate of 3.5 mm/sec.

BACKGROUND

One of the key elements of an appropriate technology CAD/CAM system for producing custom contoured cushions is a low cost foam carver. Technical information on and cutting tools for machining metals and hard plastics are readily available. However, the author failed to find any books or handbooks that contain information on how to machine soft foam which is so often used in custom contoured cushions. It is not surprising then that the author also failed to find any commercial cutting tools declared for machining soft foam. Presently, some commercial custom contoured cushion providers produce the cushions by pouring liquid foam over a positive mould of a captured body shape. Direct machining of soft foam was reported by using a custom made two edge blade at approximately 7,000 rpm (1), an orthotic rasp on a CNC machine and a wire brush[1]. There is a lack of both information on and commercial cutting tools for machining soft foam.

1 Personal communications with an engineer from U.K. and an engineer from Canada.

STATEMENT of the PROBLEM

Is there a low cost cutting tool for machining soft foam at low speed?

RATIONALE

Cutting at low rpm (revolution per minute) is appropriate

The advantage of cutting at high speed is obvious in the sense that shorter times are required for carving a cushion.

An appropriate technology foam carver needs a readily available low-cost but durable motor for almost continuous duty because carving a cushion takes time. Single phase a.c. motors and d.c. shunt wound motors are generally durable and readily available at reasonable prices. However common a.c. single phase motors run in the range of 1,400 rpm - 1,725 rpm, depending on supply frequency while small d.c. shunt wound motors run in the range of 3,000 rpm - 4,000 rpm. Hobby grade routers and laminate trimmers for wood-working are readily available, not expensive and run at rotary speeds of over 10,000 rpm. However, the author is not sure of the durability of these high speed tools under continuous duty. It is therefore reasonable to assume that cutting at low speed is appropriate given the availability of low-cost, suitable motors that run at low rpm.

The need to make a cutting tools for operation at low rpm

Router bits are designed for cutting at high speeds, it is doubtful whether they work well at low speeds. Rasps for use in routers for prosthetics and orthotics applications work in the range of 1,500 rpm - 3,000 rpm. However, they are designed for removing thin foam layers and normally requires sanding for the final finish. Whether these rasps can be used to make deeper cuts for removing larger amounts of material in special seating is unknown. These rasps are not commonly available and are certainly not low-cost.

The two edge blade cited is 1" in diameter with a cutting depth of about 4" and a round end. The advantage is that it can make deep cuts. However, it requires a machine shop and a good machinist to fabricate. Since the cutter is relatively long and heavy, it requires a robust high speed motor to run it at 7,000 rpm.

The idea of using a wire brush is most attractive because wire brushes are commonly available at low cost and light in weight. End brushes are most suitable for grinding down to a round end. In terms of operating speed, they range from un-rated to around 20,000 rpm. Unfortunately, only cup brushes that are either un-rated or rated at 4,500 rpm are commonly available locally.

Since appropriate technology involves the use readily available local materials at a reasonable cost, the choice of carving at low rotational speeds using a modified cup wire brush is most attractive.

DESIGN

The smallest suitable type of wire brush commonly available locally is a 50 mm cup wire brush, either un-rated or rated at 4,500 rpm, with 0.03 mm (approx.) crimped steel wires and a 6 mm shank. This type of brush holds the crimped wires between an outer cup of approximately 37 mm dia. and an inner disc or cup. To make a foam cutter, a vise was used to crimp the wires of a brush as much as possible towards the centre to reduce both the final diameter of the brush and the size of the 'hole' in the middle. The brush was then put on a lathe and the outer cup trimmed down to close to the diameter of the inner cup so that the outer cup will not be larger than the final diameter of the brush.. The brush was then mounted on an electric drill and ground down using a grinder to a ball shape. The resulting brush is approximately 33 mm in diameter with an effective flat end of approximately 12 mm due to the hole in the middle of the brush (Fig. 1)

EVALUATION

A open-cell foam block with a density of 45.75 kg/m^3 was used for this evaluation. For simple comparison, a CNC milling machine was programmed to make 90 mm long, 10 mm deep cuts at a feed-rate of 3.5 mm/sec. The cutting tools were also programmed to lower and lift from the foam at 3.5 mm/sec. Each tool made three cuts at 1,400 rpm, 2,400 rpm and 3,400 rpm respectively. The following tools were used for evaluation (Fig. 1): -

A) modified 50 mm cup wire brush,
B) 1" dia., 2 flute round nose wood router bit,
C) custom 1" dia., 2-edge blade.

Results of the three sets of cuts were shown in Fig. 2. In terms of finish, tool A gave a smooth cut at all rotary speeds while tools B and C gave a relatively rough cut with foam gathering at the trailing edge. The finish at 1,400 rpm was bad for both tools B and C. At the two lower rotary speeds, tools B produced an initial taper before the depth of cut became stable. At 1,400 rpm both tools B and C produced an obviously shallower cut than that at 3,400 rpm.

DISCUSSION

Results show that the modified cup wire brush performed well at cutting speeds even as low as 1,400 rpm at a feed-rate of 3.5 mm/sec while all the other cutters performed poorly at or below 3,400 rpm. This does not exclude that any or all the cutters may perform well at higher cutting speeds.

The major disadvantage of using a cup brush is that the hole in the middle creates in effect a flat end. It is fortunate that the inherent asymmetry of the resulting brush end results in a flat end of approximately only 12 mm, which is not a severe limitation in special seating. All these limitations should not be present if end brushes are available for modification. The author concludes that a stiff steel wire brush is suitable for simple modification to make a light weight low-speed cutter for soft foam. One word of caution -- like all rotating machinery, it is important to have guards for safety -- some of the wires may likely be weakened during the cutting and grinding.

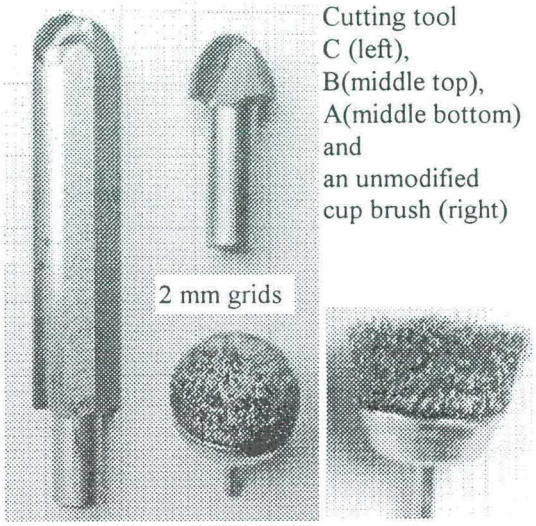

Fig. 1
Cutting tool
C (left),
B(middle top),
A(middle bottom)
and
an unmodified
cup brush (right)

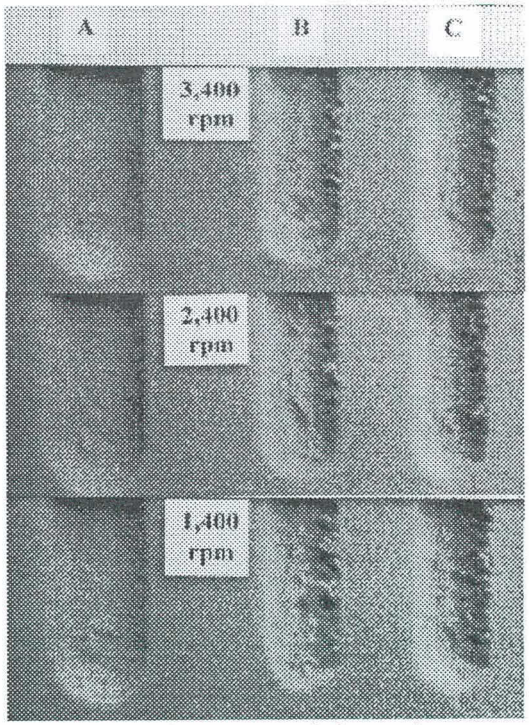

Fig. 2 10 mm deep cuts made by cutting tools A, B and C at three different rotary speeds

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REHABILITATION SERVICES IN MEXICO

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ABSTRACT

This paper presents a brief description of rehabilitation services available to people with disabilities in Mexico. The needs and priorities of this popultation, as identified by the community of persons with disabilities, will also be discussed. Lastly, examples of assistive devices designed and developed by clinical specialists in Mexico will be introduced.

INTRODUCTION

During the last six years the author has been closely following the development of the disabled movement in Mexico. This paper describes the providers of rehabilitation services in Mexico, as well as, a summary of findings from a national network of organizations representing people with disabilities.

BACKGROUND

These are important times for persons with disabilities in Mexico. The last six years have witnessed a significant transformation of the disabled movement from very limited activity to national organizations which represent multiple interests of people with disabilities. The American with Disabilities Act (ADA) has had a ripple effect in Mexico by illustrating to the disabled community what can be accomplished if appropriate political representation by organized groups of people with disabilities is taken seriously.

SERVICE PROVIDERS

Rehabilitation services in Mexico are provided through a system of socialized medicine. Institutions that provide these services include:

Instituto Mexicano del Seguro Social, IMSS (Mexican Social Security Institute)-Provides medical care to individuals employed by private companies. Coverage is paid by employees and employers. Medical coverage includes the worker, his/her immediate family and in some instances, the worker's parents. Medical care provided include all areas of medicine from general practice to specialties including rehabilitation. IMSS services the 31 Mexican states through state delegations. It operates several outpatient rehabilitation clinics in Mexico City but none in the 31 states. The Federal District (Mexico City) is also divided into delegations. Although each state delegation has certain autonomy, the overall administration and policy making is located in the central offices of Mexico City. General hospitals located in each state capital contain small rehabilitation units.

Instituto de Seguridad Social y Servicios para los Trabajadores del Estado, ISSSTE (Social Security Institute and Services for Government Employees)-Provides health care services to federal and state employees and their families. In its organization, ISSSTE is very similar to IMSS. Hospitals operated by ISSSTE are smaller than those operated by the IMSS. ISSSTE also has a rehabilitation hospital in Mexico City.

Sistema Nacional para el Desarrollo Integral Familiar, DIF (National Network for the Integral Development of the Family)-This organization provides a wide range of services that cross boundaries between social and medical services. DIF has evolved through several decades of political reorganization and is present in each of the 31 states. Presently, DIF is responsible for the care and education of abandoned children, education of blind and visually impaired children, education of children with learning disabilities, and the provision of rehabilitation services to the general population. It has implemented the Centros de Rehabilitacion y Educacion Especial, CREE (Rehabilitacion and Special Education Center) and the Centros de

Rehabilitacion Integral, CRI (Integral Rehabilitation Centers). These centers provide rehabilitation services to all requesters regardless of economic status. To determine charges for services, a socio-economic study is conducted by a social worker. Charges are established based on the individual's ability to pay. To operate in this mode, services are heavily subsidized by the state and federal government. The physical size of each facility and the variety and quality of services they offer vary greatly depending on the geographic location of the center. Services also depend on the interest and involvement of the local authorities in each state.

Secretaria de Salud, SS (Secretary of Health)-The Secretary of Health regulates an enormous amount of health related activities. It is the equivalent to the US Food and Drug Administration and the Health Department. Included in the services under the control of the Secretary are the operation of rural hospitals and one rehabilitation center.

Instituto Nacional de Rehabilitacion, INR (National Rehabilitation Institute)-Rehabilitation services are limited to one hospital in Mexico City. The INR provides orthotic and prosthetic devices. This is a training facility for orthetists and prosthetist technicians. Although equipment is antiquated, the end product is of high quality. The services offered by INR are open to the general public. Charges are based on the socio-economic study and therefore, heavily subsidized by the government. INR facilities are frequently overcrowded. A new building is presently under construction. Plans are in place to upgrade the facilities to a state-of-the-art program.

Cruz Roja Mexicana, CRM (Mexican Red Cross)-The CRM is primarily dedicated to emergency care through emergency centers spread throughout Mexico City and delegations in each Mexican state. The main hospital in Mexico has a small rehabilitation unit dedicated to provide prosthesis to low income individuals. Services are also charged based on the socio-economic situation of each patient.

Private Rehabilitation Providers-Private rehabilitation services are available in most major cities. These services are utilized by the upper economic class population. These services operate similarly to the US rehabilitation centers. Therapist are well trained and facilities are equipped with state-of-the-art equipment. Rehabilitation units in private hospitals provide similar care to US hospitals. Many therapists and physiatrists on staff have graduated from US universities.

ASSISTIVE TECHNOLOGY

Although there are different alternatives to receiving rehabilitation services, none of the above organizations provide recommendations for assistive devices. In fact, assistive technology is one area identified by the community of persons with disabilities that require significant development.

Persons with disabilities in Mexico have implemented a consortium of approximately 600 organizations. The consortium, Discapacitados Mexicanos DIME (Disabled Mexicans), has conducted numerous forums and collected information regarding the needs of persons with disabilities in Mexico. They have identified their main priorities as (1) the removal of architectural barriers, (2) access to education, (3) transportation, (4) vocational opportunities, (5) the need for affordable assistive devices, (6) and education of the professional community, as well as, the general public regarding disabilities.

Regarding the need for assistive technology, the message has been communicated to different organizations. Presently, several groups are working on the development of assistive devices. A number of organizations of people with disabilities have initiated small machine shops where basic manual wheelchairs are being fabricated. At the IMSS, the vocational training department has developed adapted machine shop tools and fabricates sport wheelchairs. Devices are fabricated by students with disabilities enrolled in the training program. Students procure their own materials and construct their own devices.

Several universities are also developing assistive devices. Devices designed and fabricated at universities tend to be more complex and similar to devices available in the US. Examples of these devices include an augmentative communication device, an environmental control unit, and computer software for different applications. Some universities are developing electronic controllers for powered wheelchairs. Powered wheelchairs are being adapted by converting manual wheelchairs through electro-mechanical devices.

DISCUSSION

It is evident that duplicity of rehabilitation services exists between the different socialized medicine organizations. This duplicity translates into inefficiencies. Considering that state and federal monies subsidize the provision of rehabilitation services, it would be possible to increase efficiency through coordinated efforts between the different organizations. According to DIME, it is unlikely that inter-agency coordination will take place soon. Different political agendas and difficult economic times are two of the main obstacles preventing the coordination between institutions.

Persons with disabilities throughout Mexico have gathered together to discuss their situation, identify and prioritize their needs, and search for potential solutions. The establishment of DIME represents a significant milestone, the birth of the organized disabled movement in Mexico. Hopefully, this example will spread throughout other nations of the Americas, where people with disabilities still do not have a common voice.

Regarding the needs of persons with disabilities identified by DIME, they are very similar, if not identical, to the needs expressed by the US community of people with disabilities. Although the resources to address these needs differ significantly, the fact that people with disabilities have gathered and agreed on their priorities establishes the first step toward achieving their goals. People with disabilities in Mexico have demonstrated their creativity by solving some of their AT needs without the development of formal industries.

The disabled movement in Mexico has made significant progress in the past few years. The fact that numerous local organizations are working together to address these needs provides them with the opportunity to find appropriate solutions to the challenges that they have identified.

People with disabilities throughout Mexico need to be recognized for their successes and their perseverance in pursuing social equality and opportunities for social development. Other groups such as, international organizations, professional organizations, universities and social action groups, need to participate with the community of people with disabilities in their efforts to gain social equality.

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SIG-18
Tech Act

USING PEER MENTORS TO FACILITATE THE MATCH OF PERSON & TECHNOLOGY

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ABSTRACT

As part of the New York State TRAID Project, a peer mentoring process was supported. It is guided by the Matching Person and Technology (MPT) Model and it has been successful in helping consumers to identify the best technologies for their use and to become more self-determining and independent in the acquisition and use of technology.

BACKGROUND

Help and continued support in learning about and using technology is not always readily available. The Technology-Related Assistance for Individuals with Disabilities Act (Tech Act) Amendments of 1994 include provisions (a) for empowering individuals to self-advocate for increased access to and funding for AT and (b) for increasing the control of individuals over the selection and procurement of their AT devices and services.

The New York State Office of Advocate for Persons with Disabilities was awarded a Tech Act grant in September, 1990. The Office of the Advocate, an independent agency headed by a member of the Governor's cabinet, established the NYS TRAID Project. As one of its systems change initiatives, the NYS TRAID Project has funded Regional TRAID Centers throughout the state since 1990. In 1996, it funded the Genesee-Finger Lakes TRAID Center (G-FL TRAID) through the Rochester Center for Independent Living in collaboration with AIM, an independent living center in Corning, New York. G-FL TRAID established a peer mentoring program by recruiting appropriate consumers and training them in the process of peer mentoring.

OBJECTIVE

The mission of the G-FL TRAID Mentors is to help improve the quality of life for persons with disabilities by facilitating the development of consumer skills in self-advocacy, self-determination, and community systems navigation so that consumers can more effectively drive their selection and use of assistive technologies (ATs) .

TRAID Mentors are persons with disabilities who are assertive and self-determining in the design, acquisition, and utilization of their assistive technology(ies). They practice the fundamentals of self-advocacy and self-determination. They know how to effectively employ the Matching Person & Technology assessment process and are familiar with technologies and technology delivery systems. Mentors have a set of prerequisite competencies which, coupled with training and on-going support, enable them to successfully assist others in effectively interacting with technology resources. Once successfully completing their training, Mentors receive a stipend for effectively serving peers in their design, acquisition, and/or utilization of technology.

METHOD

Through partnering, mentors assist consumers in increasing their knowledge about their personal needs and preferences regarding ATs as well as in improving their ability to be more self-determining and more effectively assertive in the selection and utilization of ATs. This process centers on the use

of the Matching Person and Technology (MPT) Model [1,2] and the following assessment instruments from the Model (listed in the order in which they are used):

- **Worksheet for the Matching Person and Technology (MPT) Model** - this results in consumer-identified goals in all areas of current functioning and areas where technologies may be helpful.

- **Technology Utilization Worksheet for the Matching Person and Technology (MPT) Model** - this form indicates technologies the consumer is currently using, has used in the past, and wishes to obtain.

- **Survey of Technology Use** - this form provides information on the consumer's use of general, everyday, technologies so that the introduction of any new device can be built on existing levels of comfort and familiarity.

- **Assistive Technology Device Predisposition Assessment (ATDPA) - Consumer Form** - this instrument helps consumers examine their self-perceptions in areas of current functioning, their capabilities, psychosocial characteristics, and predisposition's to the use of particular technologies.

The MPT Model assessments are designed to help potential users of technologies self-assess their expectations and preferences, background characteristics, family and environmental influences, economic factors and training needs.

Consumer responses to the items in the MPT self assessment process assist both the consumer (technology users) and service providers in making choices best suited to the needs of the user, in many cases avoiding the frustration of a technology not compatible with the preferences, personality or environment(s) of the person .

APPROACH

TRAID Mentors help consumers make up their own minds regarding their selection and acquisition of technology resources by using the MPT Model, resource listings, and resource agencies in the community. Additionally, the Mentors provide AT professionals with an orientation to this process and how it helps their consumers be more self-aware and active in effectively using and maximizing professional resources.

Follow-up contacts are made to all consumers. Mentors contact consumers weekly for the first month, biweekly for two months, and monthly thereafter. The purpose of the follow-up is to:

1. make sure consumers are satisfied with the AT resources;

2. assist consumers as they assess their need for follow-up with service providers;

3. assist consumers in identifying any adjustments in the use environments.

RESULTS

The success of the G-FL TRAID Mentoring project can be best illustrated through the successful outcomes achieved by persons who have been mentored. One example follows.

The First Meeting: DM is an outgoing, optimistic, and communicative person, close to retirement age, who contacted the TRAID project for help in being better able to write. She has multiple disabilities, the most difficult of which is severe arthritis. She is a single leg amputee and uses a wheelchair for mobility. She receives Medicaid, Medicare, and SSI, which allows her to have 6 hours of home health care daily. For the remainder of her day, she experiences the need to maximize her independence. She is not involved with any agencies other than home health care.

The personal care attendants assist with mobility, meal preparation, and household tasks. Earlier in life she worked in clerical capacities with a typewriter, but is not seeking work now due to her age. She is relatively comfortable with her wheelchair with attendant help. She can not maneuver the chair herself due to her arthritis (she has use of only one arm). She has tried power chairs and does not like them. Her greatest concerns center on the limitations from her arthritis. She wants to be able to write notes and letters. She has severe fine motor limitations. She uses a strap to hold eating utensils.

In going through the Matching Person and Technology (MPT) assessment process, DM indicated ambivalence toward technology use but good family and social support. She had not used computers, sensors, remote control devices (other than the TV remote).

Her initial self-assessment seemed to tell her that low-tech solutions would be preferable and that a high-tech solution like a computer to which to dictate may not be the best match for her, currently

The Second Meeting: With Mentor support, DM continued her MPT self-assessment, which led her to explore use of a tape recorder for taping her letters to others, in response to which they could write, or tape, back to her. Her choice of this technology has led to continuing satisfaction.

Through the MPT process, DM acknowledged neck pain while watching TV. Encouraged by her Mentor to discuss this with her OT, she subsequently chose to have a shelf installed to better position the TV and, with Mentor encouragement, she requested a new remote from the cable firm so that she could change channels more easily. She also acquired a touch lamp so that she could turn it on and off independently.

The result was a very satisfied consumer who is growing with comfort in the use of technology and says her quality of life has improved significantly. The sending and receiving of taped letters has worked out very well for her. The cost of the solutions amounted to less than $200.00.

DISCUSSION

This scenario demonstrates that the process of matching a person and technology can be facilitated with assistance from peer mentors. MPT Mentoring is a cost effective AT service which can bring more self-aware consumers into partnership with professionals, maximizing both professional time and expertise, while yielding an effective, technology based higher quality of life for the consumer.

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SIG-19
Universal Access

DESIGN AND DEVELOPMENT OF A SELF-ORIENTING 'SMART' SPOON

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ABSTRACT

The simple act of eating a meal with friends and family can greatly increase the independence and inclusion of persons with disabilities. Some of these individuals are capable of performing the eating action but do not possess the cognitive skills to recognize the proper orientation of the spoon. A self-orienting 'smart spoon' has been designed that orients itself and allows these students to eat without the close supervision once required.

BACKGROUND

Schools throughout the world specialize in teaching persons with disabilities the skills required to lead an independent life outside the school environment. The Rosedale School in Austin, Texas is one such specialized school. One activity taught at these schools that has significant potential for increasing the independence and social inclusion of the students is eating with a spoon.

While, some students are capable of feeding themselves with standard spoons; they often have problems orienting the spoon into the correct position to pick up food. This leads to frustration on the part of the student and forces the teachers to intervene by handing the spoon to the student in the correct orientation.

STATEMENT of the PROBLEM

Persons lacking the cognitive skills to recognize the correct orientation of an eating utensil face several difficulties when eating. A very important problem is created when the spoon is picked up in an incorrect orientation because the user in unable to effectively scoop food from the plate. An assistive utensil is needed that correctly orients itself either before it is picked up or immediately after it is picked up. The spoon should then lock into position to allow the user to scoop and tilt the spoon when eating. To increase the independence of the user, the device should not use straps or restraints that would require an attendant.

The device should be adaptable to all grip types and work equally well with left or right handed individuals. The final product should cost less than $20 and must be capable of being reproduced in a small woodshop using minimal number of tools. Finally, the device should also be easy to clean: either by hand or in a dishwasher and be constructed with FDA approved materials.

RATIONALE

When learning to eat with a common kitchen utensil several progressive steps must be taught to the students. One major step involves moving the food from the plate to the mouth and can be taught to most students. However, the step of recognizing the orientation of the spoon and correcting that orientation is a task that is very difficult for cognitively impaired students. If this step can be done by the spoon rather than the user it would be possible for more students to master the skills required to eat with utensils.

DESIGN

A customer-needs approach was followed throughout the design of the 'smart spoon' assistive utensil. The methodology detailed by Ulrich and Eppinger[1] was used by the design group to design, develop, and prototype the 'smart spoon' assistive utensil.

Needs of the customer in terms of function, performance, and cost dictate the design of any product and were therefore gathered very early in the design process. These needs were established through repeated interviews with teachers & staff at the Rosedale School and observations of the students eating. The top five needs for this assistive utensil that drove the project were:

1. Operable regardless of user skill level.
2. Provides correct orientation and locks.
3. Works with all kinds of grips.
4. No sharp edges.
5. Easy to make.

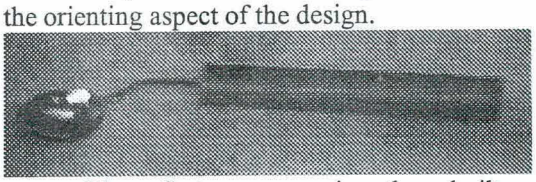
The established customer needs were then translated into engineering specifications using the Quality Function Deployment (QFD) approach[2]. Each specification was matched to a definite metric that could be measured by the design team. The driving technical issues for the project revolved around designing a spoon that would orient when the user needed it orient and then lock into position once the correct orientation was achieved. To satisfy these opposing functions it was necessary to create a 'smart' spoon that would function without input from the user.

With a defined set of approved customer needs in hand the design team started concept development. Three unique concepts were chosen for further development and proof of concept prototypes were created for testing with students at the Rosedale School.

DEVELOPMENT

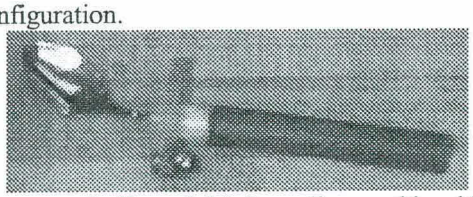
The most important finding from the first concept trials was the need to accommodate a large variety of users each with different needs and abilities. To accomplish this task, a modular approach was adopted for the alpha prototype phase of the design. This modularity adds two very important aspects to the design. First, the spoon can be easily changed to fit any student's hand and adjust to any grip. All parts are interchangeable between each configuration allowing easy customization for specific user abilities. The second and most important advantage of modularity is that the spoon can now grow with the student and adjust to varying skill levels.

The final design of the smart spoon must be capable of handling many different shapes and sizes of spoons. Often times, the spoon handle is bent to compensate for wrist movements by the students. Compensating for this bent spoon was the driving factor behind the orienting aspect of the design.

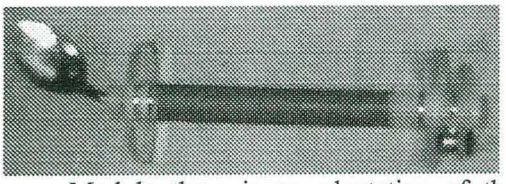


The first spoon is the built-up configuration designed to help the skilled or training student grip the spoon better.

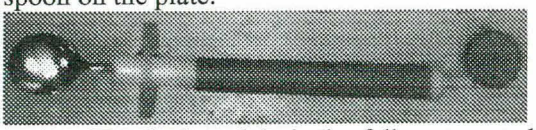
The second module is the pre-position configuration.



An eccentrically weighted acrylic guard is added to the built-up module to create a spoon that will orient itself when placed on the table. The weight in the guard provides a rotational bias that rolls the device into the correct position.



Module three is an adaptation of the pre-position configuration. Two rotating brackets are placed onto the spoon to allow it to orient without requiring the entire module to roll on the table. This is designed for students who eat on a surface where the spoon could not roll such as a towel or when the user drops the spoon on the plate.



The final module is the fully automated locking configuration. The spoon is allowed to rotate until the student picks the module off the table. This spoon uses two concentric tubes to provide for relative rotation. When the spoon is on the table, the inner cylinder holding the spoon can spin and will orient the spoon into the correct position. When the spoon is picked off the table the we the weight hanging off the end of the spoon compresses a spring and engages a locking mechanism and holds the spoon in the correct orientation. The locking mechanism utilizes a rigid lock consisting of two halves that mesh when pressed together. A modified tee-nut and lock-washer was used for the rigid locking with a small compression spring between them to unlock the cylinders when the spoon is set down.

EVALUATION

The smart spoon design successfully allows students with cognitive disabilities to eat without the presence of an assistant. All critical customer requirements can be met by employing one of the modules to meet the student's specific needs. The total cost of all four modules combined is under $11 and 'off-the-shelf' components are used for easy construction. This will allow the students to keep the spoon when they leave Rosedale and use it outside a school environment.

Plastic components make the design safe and easily cleaned while maintaining durability and aesthetics.

DISCUSSION

The smart spoon design successfully achieves the goals of this project. The modularity of the design allows for individual preferences and abilities to be addressed and provides a personalized spoon created to meet the needs of the user. User independence and inclusion are increased by eliminating the constant teacher/assistant intervention required when eating.

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APPLICATIONS OF ASSISTIVE TECHNOLOGY : INDIVIDUALS WITH SEVERE AND PERSISTENT MENTAL ILLNESS

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ABSTRACT

Evaluating functional limitations and other information received from a generic questionnaire from state mental health centers, assistive technology products were developed and determined for use in the severe and persistent mental illness population to increase independence.

BACKGROUND

There is no research in psycho-social rehabilitation literature that examines uses of assistive technology in compensating employment and independent living barriers experienced by individuals with severe and persistent psychiatric disabilities. As a result, functional limitations associated with employment and independent living barriers were examined to determine what adaptive technology could be used to address these limitations.

METHOD/APPROACH

Information was requested from state-wide (South Dakota) mental health centers asking case managers and directors to determine what functional limitations were most prevalent in their caseloads involving individuals with severe and persistent mental illness. Functional limitations were operationally defined as to what limits or prevents psychiatric impaired disabled individuals from obtaining or maintaining employment and independent living opportunities. A questionnaire was developed and sent out to the Mental Health Centers and district rehabilitation offices throughout South Dakota, asking counselors and directors to identify noted functional limitations. After receiving back the generic questionnaire the results were tabulated to determine 35 functional limitations that were most commonly seen as deterrents for individuals with severe and persistent mental illness.

The 35 functional limitations were addressed then through a Likard Scale (1 being never occurring to 5 occurring frequently) indicating how often these limitations were noted and how they should be considered when developing adaptive equipment for the each referred individual. The referral form also asked the referring party to directly state what the client needed to be able to maintain or obtain successful vocational and or independent living placement.

RESULTS

Commercially developed as well as newly engineered products were referred to an original case load of twenty-five. The mean age of this group was 43, consisting of 12 females and 13 males. Each member of the caseload had a clinical DSM-IV diagnosis of schizophrenia.

The following adaptive devices were determined to work effectively for each addressed functional limitation. The Timex(R) Data Link watch system helped decrease the amount of disorganization in daily/weekly schedules. The need for constant staff reminders of tasks that were needed to be completed decreased

considerably. The watch system also helped those with impaired short-term memory, difficulty in sequencing tasks of daily living, difficulty in adjusting to changing work schedule, and difficulty in management of time.

Intel(R) Proshare Video Teleconferencing System offered case management a way to view social appearance and manage and monitor medications, increasing efficiency in accomplishing these tasks. This technology also improved access for the client to helping staff. Other benefits of using the system was a way to decrease inadequate demanding of attention, lack of motivation, poor grooming, withdrawal and isolation, and viewing of general housekeeping skills.

CompuMed(R) Medication Device developed to help decrease the medication overdose and help with compliance was found to help those with impaired short-term memory, time lapsing, distractions caused by hallucinations, disorganization of daily and weekly schedules, anxiety, poor treatment compliance, substance abuse, and those who have difficulty in managing and monitoring their own medication.

Pill/Appointment Reminders increased portability and independence for those clients that were active in community involvement as well as in their vocational areas. Other limitations that seemed to be lessened after implementation included: impaired short-term memory, time lapsing distractions caused by hallucinations, disorganization of daily and weekly schedules, anxiety, poor treatment compliance, substance abuse, and difficulty managing and monitoring medication

Stove/shut off timer designed by the author adapted a household stove. The adaptation allowed a timer to be set for a certain time limit. When the timer reached zero the stove would turn off automatically. This adaptation proved beneficial to those with impaired short-term memory, time lapsing, distractions caused by hallucinations, anxiety, carelessness caused by hallucinations, and confusion

Push-button Locks adapted door knobs and entry ways to be entered without a key. The client had to be competent enough to remember a sequence of numbers. The limitations that were addressed included carelessness (misplacing keys), impaired memory, disorganization, difficulty in daily living tasking, confusion, anxiety. Implementation of this device also helped in decreasing staff time required to open doors with center keys.

"Voice-over" Taping involved voice recording reminders being recorded over individuals favorite work audio cassette. This adaptations helped with distractions caused by hallucinations, difficulty in reality basing, lack of motivation, paranoia, confusion, anxiety, agitation
preoccupation, inadequate demanding of attention, dependence and decreased some delusionial ideas.

FM Systems were also used to help with distractions caused by hallucinations, difficulty in reality basing, confusion, anxiety, and a demand of attention. It also decreased some client agitation and distractibility. An FM system was particularly useful for clients attending college lecture based classes.

Cost for determined devices ranged from $10.00 to $4500.

DISCUSSION

There exists a need to examine what adaptive technology can be integrated into independent living environments and vocational settings. Eight suggestions of assistive technology for individuals with severe and persistent psychiatric disabilities, acknowledging a multiple of addressed functional limitations, are provided

and have been implemented for use in both vocational and independent living situations.

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MODEL PATIENT: AUGMENTED SELF-ADVOCACY FOR INDIVIDUALS WITH SEVERE DISABILITIES

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ABSTRACT

De-institutionalization of persons with severe or profound mental retardation is underway nationwide. Even with assistive technology, few of these individuals can communicate effectively about their care needs.

This paper describes a technique to augment medical and personal care record keeping. The goals are rapid access to useful information, and provision of some of the monitoring that is lost when persons with severe special needs move out of centralized facilities, in order to enhance the well-being of this vulnerable population in the community.

BACKGROUND

Many people with severe and profound mental retardation are being moved out of centralized facilities. Some states have already experienced court-ordered phasing out of large institutions, while in other states this process is now going on or will in the near future. Most, of these individuals are affected by factors in addition to retardation which impair their ability to function, and necessitate a high level of supportive living services and medical care. These include limitations on mobility, severe orthopaedic anomalies, swallowing problems which may necessitate tube feeding, and visual and auditory limitations including blindness and deafness. Most of these individuals have chronic medical problems, someof which are associated with the genetic condition underlying the retardation. Challenging behavior, which can include life-threatening extremes of self-injury and pica (ingestion of non-edible objects), further complicates care for a number of these individuals.

STATEMENT OF THE PROBLEM

Personal and medical care charts are an especially important information source for providers who are unfamiliar with the individual. The importance of these documents is all the greater in the presence of severe communicative limitations. While some individuals can clearly indicate their preferences, and even produce reliable "yes" and "no" signals, many cannot. Unlike most consumers of medical care, they cannot clearly indicate "where it hurts", let alone how long they have felt a symptom.

Medical records of persons with multiple, severe disabilities are typically lengthy. The bigger the chart, the less likely it is that the provider will be able to extract the most relevant information in a clinically practical period of time. Some information may be handwritten and difficult to decipher. Typed text entails time-lags before the latest information becomes available in the chart. One consequence of this is that providers may be unaware of relevant events or reports.

Medical charts for individuals with severe disabilities at one institution include over 40 major sections. Often it is necessary to review many sections of a chart in order to extract necessary information. Provision of augmentative communication services offers one example. While it might be expected that the background information needed for augmentative communication could be found in the speech-language pathology reports, it is often the case that a comprehensive review of the chart is needed in order to obtain clear and

current information on domains such as vision, motor capabilities (range and capabilities of potential control acts, adventitious movements, spasticity), posture and positioning, periods of alertness, sleep problems, nutritional restrictions (relevant to selecting reinforcers), other preferences and activities (in order to identify motivating), and school or vocational programs.

Medical charts often include concise summary sheets indicating diagnoses and active medical problems. This information is schematic and limited, in order to keep it salient and rapidly accessible. Use of inert written documentation generally requires a trade-off of that nature.

Written records rarely convey a picture of the disabled individual's usual manner. Evaluations for speech-language pathology, social work and psychology deal with specific aspects of behavior, rather than aiming to evoke a vivid picture of the individual's overall social and behavioral style. Acute care providers who are unfamiliar with the individual may find it difficult to determine whether or in what ways the individual's presenting behavior and appearance is unusual. This could have serious consequence; e.g., misjudgment of a tuned-out state because it is assumed to be the individual's usual demeanor.

The inherent inadequacy of text to convey dynamic information (e.g., intentional and unintentional communicative behavior, positioning and dining practices) is also a barrier to obtaining usable information.

The emphasis of the discussion above has been on provision of medical care and other professional services. Daily supportive living services are also important to health and quality of life. Here also the severely disabled individual's communicative deficits take a toll. Job-turnover among supportive living assistants is high, and there is frequently a need for substitute workers in case of illness or changes in staffing needs. The result is that often individuals with severe communicative deficits are dependent on care providers who are unfamiliar with their preferences, and do not know how to interpret their behavior.

APPROACH

The name adopted for the interactive database being developed to respond to these needs is Model Patient. This term is intended to convey two key aspects of the approach. One is to serve as a working model of the individual, in the sense that it represents information needed by care-providers. The second is that the database will contribute to individuals' and their advocates' efforts to be effective, 'model' consumers of services by providing augmented self-advocacy. The system inclues

- video-clip introduction, to convey usual communicative techniques and manner of interacting. For the unfamiliar care provider, this can provide a quick introduction to how the individual usually communicates, and a reference for comparison to current behavior;
- touch-screen menu-driven access to information domains (e.g., positioning, nutrition, preferences, body systems);
- menu view options (e.g., date, alphabetic);
- several display options (video, sound, text);
- prompts for data-entry;
- links to tutorial information, (e.g., on relevant assistive technology);
- automatic logging of data on system use;
- computer logging and automatic techniques including bar-code data entry, use of hand-held computers, and communication between devices to log presence, use and functionality of equipment (in order to reduce loss, theft, breakage, non-use and down time), and maintenance of prescribed medication dose and schedule;[1]
- links to family, friends and advocates; [1]

[1] Features planned for a later version of Model Patient

- computer logging of presence of support personnel and therapists, including period of time spent (in order to reduce fraud);[1]
- prompts to view relevant material (e.g., for skin breakdown, to view changes in positioning, equipment, daily schedule);[1]
- automatic relating of new to existing data;[1]
- network capabilities to link residence with information sources and institutions..[1]

IMPLICATIONS

The success of Model Patient will depend on its use by individuals with a variety of backgrounds, including people who are technophobic and fearful of appearing unintelligent. A crucial design specification of Model Patient is ease of use, including minimal learning demand, i.e., the system needs to be self-teaching and immediately usable.

Security is always a concern when medical records are discussed. Information will be secured by restricting access to persons with passwords and time-limited smart-cards.

A recent study reports an alarming increase in mortality rate among de-institutionalized individuals: risk-adjusted odds of death (based on comparison between populations of equivalent severity and medical fragility) increased by 72% for persons moved out of centralized institutions.(1) The study points to the loss of the training, quality assurance and record-keeping that institutions provide to their residents as 3 of the 4 main factors that appear to be involved in this increase.

Model Patient is intended to function as a 'virtual' institution. If the goals of Model Patient are accomplished, computer-aided quality assurance and record-keeping, and training available on an as-needed basis will compensate for the absence of institutional facilities.

DISCUSSION

With the aid of state-of-the art computerized management of information and networking, it should be possible to afford individuals with severe disabilities the broader opportunities associated with living in the community, without increasing risks to health.

Model Patient is being implemented with data for three individuals with severe disabilities who are still residing in an institution and are slated to move to the community within the next year. These individuals will be followed for three months prior to and three months after their move, in order to pilot test the Model Patient concept and guide changes in its design.

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DESIGN OF THE BOWLING EMPOWERMENT TOOL

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ABSTRACT

Leisure and recreational activities are very important, but are regretfully overlooked for people with disabilities. Rosedale School tries to create independence and inclusion for their students in all facets of life, including recreation. One sport Rosedale organizes is bowling. Although there exists an accelerator ramp to aid people with disabilities in bowling, this ramp requires the user to have controlled movements of their arms. A majority of the students at Rosedale are left out of the bowling activities because they did not posses this ability. But most of those students do have the ability to push a switch with their hands, arms, or head, and most of all, they have the desire to participate. Our team took the step in meeting that desire with the design and development of the Bowling Empowerment Tool.

BACKGROUND

Assistive technology is a bridge to independence and inclusion for people with disabilities. Assistive tools free individuals with disabilities from the need for human assistance to perform everyday tasks, and enable them to participate in social activities. Although people with disabilities have many assistive functional devices, such as motorized wheelchairs, they do not have many tools to enable them to participate in fun activities. People with disabilities would need to sacrifice independence for human assistance to participate in social activities, or, worse yet, not be included.

Rosedale School is a part of the Austin Independent School District devoted to teaching people with disabilities independence and inclusion through skills training and integration with the non-disabled community. One medium Rosedale uses for their students is recreation. Rosedale organizes bowling outings, horseback riding sessions, and participates in the Special Olympics.

One of the most popular recreational activities is bowling. Bowling helps train the students' physical skills as well as social skills. The students who have difficulties swinging the bowling ball can use a ramp provided at most bowling alleys to propel the ball as shown in Figure 1. But with Rosedale's efforts to include their students in fun training activities, the lack of assistive recreational tools prevents many students from participating. Those who are unable to bowl or push the ball down the ramp cannot participate in bowling.

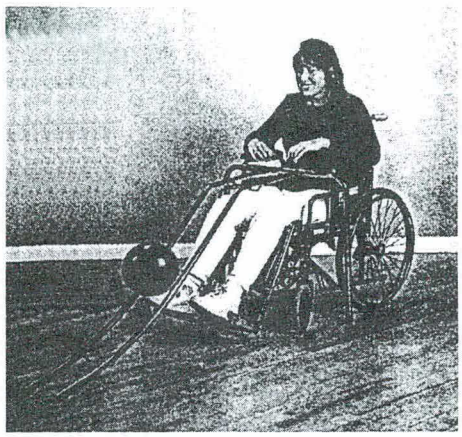

Figure 1. Accelerator ramp for bowling.

Currently, the students who are unable to push the ball down the ramp do not voluntarily participate. Although many of the students have the cognitive ability to bowl, their physical disabilities prevent them from bowling. In efforts to include them, the staff place the student's hands on the ball and help push the ball. Although this method involves the students in the activity, the students can not learn cause and effect relationships and do not get the choice of participating.

STATEMENT of the PROBLEM

Rosedale has asked us to design a device to enable more students to participate in bowling. The team decided to design and build a device to be installed onto the different ramps provided at the bowling alleys and at Rosedale School. Furthermore, since many of the students have been trained to push a special button and have already associated cause and effect relationships with the it. Rosedale asked us to incorporate the button in our design.

DESIGN

The team adapted a design methodology taught by Dr. Kristin Wood's Product Design, Development, and Prototyping graduate course, and described by Ulrich and Eppinger. Structured methodologies make the design process explicit, serve as "checklists" for design, and are self-documenting for future reference and communication of the design process. The methodology can be broken down into three phases: customer needs analysis, conceptual design, and embodiment design.

The team feels the most important part of designing a product is determining the customer needs. A total of eleven people were interviewed, ranging from students to teachers to recreational therapists. The team also observed several bowling session to fully understand the customer needs. The needs were then organized in a Quality Function Deployment Matrix (QFD). The QFD assigns a measurement of the importance of each customer need and correlates engineering specifications to the needs in order to quatitatively assess a design in terms of customer needs.

Conceptual design begins with the customer needs, then defines the functions of the device. Designing from a "function-first" perspective enabled the team to conceive solutions that focused on the customer needs. The team formed a function structure that delineated the functions of the device and described the flows through each of them. The team also defined an activity diagram to understand how the device would be used and to help interpret the solutions of the functions.

The conceptual design is carried to an optimized manufacturable design through embodiment design. The team performed analysis on different elements of the design to find optimal values for the design. Some of them, such as the geometry of the moving parts, could be constrained, and less critical values, such as the geometry of the housing, could be designed around them. The team relied heavily on prototypes to develop the design. Prototypes, ranging from crude working models to fully manufactured prototypes, helped the team visualize the interaction of the components in the design and the internal spaces. The final prototypes corresponded to the final design, which implies that constant improvement can be made to the design.

DESIGN DESCRIPTION

The design relies on a rotating device to propel the bowling ball. The rotary motion was selected because of its ability to leave the ramp unobstructed after device use for the next bowler. A weight attached to an arm and reloaded manually provides the energy for acceleration. A manual reload was selected to reduce power requirements for the device. A low power electromechanical system triggers the device using the special button provided by Rosedale school. A schematic of the mechanics of the device is shown in figure 2.

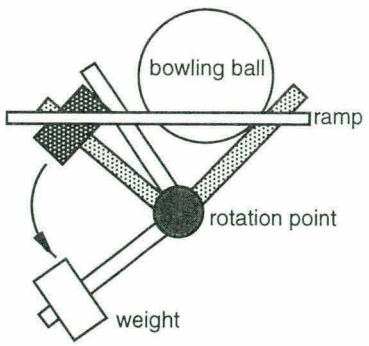

Figure 2. Design schematic.

All motions below the ramp are fully enclosed by two folding panels during use for safety. The rotary motion can be locked and the panels can be folded in for safe and compact transportation.

EVALUATION

To evaluate the design, the team revisited the QFD to determine how well the device met the customer needs.

The device can be installed onto all ramps in two steps. The user does not need tools to install the device. The device weighs 4.5 kilograms and has a collapsed volume of 0.03 cubic meters. It can easily be carried by the staff at Rosedale and some of the students.

The staff could not foresee any safety hazards with the device. All moving parts are enclosed and there are no spaces where a person can get entangled.

The maximum reloading force exerted by the user is six pounds which was deemed neither exerting nor tiring by the staff.

We also succeeded in meeting our customer's budget needs by developing a prototype which cost under $60 in materials.

DISCUSSION

The Bowling Empowerment Tool met or exceeded the ideal values for engineering requirements in the QFD. This implies that the device met every customer need defined in the first stage of the design process. But the true test of our design success was in the hands of the Rosedale students.

"We are really going to use this!", said Rosedale's recreation therapist. The students where almost more delighted in using the device than bowling without it. It let them have control over their participation through the special button that they are already familiar with. Hopefully the impact of our device will extend beyond the bowling alley and manifest itself in the independence and inclusion for the students at Rosedale School.

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DEVELOPMENT OF PROTOTYPE TOOLS FOR MEASURING SURFACE STABILITY

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ABSTRACT

This is part of ongoing work to design a portable device and test procedures to quantify the accessibility of a range of indoor and outdoor surfaces. This is to facilitate the development of specific accessibility guidelines. Four prototype devices for measuring the stability of surfaces were developed. Each was evaluated on ten test surfaces ranging from accessible carpeting to sand. The devices are in need of further refinement and validation with wheelchair work measurements.

BACKGROUND

There are a variety of characteristics that affect the accessibility of ground surfaces. The Americans with Disabilities Act Accessibility Guidelines (ADAAG) require that ground and floor surfaces be stable, firm, and slip-resistant, but they do not include a definition for stability. Devices and methods to measure slip resistance exist, and systems for studying surface firmness are a topic of previous work [1]. There is a class of commercial portable devices for performing the ASTM Vane Shear Test [2] for in situ evaluation of soil shear strength. However, this test is specific to soils and not useful for assessing other indoor and outdoor surfaces, such as pea gravel, bark chips, and carpeting.

STATEMENT OF THE PROBLEM

There is currently no system for objective field measurement of surface stability other than that applicable to soils. This leaves a need for a device to measure surface stability. It should be portable, easy to use, cost effective, and sensitive to a range of surfaces. Further, it must show good repeatability across users and surfaces and exhibit high correlation of its measurements with the amount of work involved in rolling or turning a wheelchair across the surface.

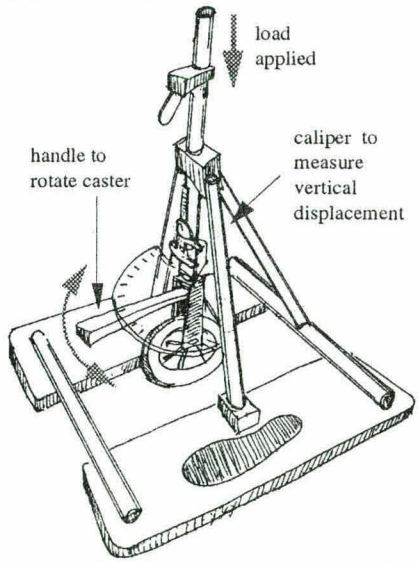
RATIONALE

The need for measuring surface accessibility is clear. Surface stability (and correlated accessibility) is valuable information for anyone using, designing or specifying surfaces for human traffic. It is also useful to people developing standards and assessment procedures for surface accessibility. The capability to collect surface stability data quickly, easily, and economically justifies developing a measurement device.

DESIGN

Several prototype devices were developed to determine surface stability by measuring lateral shear resistance. The designs fell into two classes: those that strike or penetrate the surface at some angle away from the vertical and those that are placed against the surface and rotated. The three most promising designs are presented.

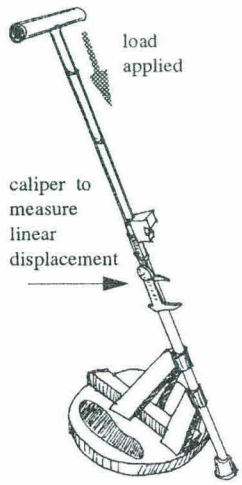
Rotational Penetrometer



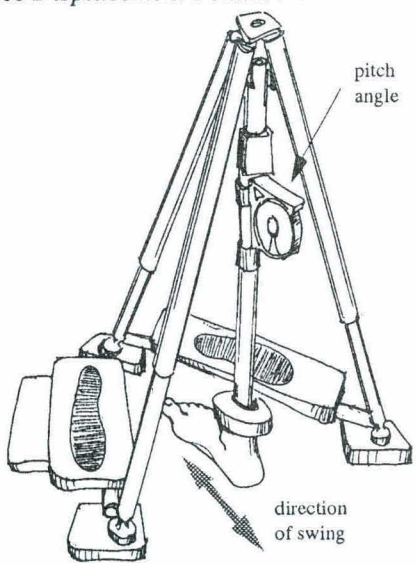
Two concentric tubes are mounted vertically to a rigid foot plate. The outer tube is fixed in place. It contains a spring scale that applies a downward force of 0 - 60 pounds to the inner tube with locking detents at 5 pound increments. A wheelchair caster is secured to the bottom of the inner tube. This tube is free to move up and down and rotate about its long axis.

Angled Penetrometer

This is a modified form of an earlier device used for measuring surface firmness [3]. Similar to the Rotational Penetrometer above, two concentric tubes are mounted to a rigid foot plate, but at 60° from horizontal and with a spring scale calibrated from 0 - 100 pounds. The bottom end of the inner tube is fitted with a sector cut from a wheelchair caster or a rubber crutch tip.



Surface Displacement Pendulum



This is constructed of a weighted prosthetic foot at the terminus of a telescoping pendulum. The pendulum is hinged from the apex of a tripod which is secured to two foot plates.

EVALUATION

For each device, the test surface was prepared before each trial by raking and reproducible tamping. Each trial was repeated with a fresh section of the surface for a total of ten trials per device per surface. An assistant stood on the devices' foot plates and maintained consistent posture. The following surface types were used:

ACAR	accessible carpet <.5" level pile no pad
BCHP	generic bark chips
CCHP	generic cedar chips
EWFA	engineered wood fiber A
EWFB	engineered wood fiber B
ICAR	inaccessible carpet, > .5" with pad
PGVL	3/8" pea gravel
RUBR	rubber mat
SAND	sand
TIRE	shredded tire

Rotational Penetrometer Test Protocol

The device is positioned on the test surface while keeping the caster from making contact. The caster is turned to the 0° position and gently lowered onto the surface. The caliper reading is recorded to the nearest 0.005". The device is pre-loaded to 45 pounds and the caliper is read again. The caster is rotated 45° in 3 seconds at a constant rate. The caliper is read a second time, an identical rotation is performed, and a final caliper reading is taken.

Angled Penetrometer Test Protocol

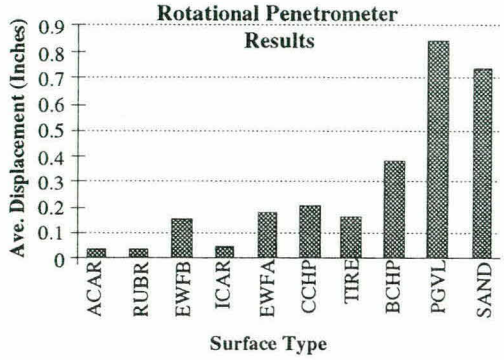
The device is positioned on the test surface. The initial caliper reading is made. The device is loaded to 60 pounds. The load is released and the new reading on the caliper is recorded.

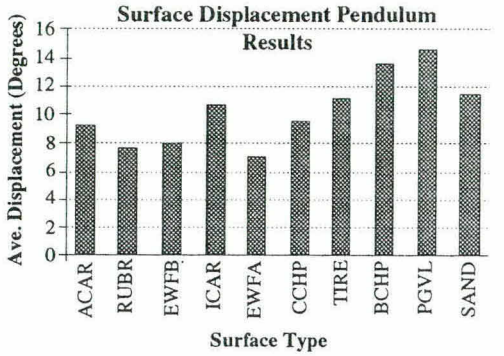
Surface Displacement Pendulum Test Protocol

The device is placed on the test surface. The initial resting angle of the pendulum is recorded. The pendulum is raised to 90° and released. The angular displacement between the initial point of contact with the surface and final resting point is calculated.

Results

Numerical findings for the Angled Penetrometer are not included here due to the superiority of the other two devices. The surface types below are ordered based on previously measured work required to propel a wheelchair across each surface





DISCUSSION

Advantages and disadvantages were found with each design regarding portability, cost, ease of use, sensitivity and repeatability. Overall, it was clear that these are early prototypes in need of refinement. Given a combination of two devices, it was possible to consistently differentiate surfaces. Yet, one of the goals of this project is to develop a standard measurement method, so a single device solution is most desirable.

Rotational Penetrometer

This design requires further study to determine the optimum speed of rotation and the number and range of rotations.

Angled Penetrometer

This device showed some promise, yet its results were unsatisfactory. There are several design issues to be optimized including the angle of approach, the shape of the penetrating tip, and the applied force. The physical stability of the device needs improvement and internal friction between the inner and outer tubes needs to be reduced.

Surface Displacement Pendulum

The size and weight of this device need to be reduced for portability. Also, using a pendulum presents problems with performing measurements on slopes. Further, the appropriate shape for the end of the pendulum needs to be determined.

Validation

As these prototypes approach their final design, a Quickie2 wheelchair with a SMART^{wheel} [4] instrumented pushrim will be used to measure the work required to navigate through a length of each of the test surfaces. This test method has been accepted as an ASTM provisional standard. We will examine how well our stability data correlate with these wheelchair work measurements.

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Universal Design: Development of an Accessible WWW Browser

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ABSTRACT

One of the main areas to improve the accessibility of the World Wide Web (WWW) is to include Universal Design principles in the design of WWW browsers. Current WWW browsers have very few features that can be used by persons with disabilities to navigate and view the content of WWW information. This paper describes an Accessible WWW Browser that implements universal design features that could be incorporated into commercial WWW browsers like Microsoft Explorer and Netscape Navigator.

BACKGROUND

The information revolution occurring in our society is creating new barriers for persons with disabilities and new Universal Design principles need to be identified to guide the development of commercial information technologies (1,2). Just like the curb cuts and ramps in sidewalks provide physical access to the spaces of streets and buildings, we need electronic curb cuts to access the information space of the WWW (3). While there are built-in accessibility features in most popular operating systems (4,5) they do not necessarily provide efficient access to software programs. Take for example WWW browser technology. Most popular browsers require the use of the mouse to select anchors (Microsoft Explorer 3.0 recently added keyboard selection alternatives). The mouse pointing operation can be very time consuming for some one using mousekeys or a voice input technology like Dragon Dictate to select anchors using mouse emulation commands. The selection problem is even worse for people with visual impairments who are trying to point to tragets they cannot cannot even see. Recent research demonstrates that the WWW has significant barriers to persons with visual impairments (6).

STATEMENT OF THE PROBLEM

There are many concerns over the accessibility of the WWW (3) and the need to include universal design principles in the design of the WWW technologies. One of the areas of major concern is the ability of WWW browsers to provide efficient access to WWW documents through both cooperation with 3rd party assistive technologies and through built-in universal design accessibility features. This paper discusses the development of an Accessible WWW Browser at UIUC to provide improved access to the WWW for persons with disabilities, and to be a tool to study and develop universal design principles for WWW browsers.

RATIONALE

The Accessible WWW Browser is based in part on the principles in the Microsoft Windows guidelines for accessible software design (7) and the concepts of seamless access (8). Additional features were identified through a task analysis of the types of typical WWW activities people perform and to take advantage of the inherit hierarchical structural of HTML documents.

DESIGN

To improve the usability of browsers for people with movement and visual impairments additional keyboard, menu and toolbar commands are needed to access and navigate HTML documents; and additional document views are needed to summarize document information. The following is a summary of the accessibility features that are part of the accessible browser.

Summary of Accessibility Features

- User focus indicator to third party assistive technology on what the user is viewing
- Color contrast control over HTML, Toolbar, Menu and Dialog Areas

- Font type and Size control over HTML, Toolbar, Menu and Dialog Areas
- Navigation controls to move between HTML tags
- Accessibility Adjustment Dialog Box
- Visibility of Universal Design Features

User focus Indicator

Third party assistive technology (especially screen enhancement programs and screen readers for people with visual impairments) tries to track the current focus of an application. Since WWW browsers basically display static HTML documents there is no focus indicator for 3rd party assistive technology to track. For example the insert caret for in a wordprocessor indicates where text will be inserted into a document. Screen enhancement software and screen readers typically track the insert caret and enlarge or speak the text around the caret. A new feature to assist in the navigation of HTML documents is the inclusion of a focus caret indicating to 3rd party assistive technologies a virtual "user" focus to information in the document the user is viewing. The caret would move between anchors and other HTML structures using keyboard, menu and tool bar commands issude by the user.

Navigation Commands

Navigation commands provide access to the structural units within the HTML mark up language. The commands allow the user to know the types of information that is brought into their view. Commands to move between HTML headers, form elements, table cells and other HTML types allow people with visual and movement disabilities to move directly to the next item of interest in the document, without the user having to coordinate the actions of the scroll bar and the visual representation of the HTML type they are looking for on the screen. This is especially difficult for persons with visual impairments since the only way currently to identify the structural elements of HTML is usually by font differences. Since people with visual impairments have difficulty or cannot seeing the screen they cannot easily identify the structural units of a document and waste time browsing unnecessarily information or miss important information by skipping over it. The inclusion of navigation commands will allow people to use the keyboard, toolbar or menu to navigate the structure of an HTML document.

Display Colors, Size and Contrast

The ability to change the color, shape and size of the information on the screen is important for people with visual impairments. The browser needs to have options to provide high contrast between the background and the foreground colors used to display HTML text. While changing the foreground and background colors is possible with many currently available browsers, it requires the user to manually change each font individually associated with the different types of HTML text markers. While the HTML text display area can typically be made to have high contrast colors, other parts of the display currently cannot be adjusted to provide high contrast with out 3rd part assistive technology (which may not be available in public access sites). The lack of adjustability includes toolbar, menus and dialog boxes. New attributes like BACKGROUND can defea some high contrast techniques.

High contrast can be provided with a preference option of white (or color) on a black background for the display of text and toolbar buttons. Other options include the ability to globally increase or decrease the size of the smallest font displayed on the computer screen and the to ability to vary the size of toolbar buttons will improve the usability for people with visual impairments that require enlargement.

Visibility of Universal Design Features

Adding accessibility features will not benefit persons with disabilities unless users know the features are available. As accessibility features are added there needs to be documentation of the features in training materials and the help files that are part of browsers. Visibility of the accessibility features will be increased by having an accessibility dialog box and menu equivalents of keyboard functions. The accessibility dialog box is a place where all of the accessibility options and some standard configurations can all be displayed at one time for the user to adjust. The standard setup

options for different types of disabilities would allow for gross adjustment to a disability, while allowing people to fine tune the options to their own unique needs with advanced controls. By giving keyboard navigation commands menu equivalents, users can easily find and learn how to use the functions.

DEVELOPMENT

The Accessible Browser is being developed using Microsoft Visual Basic 4.0 and Visual C++ 4.0. The Visual Basic is being used to build the user interface and the C++ is being used to develop an OLE control for parsing and displaying HTML documents.

EVALUATION

The browser is currently under evaluation at the University of Illinois at Urbana/Champaign (UIUC) with students, faculty and staff with disabilities. UIUC has over 300 students that have identified themselves with a disability and receive services from the Division of Rehabilitation - Education Services.

DISCUSSION

The Accessible WWW browser demonstrates in a powerful way how universal design principles can be incorporated in to WWW browser technology. The goal of this project is to both improve current WWW accessibility and to demonstrate to commercial developers of WWW browsers and plug-in viewers how to improve accessibility through universal design. The Accessible WWW Browser cannot keep pace with the features of commercial WWW browsers like Netscape Navigator or Microsoft Explorer, but it can serve as both a tool to persons with disabilities and a model to demonstrate ideas to commercial developers on concrete ways to make their browsers more accessible.

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GUIDELINES FOR THE DESIGN OF TELECOMMUNICATIONS PRODUCTS TO MAKE THEM MORE ACCESSIBLE AND COMPATIBLE FOR PEOPLE WITH DISABILITIES

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ABSTRACT

The Telecommunications Act of 1996 requires that customer premise equipment and other telecommunication equipment be accessible to people with disabilities where readily achievable. When not readily achievable, equipment must be compatible with assistive technologies where readily achievable. The Access Board was charged with developing design guidelines. They in turn convened the Telecommunications Access Advisory Committee (TAAC), consisting of members from industry, research, and consumer groups. In January 1997, the committee turned in its report. This paper summarizes the results of that report along with the rationale for it.

THE CHARGE TO THE TAAC

Excerpts from Section 255 of the Telecommunications Act read as follows:

"3. MANUFACTURING -- A manufacturer of telecommunications equipment or customer premises equipment shall ensure that the equipment is designed, developed, and fabricated to be accessible to and usable by individuals with disabilities, if readily achievable.

"4. TELECOMMUNICATIONS SERVICES -- A provider of telecommunications service shall ensure that the service is accessible to and usable by individuals with disabilities, if readily achievable.

"5. COMPATIBILITY -- Whenever the requirements of subsections (b) and (c) are not readily achievable, such a manufacturer or provider shall ensure that the equipment or service is compatible with existing peripheral devices or specialized customer premises equipment commonly used by individuals with disabilities to achieve access, if readily achievable.

"6. GUIDELINES -- Within 18 months after the date of enactment of the Telecommunications Act of 1996, the Architectural and Transportation Barriers Compliance Board shall develop guidelines for accessibility of telecommunications equipment and customer premises equipment in conjunction with the Commission. The Board shall review and update the guidelines periodically.

In order to assist in the development of the guidelines called for in the legislation, the Access Board (formallly known as the Architectural and Transportation Barriers Compliance Board) established a Telecommunications Access Advisory Committee (TAAC). This committee consisted of 36 members approximately evenly split between industry and disability fields. The final report of the TAAC covered process, performance, and compliance guidelines. This paper deals only with the performance guidelines. A complete copy of the final report can be found on the Access Board's web site (http://www.access-board.gov) or http://trace.wisc.edu/taac/final.htm.

THE CHALLENGE

From the beginning, the advisory panel was aware that it had a unique and difficult challenge. Although access guidelines had been written in the past, these guidelines had quite different constraints. First, there was not the same history of already existing guidelines to draw on (such as the UFAS when the ADA guidelines were developed). Second, the telecommunication technologies are changing so rapidly that the panel was really writing guidelines for the design of technologies which do not yet exist. Third, there was great concern on the part of industry that the guidelines not be so rigid as to prevent innovation. Fourth, the sheer diversity of the products makes specific guidelines inappropriate. For example, stating that buttons should be a certain size or have a certain feel may make no sense if we are talking about wristwatch-sized phones or pagers. Similarly, requiring a tactile ridge around buttons makes no sense on a touchscreen-based device.

The dilemma was therefore to create guidelines which were general enough to apply to a wide range of as yet undeveloped technologies and to provide industry with the flexibility needed to innovate new interface technologies - while at the same time having guidelines which were specific enough to ensure that the technologies would be accessible.

About the only factor that made this approach possible was the phrase "where readily achievable." Although written into the law to provide

an out for industries when accessibility just wasn't practical, it also made the guidelines somewhat easier to create, since it allowed a guideline to be written even when it was known that there were some particular instances where it was not possible to apply to a particular type of technology.

The resulting guidelines were as follows. In the final document, each of the guidelines is followed by a rationale. In addition, example strategies for achieving each is also provided in an appendix. Due to space constraints, only the basic guidelines are presented here.

IMPORTANT NOTE: Please note that the guidelines shown below are simply the recommendation of the Telecommunications Access Advisory Committee. The actual guidelines are in the process of being written by the Access Board. Following that, they will be forwarded to the Federal Communications Commission.

GUIDELINES

Input, Control and Mechanicals.

I-1. Locate, Identify, and Operate Controls Without Vision. Where readily achievable, product input, control and mechanical functions shall be fully operable via at least one mode whose components are locatable, identifiable, and accurately operable without requiring the user to see.

I-2. Operate with Low Vision without Requiring Audio. Where readily achievable, the product input, control and mechanical functions shall be fully operable via at least one mode which is operable by individuals who have low vision but are not legally blind, which does not rely on audio output.

Note: 20/70 after correction is the beginning of low vision. 20/200 after correction or a field of vision less than 20 degrees after correction is the definition of legal blindness used here.

I-3. Operate without Color Perception or with Color Perception Limitations. Where readily achievable, product input, control, mechanical and display functions shall be fully operable via at least one mode that does not require color perception.

I-4. Locate, Identify, and Operate Controls without Hearing. Where readily achievable, product input, control and mechanical functions shall be fully operable via at least one mode whose components are locatable, identifiable, and accurately operable without requiring the user to hear.

I-5. Low Manipulation Requirement. Where readily achievable, product input, control and mechanical functions shall be fully operable via at least one mode that does not require fine motor control or simultaneous actions.

I-6. Operate with Limited Reach and Strength. Where readily achievable, product input, control and mechanical functions shall be fully operable via at least one mode that is operable with limited reach or strength.

I-7. Non-Time-Dependent Controls. Where readily achievable, product input, control and mechanical functions shall be fully operable via at least one mode that does not require a response within a period of time, or where the response time is adjustable over a wide range.

I-8. Operate Controls without Speech. Where readily achievable, product input and control functions shall be fully operable via at least one mode that does not require speech.

I-9. Language and Cognitive Requirements. Where readily achievable, product input, control and mechanical functions shall be fully operable via at least one mode that minimizes the cognitive, memory and learning skills required of the user to operate the product.

Output, Displays and Feedback.

O-1. Visual Information Available in Auditory Form. Where readily achievable, all information (text, static or dynamic images and labels) which is provided visually shall also be available in auditory form .

O-2. Make Visual Information Accessible by People with Low Vision Without Requiring Audio. Where readily achievable, all information which is provided through a visual display including text and dynamic images, labels or incidental operating cues shall be perceivable via at least one mode by individuals who have low vision but are not blind, without requiring audio presentation.

O-3. Access to Moving Text. Where readily achievable, text which is presented in a moving fashion will also be available via at least one mode in a static presentation mode at the option of the user.

O-4. Visual and / or Tactile Availability of Auditory Information. Where readily achievable, all information which is provided auditorially, including those "incidental operating sounds" and speech, which are important for use of the product, shall be available via at least one mode in appropriate visual form and / or where appropriate in tactile form.

O-5. Make Auditory Information Accessible by People Who Are Hard of Hearing without Requiring Vision. Where readily achievable, all

information which is provided auditorially, including "incidental operating sounds," which is important for use of the product, shall be available via at least one mode in enhanced auditory fashion (for example, increased amplification, or reduction of background noise).

O-6. Prevention of Visually-Induced Seizures. Where readily achievable, visual displays shall be designed so as to avoid high probability of triggering a seizure in an individual with photo-sensitive epilepsy.

O-7. Prevention of Sound-Induced Seizures. Where readily achievable, sound displays will be designed so as to avoid audio behaviors that create a high probability of a seizure in an individual with sound-induced epilepsy.

O-8. Audio Cutoff. Where readily achievable, products which use audio output access modes, shall have a headphone jack or personal listening device (e.g., phone-like handset or earcup) which cuts off speaker when used.

Documentation.

D-1. Ability to Access Product Documentation and Related On-Line Information. Documentation (printed, online or tutorial, including promotional materials) shall be accessible and usable by individuals with all disabilities or alternate formats shall be available.

Compatibility Guidelines.

C-1. External Electronic Access to All Information and Control Mechanisms. Where readily achievable,

1. all information needed for the operation of a product (including output, alerts, labels, online help, and documentation) shallbe available in a standard electronic text format on a cross-industry standard port;
2. all input to and control of a product shall allow for real time operation via electronic text input into a cross-industry standard external port and in cross-industry standard format; and
3. the port used for 1 and 2 shall not require manipulation of a connector by the user.

C-2. Connection Point for External Audio Processing Devices. Where readily achievable, products providing auditory output shall provide the auditory signal via an industry standard connector and signal level.

C-3. Hearing Aid Coupling. Where readily achievable, products providing auditory output via an audio transducer which is normally held up to the ear shall provide a means for effective wireless coupling to hearing aids.

C-4. Non-Interference with Hearing Technologies. Where readily achievable, products shall not cause interference with hearing technologies (including hearing aids, cochlear implants, and assistive listening devices) which are used by a product user or bystanders.

C-5. Prosthetic Compatibility of Controls. Where readily achievable, touchscreen and touch-operated controls shall be able to be activated without requiring body contact or close body proximity.

C-6. Text Telephone Connectability. Where readily achievable, products which provide a function allowing voice communication and which don't themselves provide a text telephone functionality shall provide a standard non-acoustic connection point for text telephones. It shall also be possible for the user to easily turn any acoustic pickup on the product on and off to allow the user who can talk to intermix speech (live microphone) with text telephone use.

C-7. Text Telephone Signal Compatibility. Where readily achievable, products providing voice communication functionality shall be able to support use of all cross-manufacturer non-proprietary standard signals used by telecommunication devices designed for use by or with people who are deaf, hard of hearing or have speech impairments.

CONCLUSION

An important new set of access guidelines is being developed. Although directly targeted to telecommunications products, they have much wider implications as well. One side effect of this process has already been discussions toward the formation of a new society, the Association for Accessibility Engineering Specialists. The guidelines will be continually monitored and revised. Participation by all is important to their evolution.

ACKNOWLEDGEMENT

The guidelines represented in this paper are the result of the deliberations of the Telecommunications Access Advisory Committee (TAAC), whose membership is posted along with the final document at http:// www.access-board.gov.

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A WHEELCHAIR WORK MEASUREMENT METHOD FOR ASSESSING SURFACE STABILITY

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ABSTRACT

Currently, there are no standard test methods that produce objective information about the degree of accessibility of a surface in terms of the stability provided for walking or wheeling. The purpose of this research project was to develop a test method that measured the work required to turn a wheelchair 90 degrees using a SMART^{wheel}. Testing conducted on a wide range of surface types showed that the test method was reliable and sensitive enough to measure slight differences in surfacing materials. Repeatability of the test method was demonstrated through testing conducted with three different test wheelchair riders.

BACKGROUND

The Americans with Disabilities Act Accessibility Guidelines (ADAAG) contain the current standards for buildings and facilities [1]. According to ADAAG, accessible routes must be stable, firm, and slip-resistant. However, ADAAG does not specify how the stability, firmness or slip-resistance of a surface should be measured. There are test methods and devices for measuring slip-resistance, and new ones are under development for assessing surface firmness [2,3]. This research project focused on the need for a surface stability test method. Surface stability can be defined as the degree to which a surface resists sudden changes in position when a force is applied. When the force is removed, a stable surface returns to its original condition.

STATEMENT of the PROBLEM

Currently, there are no test methods that can be used by developers, architects, land managers and others to determine how stable a surface is. In order to provide indoor and outdoor accessible routes, and to disclose information about the degree of accessibility of a particular path, a standardized method for measuring surface stability is needed. Existing stability measurement devices (e.g. shear vane meter) were designed to measure only a specific type of material (e.g. soil), and thus do not produce reliable results on a wide range of surface types including carpet, wood chips and gravel.

RATIONALE

A measurement method is needed to assess the stability of walking and wheeling surfaces and to improve accessibility for people with mobility limitations. The measurement method should subject the surface to forces similar in application and magnitude to those that actually occur as a person traverses the surface. Surface stability tends to affect access for wheelchair users to a greater extent than ambulatory individuals. An unstable surface such as pea gravel significantly increases the effort required to turn a wheelchair. By measuring the work required to maneuver a wheelchair on a given surface, the degree of surface stability can be objectively determined.

DESIGN

Test Equipment and Setup

A 16 in. width rehab wheelchair (Quickie 2 by Sunrise Medical) with pneumatic tires and front casters, 24 in. diameter rear wheels, and 20 in. diameter pushrims was used as the test wheelchair. One SMART^{wheel}, a specially instrumented main wheelchair wheel capable of measuring forces applied to the pushrim [4], was mounted onto the test chair. A 75.5 kg (166 lb.) able-bodied person propelled the chair during testing. The person was seated in the wheel-

chair such that 40 ±2% of the total weight was supported by the front casters and the rear wheels supported the remaining 60 ±2%, when measured in a static position.

A turn guide test fixture with a radius of 31.1 cm (12.25 in.) was used to guide the wheelchair through a turn maneuver. A computer data acquisition system recorded the forces measured by the SMART^{wheel} at a frequency of 50 Hz. Only the forces tangential to the pushrim and parallel to the direction of travel were measured.

Test Procedure

Starting from a stationary position, the person propelled the wheelchair on the test surface around the turn guide using four uniform pushes until the wheelchair was oriented 90 deg. from its starting position. Each trial was completed in 7.0±1.0 sec. Trials were considered acceptable if the wheelchair came to a stop at the end of the turn such that all the energy exerted by the wheelchair rider during the last propulsion stroke was used to turn the wheelchair the specified amount. Loose fill surfacing materials were leveled prior to each trial. Five acceptable trials were conducted on each test surface.

An estimate of the work required to negotiate each test surface was calculated using the pushrim force measurements. Data analysis programs were developed in MatLab (The MathWorks Inc.) to calculate the average torque required to propel across each test surface. An estimate of the total work required was calculated by multiplying the average torque values by the estimated total wheel angle displacement over the length of the test (l), and then dividing by the length of the test to normalize the value to work per meter ($(2\pi/d\pi)$ rad/m x l/l = 3.28 rad). For each test surface, the low and high work per meter values were discarded and the remaining three trials were averaged to determine the average work per meter required to negotiate the surface.

EVALUATION

Thirteen different types of surfaces were measured using the wheelchair work measurement method: accessible carpet (ACAR), inaccessible carpet (ICAR), rubber mats (RUBR), two types of engineered wood fiber (EWFA, EWFB), generic cedar chips (CCHP), bark chips, shredded rubber (TIRE), sand, pea gravel and a wood ramp set at 7.1% (R071), 8.7% (R087) and 11.0% (R110) (Figure 1).

The repeatability of the wheelchair work measurement method was evaluated by conducting measurements with three different wheelchair riders on four of the surfaces (ICAR, EWFA, CCHP, R071) (Figure 2).

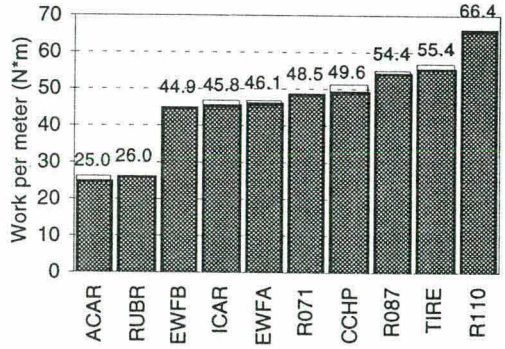

Figure 1. Work required to turn wheelchair.

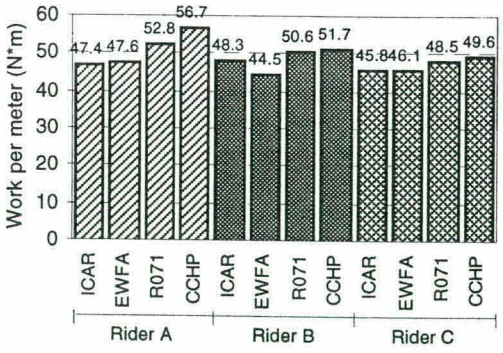

Figure 2. Repeatability testing with three wheelchair riders.

DISCUSSION

This wheelchair turning work measurement method provided objective information about the stability of different surface types ranging from accessible carpet to shredded tire. This test method simulated "real world" conditions as experienced by a manual wheelchair user by measuring the actual forces that must be applied to the wheelchair pushrim in order to maneuver a wheelchair on a particular surface. The test method produced reliable results on all test surfaces measured, with the exception of three "inaccessible" surfaces (bark chips, sand and pea gravel) which could not be negotiated by the wheelchair rider according to the test protocol. The test method produced repeatable results on all test surfaces (s.d.<1.7) and was sensitive enough to clearly differentiate between similar types of surfacing materials (e.g. EWFA and EWFB).

Repeatability testing performed with three different wheelchair riders showed that the work per meter values obtained were dependent on the wheelchair rider. More importantly, the rank order of the four surfaces were the same for each of the three riders, with the exception of ICAR and EWFA measured with rider B. However, ICAR and EWFA were not significantly different for riders A and C.

These objective measurements enabled comparisons to be made with the work required to negotiate the ramps. ADAAG specifies a maximum slope (1:12 or 8.3%) for accessible ramps. Therefore, the work required to negotiate a turn on a specific ramp angle can be used as pass/fail performance criteria for accessible surfaces. This test method is now part of a recently approved ASTM provisional standard for the determination of the accessibility of playground surfaces. The provisional standard specifies that playground surfaces must have average work per meter values less than a 7.1% (1:14) grade ramp.

For outdoor recreational environments, pass/fail performance criteria is not desirable. Instead, a means for disclosing objective information about the stability of an outdoor recreation access route or recreation trail is needed. This stability measurement could be used to classify the surface into categories (e.g. unstable, stable, very stable) or by disclosing a surface stability rating.

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SIG-20
Cognitive Disabilities & Technology

ELECTRONIC VOCATIONAL AID FOR PEOPLE WITH COGNITIVE DISABILTIES

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ABSTRACT

A computer aid was developed to provide guidance in a vocational task for people with cognitive disabilities. The aid is able to sense the user's progress in a task. By sensing and comparing the user's progress to the computer's knowledge of correct task performance, the computer is able to provide appropriate reminders, warnings, and praise. The device was tested with two subjects in a sheltered workshop. With the device, the subjects exhibited production levels which were higher than production when working alone or with timed reminders, and comparable or higher than production while working with a job coach.

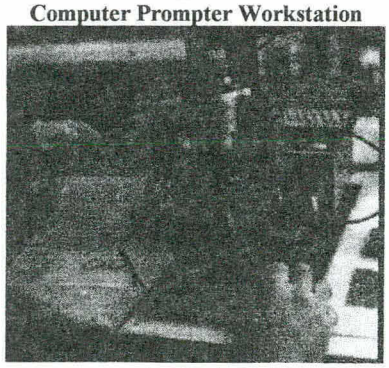
BACKGROUND

Many people who suffer from cognitive disabilities are able to learn vocational tasks. However, they may have impediments to performing the task independently. They might have memory deficits, making it easy to forget what to do next, or they might be easily distracted or have trouble resuming a task once distracted. These people can benefit from guidance to help them maintain productivity, but they do not necessarily need constant or detailed guidance. Often, monitoring and guidance will be provided by a human supervisor or job coach. However, once a person has learned a task, monitoring for infrequent client errors can be tedious for the job coach, while paying the job coach for such monitoring can be expensive. One possible alternative is to develop a computer system which can monitor the client's actions and provide appropriate feedback. This would assist the client in performing his or her job, while leaving human aides free to help those in greater need.

METHOD

An electronic aid was developed to monitor a specific task. This task involves using an electric screwdriver in a modified drill press to attach a clip to a plate. The workstation for this task is shown in Figure 1. The assembly was modified with sensors to detect whether the correct materials were in place, whether the screwdriver was used properly, and whether the task was completed successfully and the finished product removed.

Figure 1
Computer Prompter Workstation



The sensors attached to the screwdriver assembly were connected to a palmtop computer (Psion). A C program was written to monitor the output of the sensors and compare it to correct task performance. If the user made an error, the computer could then offer advice. Also, the vocational task was divided into subtasks. Appropriate times to perform each subtask were programmed into the computer, and if the computer detected an excessively long delay it could offer the user a reminder concerning what to do next. Finally, if the task was performed correctly the computer could offer praise. Advice, reminders, and praise were offered audibly, through attached headphones. When the device was not

producing messages, music of the user's choice could be played through the headphones.

Once the device was completed, it was tested by two clients in a sheltered work environment (the Vocational Rehabilitation Center, Pittsburgh). Subject DS has profound mental retardation, poor language skills, and a short attention span. DS was first monitored for two days while working with a job coach. For the next three days he worked while listening to music through headphones. Reminders to keep working were given by the job coach approximately 10 times per hour, independent of the subject's activity at the time of the reminder. After a two day weekend hiatus, he was introduced to the computer prompter. He demonstrated that he understood the computer generated voice prompts. He was then observed working with the prompter for four days. During these four days, as well as the five days of baseline recordings, an observer was constantly present to record the subject's productivity and response to the device. In order to correct for the effect of the observer's presence, DS was observed with the prompter for a fifth day using a ceiling-mounted, miniature, remote television camera. The prompter was then used by the second subject while DS returned to a normal workstation. After three weeks DS was observed for one day using the prompter while observed remotely with the camera.

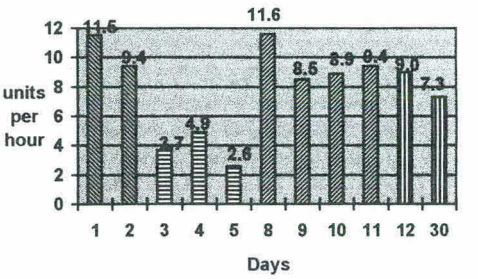
The second subject, MR, has moderate mental retardation, good language skills, and is easily distractible. He had not worked on the plate assembly task for several months. He was observed for four days working with a job coach. He was then observed for five days with the prompter, with a two day weekend break. For the final two days, MR worked with a job coach for half the work day, and with the prompter for the other half. On the first day he worked with a job coach in the morning and the prompter in the afternoon, and on the second day the order was reversed to control for circadian rhythms.

RESULTS

DS

During training, DS demonstrated an understanding of the intent of the prompter's audio messages. In practice, he was frequently observed to ignore them, as well as prompts from a job coach. DS's productivity during the study is shown in Figure 2.

Figure 2
Productivity: DS



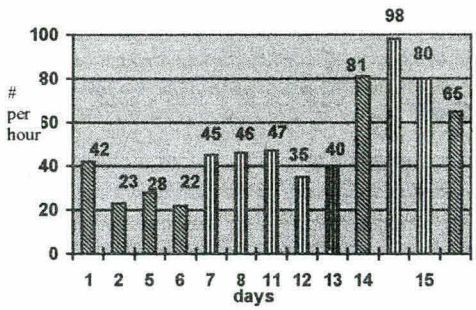
During the first two days, DS showed an increase in production compared to his usual level of about 7.5 units/hour, probably due to the increased attention of the job coach during observation periods. During the following three days, when only timed reminders where given, productivity fell dramatically. During days 8 through 11, with the computer voice prompter, the subject's productivity returned to the levels observed with the job coach and remained at these levels consistently. On day 12, when DS was observed using the remote camera, his productivity remained high. When he was observed three weeks later, without intervening computer experience or the assistance of his job coach, his productivity was still as high as his usual rate before the study began.

MR

Productivity levels for MR are shown in Figure 3. During his first day on the plate assembly task he averaged 42 plates per hour. During the next three days with the job coach, this productivity level dropped. During the five

days in which MR used the prompter, his productivity returned to the level he initially achieved without the prompter, and remained there consistently. During the final two days, in which he alternated between working with a job coach and working with the prompter, his productivity was at its highest level in both conditions. His productivity using the prompter was higher than with the job coach, both in the morning and afternoon.

Figure 3
Productivity: MR
diagonal shaded bars: work with job coach
vertical shaded bars: work with prompter



DISCUSSION

A computer prompter was developed to assist persons with cognitive disabilities who are performing vocational tasks. This device senses the environment and offers context appropriate, audio messages to the user. Clinical trials with two easily distractible subjects over several weeks indicate that this device can motivate moderately to severely retarded youth to attend to their task. The individuals studied were able to maintain levels of productivity which were comparable to working with a job coach. Such a device also appears to be superior to a method of simply providing timed reminders, without the ability to sense and respond to production errors or correct task performance.

This experiment only considered individuals who had already learned their vocational tasks and developed appropriate skills. It is unlikely that a device such as the cognitive prompter could effectively aid someone with cognitive disabilities during the process of job acquisition and training. However, a device such as this provides a cost-effective means to help individuals maintain established levels of job performance in highly repetitive jobs.

Another factor influencing the effectiveness of computer aids is the motivation level of the user. This study, along with previous pilot studies, indicates that this device is most effective with clients who are motivated to perform well. An unmotivated individual can easily ignore the verbal prompts offered by the computer.

A computerized device to monitor task progress and provide verbal assistance to the user can benefit both individuals with cognitive impairments and the people who work with them. For the user, such a device offers the opportunity to improve performance and gain independence from job coaches. For job coaches, a computerized prompter can provide freedom from the often boring and frustrating task of monitoring for infrequent client errors. This allows the job coach's skills to be utilized for clients with a greater need for human guidance and intervention. Finally, using a computer aid for routine monitoring could make vocational rehabilitation and training programs more cost effective. Thus, further research in this area promises many benefits for all those involved.

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USING AVAILABLE TECHNOLOGY FOR REMINDING

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ABSTRACT

Our client suffers from severe short term memory (STM) deficiency. He requires an attendant to remind him to do his many medical and ADL tasks throughout the day. In order to increase his independence, we developed an automated reminding system. This system uses off-the-shelf software and hardware to remind of the tasks needed doing and to log the responses. The attendant also logged the responses on a data form. The need to remind rate dropped from 75% before using the system to 8% ($p<0.001$) while using the system. We expect this system to increase our client's independence and reduce the need for an attendant to be constantly present.

BACKGROUND

Any impairment in memory can be disconcerting to an individual. Many people are affected by short term memory loss. It can result from brain damage from accidents or birth defects. It may be related to degenerative diseases such as Parkinson's or Alzheimer's (DeWeer, 1994) and is associated with amnesia (McDonough, 1995). Memory loss increases with age. Youngjohn and Crook (1993) report a significant decline in fact retrieval using the Grocery List Selective Reminding Test as age increased. Thus memory loss is an important problem affecting many categories of people.

Loss of short term memory in particular can be very difficult to deal with. Sufferers have trouble remembering to perform necessary tasks such as taking medication or drinking enough fluids. This leads to frustration and potentially dangerous inaction or medication overdosing. STM loss can also be very expensive. If important tasks necessary for health are forgotten, patients or society may incur the costs of otherwise unnecessary hospitalization. In order to provide constant reminders to patients, personal care attendants (PCA) may be necessary, but they are also quite expensive. In addition, frequent changes of care givers can sometimes be confusing and frustrating to patients with STM loss. Also, if a PCA does not report for duty, a family member must miss work if a substitute cannot be found. Not only is this costly to the family, but it is costly to society as well.

In order to prevent these costs, there have been several attempts to develop aids to provoke the memory. In the management of medication, devices such as pill wheels and tear-off calendars serve to remind. MacDonald et al. (1977) report that patient use of the pill wheel failed to increase medication compliance, but that tear-off calendars increased compliance.

Advancing technology provides means to automate memory augmentation. For example, Xerox Europac is developing a new product, "Forget-me-Not" (Langreth, 1995). This is a small computer that keeps track of every event a person experiences and allows the user to later access the information. This type of system, however, is meant to be used in an office setting.

Though technology is becoming more available, there is very little literature on the evaluation of it in the use of STM loss. Development of this area will be beneficial to many patients and care givers.

OBJECTIVE

The purpose of this study is to evaluate the use of available software running on a

laptop computer to remind a STM deficient patient.

METHOD/APPROACH

Our client was a seventeen-year-old male with STM loss due to spina bifida. He is insensate below the waist and needs to be reminded constantly to perform tasks of medical and daily living. To evaluate the system, we chose a set of fifteen tasks that were repeated daily. Care givers completed a form by entering task, time the task was completed, performance site, computer availability, and whether reminding was necessary. Three care givers collected data for 20 days, nine with the system in use.

Our client had a Macintosh PowerBook 140 laptop computer. We sought daily scheduler programs that would meet these requirements: it must 1) be easy for the client to use; 2) provide an alarm reminder (visual and aural); and 3) log the client's response to each of the reminding events. After evaluating the software available for Macintosh computers, we chose Easy Alarms® version 2.2 from Nisus Software, Inc. We used the word processing program BBEdit version 2.2.2 by Rick Seigel in conjunction with the alarm program.

Following the Easy Alarms instruction manual, we set up a calendar with the example set of fifteen tasks. The calendar prompted the client once a day for each of the activities. Upon completion of the task, the client entered "OK." The program then activated BBEdit and logged the date, time, and activity. After logging, the program automatically closed and saved the log.

RESULTS

Table 1: Reminding Rate and Computer Use

Computer\Remind	NO	YES	TOTAL
NO	27	67	94
YES	82	6	88
TOTAL	109	73	182

When our client was not using the computer, he needed to be reminded to perform a task 82 out of 109 times (75%). When he was using the computer, he needed reminding 6 of 73 times (8%). This is a significant difference ($\chi^2 = 78.613$, D.F. = 1, $p < .0001$).

For the relation between the task being performed and the rate of reminding, we obtained $\chi^2 = 7.660$, D.F. = 8, and $p = .4674$. Thus, there was no significant relation between the rate of reminding and the task being performed.

When the rate of reminding and care givers were compared, the results were $\chi^2 = 3.874$, D.F. = 4, and $p = .4234$. These results show that there is no significant relationship between the reminding rate and the care giver who is doing the reminding.

The location for 99.8% of the analysis occurred at the client's home, so relations between location and reminding rate could not be determined.

When time deviations were compared with individual tasks, the first three tasks were omitted because they occurred early in the morning and were not consistently recorded. Tasks 6, 10, and 12 were also omitted because these were tasks pertaining to eating, and the client had to get a feeding tube and could not eat. Therefore, there was incomplete data for these tasks. The statistical analysis showed that the lowest deviations occurred for tasks 5 and 9, taking medication.

When we compared time deviation with computer use, there was a comparable deviation for the time the task was completed when the client did not need to be reminded (12.43 minutes with a s.d. of 20.85 when the computer was used and 12.41 minutes with a s.d. of 15.23 when the computer was not used). When the client was not using the computer, care givers allowed an average of 10.8 minutes to elapse before they reminded the client to perform any of the tasks.

DISCUSSION

The reminding rate dropped from 75% to 8% when the computer system was used. Therefore, computer use significantly reduced the need for reminding.

There is no significant relation between the reminding rate and care givers and the reminding rate and the task being performed. This suggests that the effectiveness of the computer use is independent of these variables.

In comparing the time deviations among the tasks, there was a markedly lesser deviation on the tasks referring to taking medication. This occurred because care givers considered this the most important task for our client and thus paid more attention to it.

Comparing the time deviations with computer use showed that there was no significant difference between the time elapsed for not needing reminding. This suggests that short term, the use of the computer had no effect on the client's ability to remember on his own.

Though this offers some information about the use of available technology for STM loss patients, some limitations existed in this study. First, we used a laptop computer in this study because one was readily available to the client. However, laptop computers are expensive and continuously powering one can sometimes be difficult. To overcome this, a PDA device could be used.

Second, because we used Macintosh systems, we only evaluated Macintosh software. To give a better idea of the ideal reminding system available, PC software needs to be evaluated.

Finally, because the client needed to be hospitalized, the data collection was relatively short term. To be more significant, this study needs to be conducted over a long term period and in the absence of a care giver to assure complete success.

Plans are currently being placed to search these venues.

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EVALUATION OF AN ELECTRONIC AID FOR PROSPECTIVE MEMORY TASKS

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ABSTRACT

A pilot study was conducted to determine if the use of a Voice Organizer, an electronic memory aid, can significantly increase prospective memory function over using a written list. In addition, use of the Voice Organizer to increase prospective memory function is compared between students with learning disabilities or attention deficit disorders and students without these disorders.

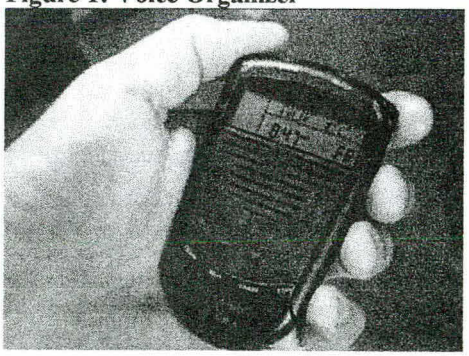
BACKGROUND

Prospective memory requires the ability to remember a task that needs to be performed; remember when it should be performed; and remember to perform it. Prospective memory relies on a mechanism described as the self-initiation of retrieval cues. When self-initiation fails and external cues are not present, important tasks of daily living are not completed

The use of external memory aids has been documented extensively (Harris, 1992; Cohen, 1993; Ranskind, 1993; Wilson, 1992; and Intons-Peterson & Newsome, 1992). Unfortunately there is little documentation on the efficacy of such aids being used with memory impaired people (Wilson 1992; Intons 1992). Some of these aids are quite complex, with memory and comprehension demands that require one to remember the sequence of steps needed to program the device. Ranskind (1993) states that there are only anecdotal reports on the effectiveness of external memory aids used to help people with learning disabilities in compensating for their difficulties in organization, attention, and memory.

The Voice Organizer uses a voice recognition technology in which data is entered through: pushing the record button; speaking into the device and saying the tasks to be performed; and pushing a time button to speak the time and day or date that the device will remind the person to perform the programmed task. When an assigned task comes due a beeping sound, similar to that of a pager, is produced. The user pushes the play button to hear the task to be performed. In addition to this basic function of the device, there are several other features that could increase prospective memory function. These include the ability to program recurring reminders; to program and retrieve phone numbers; to defer messages and reassign dates and time; and to review programmed events.

Figure 1: Voice Organizer



METHODS

Five college student who have been diagnosed with attention deficit disorder or learning disability and five students who do not have a cognitive impairment were identified to participate in the study. An ABAB design was used in which subjects receive a pre-test of 22 calling tasks to be performed over a one week period of time using a list with assigned dates and times for each calling task to be conducted. Voice mail was used, with electronic date and time stamp to validate completion of assigned tasks. After the completion of the pretest, each subjected was given a Voice Organizer (Figure 1) and one hour of individualized training in the use of the device. The Voice Organizer was programmed with 22 telephone tasks to be completed during week 2 of the study. During week 3, the Voice Organizer was turned back in and each subject received a

new list of 22 telephone tasks to be completed. During the fourth week, the Voice Organizer was given back to the student with 22 newly programmed telephone tasks to be completed. An ABAB design was selected to provide evidence of an intervention effect since the response of the Voice Organizer treatments was observed on two separate occasions. If changes in performance on the task test co-occur with treatment (the use of the Voice Organizer) and re-treatment, it will be highly probable that the change in performance is related to the Voice Organizer.

The task test was scored with one point if the assigned task was completed and an additional point if the assigned task was completed within 15 minutes of the assigned time.

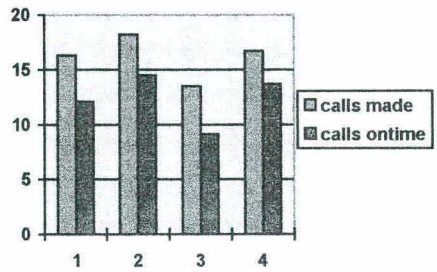
RESULTS

The number of calls made by each person, and the number of calls made on time, were recorded for each of the four weeks. The means and standard deviations are given in Table 1, and shown graphically in Figure 2.

Table 1
Calls made and calls on time across subjects

Week	Calls Made	Calls On Time
1	mean = 16.3 std dev = 4.76	mean = 12.1 std dev = 4.41
2	mean = 18.2 std dev = 3.94	mean = 14.5 std dev = 4.35
3	mean = 13.5 std dev = 6.04	mean = 9.10 std dev = 5.67
4	mean = 16.7 std dev = 5.17	mean = 13.7 std dev = 5.03

Figure 2
Mean calls made and calls made on time across subjects for each week



The number of calls made and calls made on time were compared between weeks and between conditions using ANOVA and t-tests. A significant improvement in performance was found for results with the Voice Organizer compared to the written lists ($p=0.042$, $F_{1,8}=5.865$ for calls made; $p=0.001$, $F_{1,8}=30.350$ for calls on time). However, t-tests revealed no significant differences at the $p=0.05$ level between individual weeks.

The data for subjects with memory deficits were also compared to data for control subjects. The results are summarized in Table 2 and illustrated in Figures 3 and 4. Significant differences were not found between control subjects and test subjects for observed task performance.

Table 2
Comparison of control subjects and test subjects (with memory deficits) for total score (calls made + calls on time). Values are given in mean scores with standard deviations in parentheses.

Week	Control Subjects	Test Subjects
1	29.4 (10.83)	27.4 (6.91)
2	37.8 (6.30)	25.6 (4.50)
3	24.8 (12.48)	20.4 (10.74)
4	28.8 (10.77)	28.8 (10.06)

DISCUSSION

The results of this research show a significant increase in calls made on time using the Voice Organizer compared to the two control weeks. However, there is no significant difference between the initial scores in week one, using a list, and the scores in week two using the device or week four using the device. The greatest increase in calls made on time appears between weeks three and four. This is partly due to the apparent *decrease* in performance in week three, possibly due to users becoming habituated to the device. Since the change in performance on the test task co-occurred with use of the Voice Organizer during weeks 2 and 4, it is highly probable that the change in performance was related to using the Voice Organizer. However, the change in performance observed between individual weeks has been determined to be insignificant.

Figure 3
Mean calls made each week for control subjects and test subjects

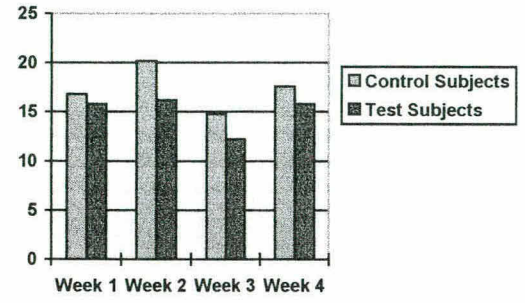
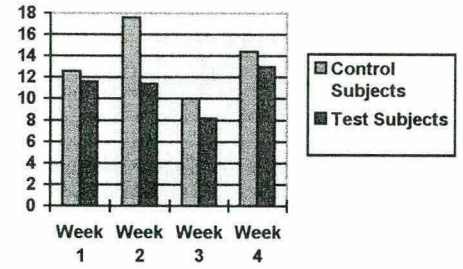


Figure 4
Mean calls made on time each week for control subjects and test subjects



If this electronic memory aid does provide an improvement in the performance of prospective memory tasks, the improvement appears to be in the number of calls made on time rather than the number of calls completed. This may be explained by the fact that people with a written list will eventually consult it, realize that a task needs to be performed, and perform the task. However, they may not consult their list soon enough to perform the task on time. The electronic aid will prompt the user when a task is due to be performed, thus helping him or her perform the task punctually.

This research does not indicate a strong improvement in performance with an electronic memory aid. However, the electronic aid does show some promise for improving performance, particularly punctuality. The uncertainty in these results is probably due in part to the small sample size in this experiment. It would be desirable to conduct a similar experiment with a larger subject pool to determine whether significant differences can be found in the performance of prospective memory tasks.

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COMPARISON OF COMMERCIALLY AVAILABLE ELECTRONIC PROSPECTIVE MEMORY AIDS

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ABSTRACT

Four electronic prospective memory aids were studied: the IQ Voice Organizer™, the DigiPad, the Data Link Watch, and the NeuroPage®. The devices were evaluated to determine effectiveness, ease of use, and the required abilities of the user. A matrix was developed to evaluate the cognitive, sensory and physical abilities required of the user. This matrix can assist consumers and providers in selecting an appropriate device for specific cognitive limitations.

BACKGROUND

Prospective memory is important to the performance of tasks of daily living. Prospective memory includes remembering what tasks need to be performed, remembering when and where to perform the tasks, and remembering to actually carry out the task at the appropriate time. If a person is unable to perform these cognitive tasks, external cues are necessary to provide reminders (Craik, 1986). Assistive technology to aid people with prospective memory deficits can take several forms. The consumer can be taught strategies and exercises to increase their prospective memory abilities. Alternatively, external cues can be provided through low-tech methods (such as written lists and calendars) or high-tech methods. This study focuses on electronic memory aids, a high-tech method of providing external cues.

Electronic memory aids have some advantages over conventional techniques such as written reminders. For written reminders to be effective, the user must remember to check his or her notebook or calendar regularly. Electronic devices, on the other hand, often alert users through an alarm. Also, notebooks and calendars are not always easily portable. If users cannot carry their reminder system with them, they are unable to enter new appointments. Electronic aids, on the other hand, are often designed to fit in a persons pocket or, in the case of watches, be worn on a wrist.

Electronic memory aids also have some disadvantages. First, they often place a new set of cognitive demands on the user. The user must learn how to use the device, remember to carry it with him or her, and remember to use it. In addition, these devices have technical limitations, such as limited memory capacity, controls which are small or otherwise difficult to operate, and small visual displays.

METHOD

Four commercially available electronic memory aids were used on a trial basis. These devices were the IQ Voice Organizer™ Model 5200 by Voice Powered Technology International, Inc., the NeverMiss DigiPad™ Model 40008 by ICP, Inc., the Data Link Watch by Timex™, and the NeuroPage® by Hersh and Treadgold, Inc. Each device was evaluated using a cognitive demands analysis (McCue, 1994) which was modified to include sensory and physical demands.

Voice Organizer

The Voice Organizer is a pocket-sized device which allows verbal messages to be recorded and played back audibly at a specified time. The device will also allow reminders to be recorded without times or dates attached, and telephone numbers to be stored and retrieved using voice recognition technology. Recording messages to be played back at a specific date and time requires a combination of button presses, voice recording, and voice commands. A visual display is used while programming. Timed reminders are announced

with an audible alarm, and the messages can be played with a single button press. Retrieval of other memos and data requires use of several small buttons. Cost: approximately $100.

DigiPad

The DigiPad is a pocket-sized device which allows verbal messages to be recorded and played back. The messages do not have an associated time, but are stored in a list which the user can move through by pressing buttons. The messages are given audibly. The device has four buttons, all of which are used for programming and only three of which are used for retrieval of stored messages. Cost: approximately $35.

Data Link Watch

The Data Link Watch is a system which includes a wristwatch and a software program for a personal computer. The user's schedule is stored on a personal computer, along with memos and phone numbers, using the Data Link software. Selected items can then be transferred to the watch by setting the watch to data transfer mode, holding the watch near the computer screen, and issuing the appropriate command on the computer. The watch will then alert the user with an audible alarm when an item from the schedule is due. Once the alarm sounds, a brief message is displayed in the watch display. Other information (such as memos with no set time and phone numbers) can be displayed on the watch display using the buttons on the watch. These are a set of six small buttons with varying functions depending on the watch's mode of operation.

Currently, the Data Link Watch is only available for IBM compatible computers. Cost: approximately $100.

NeuroPage

The NeuroPage is a pager which is used to provide reminders in accordance with the user's schedule. The user's schedule is sent to the office of the manufacturers. There, the schedule is entered into a computer database. The computer signals the pager whenever a schedule item is due. The user receives either an audible alarm or a tactile (vibration) alarm. A message associated with the schedule item is then displayed on the device's visual display. The user only needs to press one button to stop the alarm and acknowledge receipt of the reminder.

The NeuroPage system can also be used to locate missing persons. The user's caregiver can call a phone number and give the identification number of the user's device. This will cause the user to receive an alarm and a set message (i.e. "Call John Smith as soon as possible at 123-4567"). Cost: Set-up fee $200, plus a monthly service fee between $75 and $170.

Results

The devices described above were analyzed for the cognitive, physical, and sensory demands which they make of the user. The results of this analysis are summarized in Table 1.

Discussion

The different devices analyzed represent four different approaches to electronic memory aids. These approaches have different positive and negative aspects. The Voice Organizer is very flexible, highly portable, and provides the user with a great deal of control over programming. However, it can be hard to program because of the small buttons, the complex programming method, and voice recognition problems with the vocal commands. The DigiPad is easier to use, but does not allow timed alarms and has limited memory capacity. The Data Link Watch is very portable, since it can be worn on the wrist, and the computer interface allows backup storage of information. However, programming can only be done easily from the computer, so that the user must wait until he or she is at the computer to add new appointments. In addition, the display is small and messages must be very brief. The watch buttons are also very small. The NeuroPage places the least demands on the user, while providing

Table 1: Degree of Cognitive Abilities Required for Selected Prospective Memory Aids

L = Low; M = Moderate to High; N = Not Necessary; P = Necessary only for Programming

	Voice Organizer	Digi Pad	Data Link Watch	Neuro Page
Ability to Organize and Plan	P	N	P	P
Ability to Problem solve	P	N	P	N
Ability to remember and to learn	M	L	M	L
Ability to be attentive and to concentrate	M	L	M	M
Ability to see	P	N	M	M
Ability to hear	M	M	M	N
Ability to feel and touch buttons	M	L	M	L
Ability to comprehend orally	M	M	N	N
Ability to visually read and comprehend	P	N	M	M
Ability to process the speed of spoken language	M	M	N	N
Ability to speak	P	P	N	N
Ability to write	N	N	P	P
Accuracy Ability Required	M	L	M	N
Flexibility Required	P	N	P	N
Ability to self initiate	P	M	P	P
Ability to input and respond at an appropriate speed	L	N	L	L

alarms at appropriate times. However, the user's schedule must be sent to the manufacturer to be entered into the computer. This makes additions to the schedule rather difficult. Also, monthly service charges can make this an expensive alternative.

In addition to these various positive and negative features, these devices place different demands on the user's cognitive, physical, and sensory abilities. All of these features must be taken into account when recommending a prospective memory aid to a consumer.

In this project, devices were only tested by one or two individuals, and these individuals do not themselves possess memory deficits. Furthermore, only a small set of commercially available devices were considered. It would be desirable to further this project by comparing a larger selection of devices, and working with people who have memory deficits. In this way, a resource of information could be developed for assistive technology providers who recommend prospective memory aids to consumers.

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Designing an Interactive Prosthetic Memory System

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The Rehabilitation Institute of Pittsburgh
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ABSTRACT

The development of a portable prosthetic memory aid involving a cooperative effort of small business, hospital, and university personnel is described. Reminder messages are downloaded into the device from a clinicians PC. Patients with memory deficits are required to follow the message and select keys on the device to demonstrate task completion. Monitoring of patient responses and updating messages is achieved through file transfer from a home docking station.

BACKGROUND

The application of cognitive prostheses to improve memory skills has met with encouraging results. Numerous software programs have been written and researchers have discussed applications to facilitate remediation of functional daily activities (Harrell, Parente, Bellingrath, & Lisicia, 1992, Kirsch, Levine, Lajiness-O'Neill & Schneyder 1992; Cole, Dehdasti, Petti, & Angert, 1994; Bergman, 1991; Napper and Narayan, 1994; Parente and Anderson, 1991). The use of portable electronic reminders in rehabilitation of cognitively impaired adults has received less attention in the rehabilitation literature. Friedman, Kostraba, Henry, and Coltellaro (1991) described a wearable memory device that attached to a belt and provided a visual display of a pre-programmed message. An enhanced verbal reminder was also developed by Friedman (1993) to provide radio and ultrasonic cues for locomotion and manipulation of objects in a specific environment. An electronic reminder using a paging service has also been developed (Hersh and Treadgold, 1994).

STATEMENT OF THE PROBLEM

While the term, cognitive prosthesis was coined 25 years ago (Fowler, Hart and Sheehan 1972), it has not been until recently that portable prosthetic aids are being designed for the rehabilitation market. The application of over the counter reminders, planners, palmtop computers and personal digital assistants have had limited success. Commercial electronic reminders: 1) do not provide optimal keyboards for individuals with physical or visual limitations, 2) require complex sequences of key and cursor movements to operate, 3) are often difficult for patients to program, 4) fail to require verification of task completion, and 5) do not measure key selections to assist the clinician in treatment planning. The use of a paging service (i.e., NeuroPage, Hersh & Treadgold 1994) developed for individuals with head injuries appears to address the complexity of operation and programming issues, however it does not provide for monitoring of patient performance and requires reliance on an external paging service to update messages.

DESIGN

The prosthetic memory system incorporates five phases of memory assistance and uses three distinct devices (A,B,C). Phases of assistance include: 1) training in use of a portable Prosthetic Memory Aid (A) by a speech-language pathologist/cognitive rehabilitation therapist, 2) software (B) for programming of memory messages and alarm selections on a clinician's computer, 3) use of the PMA with downloaded messages from the clinician's computer, 4) Monitoring of patients responses through a home computer docking station (C), and 5) transfer of message programming from the clinician to the caregiver with all software and hardware components (A,B,C) eventually operating out of the home.

The portable PMA (A) has three primary functions: to signal the patient, present a message, and record a patient's

response. Design features include: signaling options (light, noise, vibration and/or voice), presentation options (LCD text and/or digitized speech), a small keypad for responding, response option monitoring and verification messages. The clinician's software (B) includes: message input, selection of signal type, alarm setting, message priority and degree of difficulty options, message response analysis, a PMA simulator, and file transfer. The home docking station (C) provides software: for charging the PMA battery, up/down loading messages, and alarm & message editing.

DEVELOPMENT

The development of the PMA has been a cooperative effort of Quaker Enterprises (a small business computer consulting firm), The Rehabilitation Institute (a non-profit rehabilitation facility), and the Geneva college electrical engineering department.

EVALUATION

Four young adult outpatients completed a preliminary beta-test of the PMA simulator. All patients experienced memory deficits secondary to either head injury or seizures. They ranged from 4 to 12 months post-onset (MPO). Performance on The Rivermeade Behavioural Memory Test revealed memory abilities ranging from severely impaired (0/24) to within normal limits (22/24). Subjects memory skills were also rated upon discharge from inpatient therapy on the Functional Independence Measure. Performance ranged from a score of 2 - maximum assistance to 6 - modified independence with a device. Messages were programmed in the clinician's PMA software and three alarms were set to go off during a one hour therapy session. Patients were instructed to follow through on each of the following messages: 1) "Put the check in the envelope", 2) "Call time and temperature and record it in your logbook", and 3) "Get the newspaper". These messages were reviewed at the beginning of the session and expected performance was demonstrated. As the PMA software did not incorporate an auditory alarm or digitized speech output at the time of this beta-test, a Micronata Talking Day Planner was used to generate a digitized speech message. Patients were required to turn off the alarm, view the printed message on the simulator, do the task, and select the completed button on the PC to signal message accomplishment. The FIM rating scale was also applied to measure task performance.

TABLE 1

Patient Information and Performance

	1	2	3	4
Age	20	21	24	29
Gender	F	F	M	M
Etiology	TBI	Sz	TBI	TBI
M.P.O.	5	5	4	12
Rivermeade	24	22	0	3
Memory FIM	6	5	2	2
TASKS				
Envelope	6	6	3	5
Phone	6	4	3	4
Newspaper	6	4	3	4

DISCUSSION

All patients were able to complete the tasks at the appropriate time with some level of assistance. In spite of severe memory deficits for 2 of the patients, the reminder message cued them to attempt the tasks. The use of prosthetic memory aids is often considered after traditional cognitive rehabilitation approaches have met with limited results. Also, the majority of research studies do not use patients until after 6 - 12 months to rule out any possible changes from spontaneous recovery. Our approach is to employ prosthetic memory aids early in the recovery process to permit patients with memory deficits to require less assistance from family members or health care staff. As changes in health care delivery result in less treatment time in traditional hospital settings, provision

of a prosthetic memory system in the patient's home may serve to facilitate increased levels of independence.

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Paralyzed Veterans of America (PVA)
Student Design Competition

1997 PVA Student Design Competition
Project Submissions

An Improved Method for Measuring Power Wheelchair Velocity and Acceleration Using a Trailing Wheel Design Brad Lawrence, University of Pittsburgh

Development and Design of a Self-Orienting "Smart" Spoon Joe Wieck, University of Texas at Austin

Environmental Control Unit Lisa Wurst, Wright State University

Redesign of the Standard Hospital Wheelchair Christopher Bruno, Milford, MA

Design of a Mechanical Wheelchair Elevator Alberto Vargas del Valle, University of Peurto Rico

The Flexible Contour Backrest for Wheelchairs - A New Design Offering Adequate Posture and Comfort Frederic Parent, Ecole Polytechnique de Montreal

Speech Articulation & Hearing Perception Software Ali Morowei, University of Manitoba

Design of an Exercise Arcade for Children with Disabilities Gary Downey, University of Tennessee-Memphis

****Can Crusher with a New Concept for the People with Disbilities** Uichung Cho, University of Texas-Austin

Design of a Letter Labeler Stacy Genovese, University of Texas-Austin

Design of the Bowling Empowerment Tool An Tran, Austin, TX

***Development of a Computer-Based Interpretation System for Deaf-Blind Individuals** Beth Finn, ASEL duPont Hosp for Children

3D Graphical Anthropometric Models of Children for the Creation of Rehabilitation Aids Matthew Beitler, ASEL duPont Hosp for Children

Rapid Prtotyping of Customized Wheelchair Trays Isabelle Haulin, ASEL duPont Hosp for Children

Development of an Adaptive Gurney Basil Ilain, Cleveland, OH

****Development of a Spring-Loaded Brace Walking Aid** Ahmad Noorhani, Cleveland, OH

Leg Lifter Korey Singleton, University of Illinois-Chicago IDHU/ATU

****A Reusable, Self-Adhesive Electrode for Intra-Operative Stimulation** Joshua Moss, Cleveland Heights, OH

Standing Assist Device Benjamin Murphy, Tuscaloosa, AL

****Roller Hockey for Athletes with Physical Disabilities** Nathan Strong, Vermont Technical College

The Page Turner Seth Murray, Boulder, CO

USU Automatic Rocker Rick Escobar, Utah State University

Automated Building Accessability System Jason Brown, Barnhart, MO

Habitat Assistive Living Systems using Voice Recognition Gregg Browinski, Lawrence, MA

Adaptable Stand-up Pediatric Wheelchair Mike Robbins, Edmonton, Alberta, CANADA

****A Pool Mobility Device for Children with Disabilities** Faunne Brown, University of Tennessee-Memphis

The Design and Delivery of a Learning and Communication System Martin Crocco, Litchfield, NJ

**Winning Projects; *Honorable Mention Project

1997 Paralyzed Veterans of America (PVA) Student Design Competition

We in the Rehabilitation Technology profession have witnessed literally thousands of new products and interventions over the past decade, but I am constantly aware of haw many areas still need our wizardly attention. I dare say that nearly every rehabilitation clinician, given the opportunity to reflect on some of their recent cases, could easily identify some patient's problem, for which there exists no sources for readily available technology. The fact remains that only a few of these clinicians, be they OT's, PT's, Augmentative Communication Specialists, etc., have access to the engineers and technicians who may be able to spare the time and resources needed to come up with cost-effective solutions to these problems. That's exactly why this competition continues to flourish; by identifying the types of projects that we have now come to expect. That also helps explain why our judging gets tougher year to year, because these young engineers have learned exactly where to turn to identify "real world" issues and problems. By having their finger on the pulse of the clinical community, we are seeing projects that are unique, yet universally understood, forcing the authors to investigate all possible commercial interventions and/or similarities before re-inventing the wheel. And by choosing our judges from among the clinical community and consumers, we insure that our choices represent these very real needs. In short, it is very easy to identify with these projects if you work in the rehabilitation field. These ARE your concerns!

In our early years, the esoteric was mixed with the futuristic; "needs" were often mingled with "wants," in an effort to impress the author's technology prowess. The practicality of this years projects, proves that we are truly reaching our objectives. The entire purpose of this project and it's sponsor, PVA, is to inform the rehabilitation community of such works, in the hopes of helping others.

Feel free to talk directly with our 1997 winners, and encourage them regarding their particular projects. I am sure they would be happy to send out additional photos, etc., or to discuss the most intricate details of their project. We commend and acknowledge the **Paralyzed Veterans of America** for it's passionate service to the United States, and particularly to those newcomers to RESNA. As I step down from my post as Chairman of this project, I would just like to say 'Thank You" for the opportunity to help build the RESNA/PVA Student Design Competition. If the past several years are any indication of success, I can hardly wait to see what will transpire in the years to come as Glenn Hedman takes over. Please take the opportunity to meet and congratulate our 1997 winners, as we "RESNA-ITES" converge on the Three River's City. May God Bless You All,

David F. Law, Jr.
PVA Student Design Competition Chair

SPRING LOADED BRACE WALKING AID

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ABSTRACT

For children with Cerebral Palsy, the challenge of walking is often complicated by high levels of muscular tone. This tone causes a movement characterized as "scissor-stepping". This pattern has not been observed to be corrected through commercially available orthotic braces, therefore a custom orthodic was developed using a step-by-step approach. The first prototype has been tested, and it was proven to improve the patients' walking pattern by preventing the "scissor stepping". Currently, more devices are being made to study the effects on a larger group of pediatric patients.

BACKGROUND

Cerebral palsy is a disability that results from direct or indirect damage to the motor center of the brain. One of the effects is a mis-coordination between the brain and the muscle, which may also effect the walking pattern. A result of this neurological damage is high levels of uncontrolled tone in the extremities. For instance, the children who have this disability often begin to walk by crossing their legs, a habit commonly known as scissors-stepping. In addition to the "scissor-stepping, these children try to compensate for poor balance by hyper extending their upper body forward and anteriorly tilting their pelvis while walking.

This walking pattern limits the walking potential of the patient. Therefore, a walking device is needed to

i. prevent the legs from crossing each other
ii. prevent the children from tilting their pelvis
iii. develop the leg muscle to improve abduction

A five year old boy with Cerebral Palsy, under the care of therapists at MetroHealth Medical Center, was chosen as the initial trial subject. He exhibited both the "scissor-stepping" pattern and the hyper extension compensation of his balance. Under the supervision of the therapist, the child was able to walk approximately 30 feet with a rolling pediatric walker.

APPROACH

The project was divided into nine specific product development stages to ensure the effectiveness and the success of the project.

Identifying Customer Needs

The patient's movements were recorded on a video tape in order to study his walking pattern during the therapy session. This video was analyzed to ensure that a fundamental understanding was reached to discern between the motor limitations of the condition and the limitations resulting from excess tone.

Concept Generation

The brainstorming technique was used to generate ideas at this stage. In addition, a meeting with the therapist, physician, and orthotist too k place to discuss possible designs. It was decided that the device should consist of three components: 1.)pelvic brace, 2.)leg extension, and 3.)leg cuff.

The design of the leg extension mechanism was the most complex and challenging portion. The extension would need to consist of three different parts:

i. Moving mechanism
ii. Outward force mechanism
iii. Leg connection

As a result, there are at least 4 different designs for each separate part.

Concept Selection

Some working concepts were selected for the detail design phase. Screening and scoring technique for selecting the design was not used for this particular project because of a limited number of people involved in this project. Instead, an open discussion with several different people was more appropriate in determining which design should be chosen for the detail design. Therefore, a few meetings were scheduled with the advisor, sponsor and physician to discuss some possible designs. The final design for each part was selected after several discussions. As a result, the following mechanisms had been selected to be used in the first prototype:

i. Leg extension - Two-hinge mechanism
ii. Outward force - Belleville spring (compression)
iii. Leg connection - Slider hinge

Detail Design

A detail drawing was made for each selected design. Each part was dimensioned carefully, so that the part could be machined precisely. In addition, stress-strain calculations had been made along with the drawings to ensure the strength and the safety of the device.

Building Prototype

The prototype was fa bricated in the machine shop according to the detail design.

Collecting Feedback

A rough first prototype had been presented to the advisor, sponsor, and physician for feedback. Moreover, the prototype had been physically tested in a mechanical lab to estimate the performance and the strength of the device.

Making Improvement

After a careful study on the feedback, some changes were needed to be made in order to improve the device. There were two major changes:

i. Change the Belleville spring to a linear spring.
ii. Addition of a Teflon layer between the spring and the plate to reduce friction.

Testing Prototype

A custom pelvic brace and the custom leg braces were made for the patient. The brace was made of low temperature thermal plastic which can be molded when heated, and become hard and rigid after it gets cooled. The braces would need to be machined in order to attach the leg extensions to the braces.

The test first was recorded on a video tape for further observation. In

addition, a set of evaluation sheets were made in order to get comments and feedback about the walking device from other observers. The questions had been specifically divided into five categories: general, spring and leg extension, pelvic support brace, leg brace, and subjective. Moreover, one-to-ten scale was used to answer all the questions in order to get more accurate results.

Testing Result

The sponsor and the therapists who tested the device were very satisfied with the result because the device managed to prevent the "scissor-stepping" and prevent the pelvic from anteriorly tilting.

DISCUSSION

Basically, there are three major criteria in determining the success of the project. First, the completion of a prototype in a specific time period. This was successfully achieved by the end of the given time period.

The second criterion was to meet all the specifications that were stated in the Product Specification phase. Generally, the prototype had met most of the specifications listed in the Product Specification part. For instance, the manufacturing cost is far below than $150, and the adjustable spring force is about the same with the specification. However, the prototype is heavier than the weight in the specification. Therefore, there is a need to find the way on how to reduce the total weight of the device.

Finally, the most important criterion of this project is to meet the ultimate objective of the project, that is to come up with a walking device that helps to improve the patient's walking pattern. Practically, the device managed to prevent the legs for crossing each other and at the same time prevent the pelvic from anteriorly tilting.

Conclusion

In general, this is a successful project because it has meet most of the objectives of the project. The device can be described as a good first generation prototype. However, this prototype needs to be tested several times in order to know more about its capabilities.

The device is being duplicated to enlarge the number of patient tests. Currently, a group 10-15 patients is being formulated to use the walking device over a 6 month testing trial. The study will provide more accurate results. The present information gathered on the device has shown that it is successful in the improvement of the walking pattern of a pediatric patient with Cerebral Palsy.

A REUSABLE, SELF-ADHESIVE ELECTRODE FOR INTRA-OPERATIVE STIMULATION

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ABSTRACT

A suction-type stimulating electrode was designed and fabricated to allow intra-operative testing of lower extremity muscles during routinely scheduled surgical procedures. The suction device can adhere to a small exposure of muscle surface with large, reproducible contact forces and remain immobile for several minutes. It is therefore a useful tool in locating the optimal site for a permanent electrode for FES applications, as well as an ideal means of providing accurate and repeatable stimulation in various locations. When operated with a 10-cc syringe, the device can generate up to 23 N of contact force; correlation between measured and analytically predicted contact forces was 0.989.

BACKGROUND

Epimysial electrodes for functional electrical stimulation (FES) consist of platinum disks with Dacron-reinforced elastomer skirts which are sutured directly to the surface of the muscle at the nerve entry point. Having been implanted in more than 50 patients to date, experience with surgical placement of these electrodes in the upper extremity and clinical success in hand grasp neuroprostheses is well documented [1-4].

The success of the epimysial configuration in upper extremity applications of implantable FES technology makes it the logical choice for lower extremity applications as well. Although there have been isolated attempts to implant epimysial electrodes into the muscles of the lower extremity [5], further study is necessary to determine the performance of the electrodes on these muscles. The relative strength and selectivity of the stimulated contractions, the optimal location of epimysial electrodes in the quadriceps, gluteal, and paraspinal muscles, and efficient surgical approaches to implantation and lead routing are all important aspects under consideration. Electrode positioning directly affects the ability to generate sufficient extension about the trunk, hip, and knee, and optimization is therefore critical for proposed standing and walking FES applications.

STATEMENT of the PROBLEM

In order to locate an optimal electrode position, surgeons currently probe the exposed muscle with a stimulating wand; permanent electrode placement is based on their observation and palpation of the induced contraction. However, if the probing electrode is applied with more force in one area than another, the resulting contractions may not accurately indicate the more suitable position for a permanent electrode. In addition, the probing electrode cannot be held reliably by hand at one precise location during a contraction. Finally, qualitative results are not sufficient for discerning small differences in stimulated response. Therefore, the goal of this study was to design a tool to characterize quantitatively the stimulated response to epimysial electrodes in the lower extremity and optimize final electrode placement.

The final device must accurately simulate the behavior of a standard, sutured epimysial electrode. However, it must also be easily removed and re-applied to the muscle surface at various locations for response mapping during routine surgical procedures. The device must also contact the surface with repeatable force and remain immobile during several minutes of testing, regardless of the plane on which it is applied; such features will facilitate quantitative comparison of muscle recruitment properties for

various stimulating locations. Additionally, the narrow, deep muscle exposures created during lower extremity surgeries necessitate a small device (no dimension greater than one inch).

RATIONALE

To meet each of the design requirements, a suction device was designed and fabricated. The stimulating surface and lead wire are exactly those used in a standard epimysial electrode, thereby accurately simulating these electrodes. The force with which the device contacts the muscle tissue depends on the difference between air pressures inside and outside the suction chamber. Atmospheric pressure outside the chamber is constant in every direction, and pressure inside the chamber can be controlled by connecting it to a closed system of volume, such as a syringe. The suction chamber need not be significantly larger than the 0.25" platinum stimulating disk, keeping the device relatively small. In addition, an easily sterilized, biocompatible material was chosen.

DESIGN

A two piece injection mold was fashioned from brass, and the device was made from silicone rubber (MDX-4-4210 Medical Grade Elastomer, Dow Corning, Midland, MI). Rubber tubing (0.030" ID, 0.065" OD, Silastic, Dow Corning) was used to connect the air reservoir of the suction chamber to a syringe via a 3-way stopcock. The platinum disk electrode and lead were obtained from the Technical Development Laboratory of the Cleveland FES Center and is the same type currently being used in permanent epimysial electrodes for both upper and lower extremity applications. The external dimensions of the device are shown in Figure 1. The holes in the tubing which allow air to be drawn out of the suction chamber are cut by hand.

As volume in the closed system is increased by drawing back the syringe plunger, a vacuum is created within the device. This vacuum draws the tissue into the chamber and atmospheric pressure depresses the top surface of the device, bringing

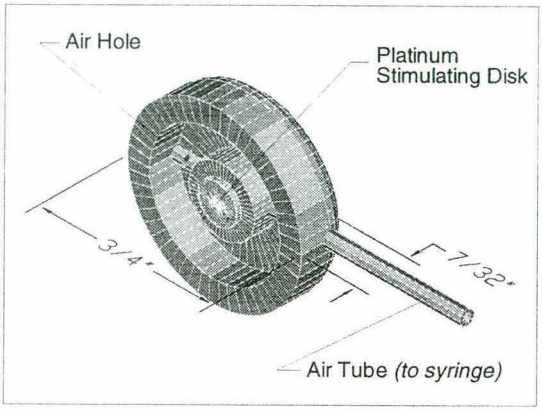

Figure 1: Bottom view of suction-type epimysial electrode

the muscle and electrode into contact. After the device is sealed from the syringe by the stopcock, the surgeon is free to use both hands while the electrode remains applied with constant force. The stopcock is opened to release the device.

DEVELOPMENT

Several size constraints were considered during fabrication while attempting to keep the device as small as possible. For example, an adequate surface area within the walls was necessary to convert pressures to the required force ($F = P \times A$). The thickness of the walls and top surface also contributes to the overall size of the device, but a minimum thickness was maintained to provide a sufficient seal and rigidity. Finally, the air tube was kept a minimum distance from the tissue surface to prevent excess blood and debris from blocking the air flow.

EVALUATION

In a preliminary test, the electrode adhered to a smooth, dry surface in excess of one hour, far exceeding the design requirements. Therefore, the contact force generated by the device at various levels of air evacuation was most rigorously tested. Adhesion forces were predicted from the geometry of the suction chamber:

$$P_{chamber} = (V_{chamber} \times P_{atm}) / (V_{chamber} + V_{syringe})$$

$$F_{adhesion} = (P_{atm} - P_{chamber}) \times A_{chamber}$$

An electrode housing was fabricated and attached to a spring (k=305.7 N/m), which was in turn attached to a movable, motorized surface. Vacuum pressure was created with various levels of syringe evacuation, adhering the electrode to a stationary, smooth surface. The spring was then stretched at a constant rate of 6.70 in/min by the motor. When the force in the spring exceeded the electrode adhesion force, the suction device was pulled away from the stationary surface. The increase in spring length was then recorded, and force was calculated with the spring constant.

Figure 2 illustrates the results obtained by this method as they compare to those predicted analytically. Although the measured values were consistently lower than those predicted, they followed the same relationship to syringe evacuation with a correlation of 0.989. Limited *in-vivo* testing has also been achieved in several dogs; preliminary qualitative results indicate both excellent electrode-tissue contact and adequate adhesion force with minimal syringe evacuation.

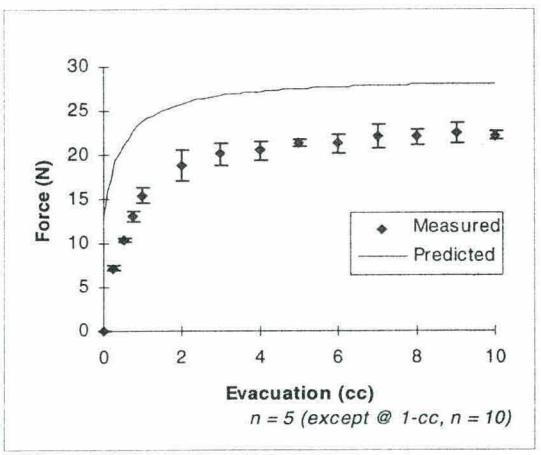

Figure 2: Adhesion forces versus syringe evacuation

DISCUSSION

The results indicate high potential for the suction-type epimysial electrode as an intra-operative testing device. The narrow range of adhesion forces at a given level of syringe evacuation is evidence for the repeatability of the device, while the large overall range and predictability of forces will provide the surgeon with improved probing capabilities. *In-vivo* testing has shown that the device can remain immobile on strongly contracting muscle, further supporting its utility in quantitative muscle force data collection. By virtue of its size and shape, the device cannot be forced underneath the muscle surface, thereby keeping responses consistent with those that would be obtained with a standard epimysial electrode. The large forces shown in Figure 2 indicate that a smaller suction chamber may be adequate; a device with slightly thinner walls and a smaller functional surface area is currently being fabricated for testing.

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Can Crusher with a New Concept for the People with Disabilities

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ABSTRACT

People with disabilities want to perform meaningful activities that can improve their self-esteem and induce positive interactions with other people [1]. Can crusher is one of the system that can fulfill these demands. Financial rewards and the confidence for the independent/cooperative work are the major benefits that the can crushing system provides.

At Rosedale school in Austin, students with disabilities crush cans for the above mentioned purposes. However, current systems require frequent interventions of the teacher due to jamming and misalignment of cans, high loading position, and the lack of the process-information-window. In addition, the level of the visual and auditory excitement during operation is insufficient to induce the dynamic involvement of students.

This paper focuses on the design and construction of a functionally reliable and ergonomic can crushing system for people with disabilities. The uniqueness of our system is in the new crushing mechanism — flattening instead of traditional buckling. The system with the flattening concept shows variety of advantages over current can crushing systems. In addition, ergonomically designed can-loading unit and the process information window enhance the independent/cooperative work of students.

BACKGROUND

What is the best way to assist people with disabilities? The financial aid, love and physical care that help them to perform routine daily activities may not be enough. They have the right and desire to improve themselves and experience the precious feeling that they are also valuable members of this society. Most of them have the ability to fulfill their rights even though some of their physical and/or mental resources are limited. Rosedale school in Austin educates children with disabilities for their lives with enhanced quality. Rosedale tries to provide students with the independence, improved self-esteem, and experience of a greater quality of life through appropriate educational opportunities and quality instruction as well as abundant care and love [2]. In that context, students at Rosedale operate can crushers to crush cans to experience financial rewards and confidence for the independent/cooperative work.

STATEMENT OF THE PROBLEM

The can crusher is a system that compresses cans with various shapes to the allowable volume. In contrast to the normal can crusher, the can crusher for the people with disabilities should also enable the convenient loading of the can to the crushing location, the easy interface between the people with various disabilities and the crushing operation, and safe collection of cans with minimal effort. The can crushing system can be utilized to improve self-esteem and induce positive interactions with other people by providing financial rewards and the confidence for the independent/cooperative work.

At Rosedale school in Austin, too many cans are donated to be crushed by students with current can crushers: commercial manual, commercial electrical, and '95 UT can crushers. The manual can crusher requires too much effort to be operated by people with disabilities. The commercial electrical can crusher is mostly used in many classes. As the product is designed for the people without disabilities, most of the operations are performed by teachers. The only thing that students can do is to push the button to start the operation. Besides, frequent jamming lowers the performance of the crushing process. All three systems crush cans with the buckling mechanism, and students alone cannot even complete the single process-cycle (loading, crushing, and collection) without the assistance of the teacher.

The project aims to provide a working prototype that can be used by people with disabilities with minimal failure and anti-ergonomic factors at least for a year. Most of the can size is 12 Oz, and the crusher is designed to crush this type of cans. The prototype is operated by a single or several (2-3) students with limited motion skills. It is emphasized that the crusher should be operated independently by students with minimal intervention of the teacher or the supervisor, and the natural cooperation between students should be enabled. This basic process scheme is originated from the introductory video that was provided at the first Rosedale visit — "independence and inter-relationship".

DESIGN & DEVELOPMENT

The task clarification, conceptual design, embodiment design, and detail design are the commonly accepted flow of the design process [2,3]. The can crusher design is based on this process-frame, and the virtual design is refined through wood prototyping. Considering the fabrication of the system at Rosedale, the manufacturing/assembly issues are concurrently considered from the conceptual to detail design phase.

The crushing system can be decomposed into three sub-systems: compression, loading, and collection of cans. Each sub-system is designed independently first, and then they are combined for the parametric tuning through the test with the alpha prototype.

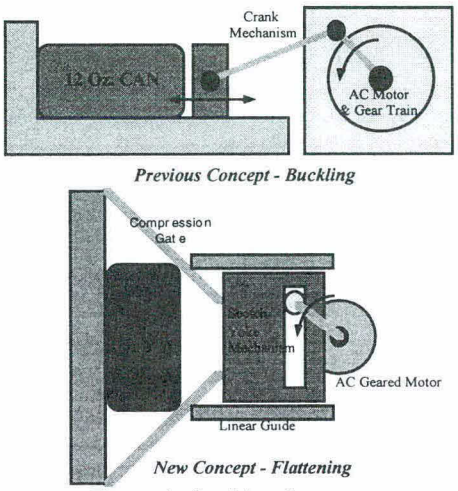

Figure 1. Crushing Concepts

Our new can crusher flattens cans with the Scotch-Yoke mechanism rather than buckles cans with the conventional Crank mechanism [2] as shown in Figure1. In comparison to the buckling, the flattening concept requires less stroke for the reciprocating motion. Due to this reduced stroke, the required motor power can be dramatically reduced, and the system cost can be reduced.

In order to measure the required force history during the flattening, a simple test jig has been fabricated prior to the embodiment design. Using this jig, the load history is measured with the instron, and the result is used to decide the power of the motor.

After the force history is recorded, the test to decide optimal initial gate angle was performed. It is desirable to minimize the angle in order to reduce the length of the linkage attached to the AC gear motor shaft, which is proportional to the required stroke of the linear motion. The important experimental result is the optimal initial gate angle is 45 degrees. If the angle is more than that, the stroke increases and the initial load increases. If the angle is less than 45 degrees, the required initial load increases dramatically. This result comes from the fact that the can tends to deform in radial direction without bending when the angle is less than 45 degrees.

The system is designed for two situations: the operation of the system at Rosedale by 2-3 students, and the operation by a single student at other locations. For appropriate operations in both situations, auto/manual switch is provided. Under the auto mode for a single student, the can is crushed automatically when a can is properly loaded. The manual mode is designed to induce the natural coorperative work among 2-3 students. When a student load a can, the signal light is turned on to inform other student(s) the proper time to start next operations.

It is so complex to decide appropriate materials virtually, and the selection of the material is a discrete decision making. So it may be a reasonable approach to select optimal material by observing failure modes. The alpha prototype is mostly fabricated with the pine (cheapest one). Once the strength problem is found, the dimension is increased if possible or the material is replaced with the higher level one. For example, the link of the Scotch-Yoke (S-Y) mechanism was fabricated from the polycarbonate, and it showed the severe deformation and the crack. So, the polycarbonate was replaced to the aluminum as the dimensional variation of the link was not possible due to other constraints.

Various tests were performed with the alpha prototype in order to find out initial design faults and adjust design parameters. It is almost impossible to design a reliable product with a single prototype as the single set of behaviors is insufficient to modify the design parameters. We tried to determine the critical functional failure source, and then performed the concentrated test changing the alpha prototype. For example, the jamming of the can was eliminated by tuning the gap between gates and the material of the reaction block with the Edisonian approach. For this test, the alpha prototype was modified continuously until all significant failure modes are removed.

DESIGN EVALUATION

In Figure 2, the overall new can crusher is shown. It is composed of three main function blocks: loading, compression and collection. All

three function blocks are mostly distinct from those of previous products to remove previous faults.

One of the common problems previous can crushers are jamming. Due to the frequent jamming, too frequent interventions of the teacher or supervisor were required. Contrast to current can crushers, our new can crusher crushes cans with various initial shapes without jamming owing to the flattening concept.

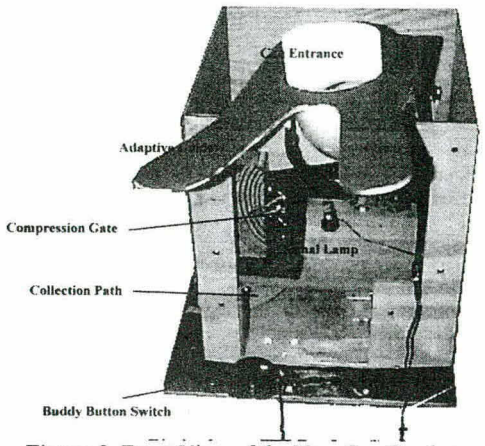

Figure 2. Front View of the New Can Crusher

In the test run at Rosedale, the response of the teachers and the students was very positive because our can crusher can crush severely deformed cans and is reliable. During the compression of about 70 cans, only 3 jamming occurrences were observed. In addition, the crushed cans have no sharp edges due to the flattening method.

The measured cycle time is 10 seconds, while the cycle time of the previous products is 8 seconds. Based on the response from the teachers and students, this seems to be no problem at all as students with disabilities can not manage to respond the fast can crushing process.

The loaded cans are automatically collected in a trash bag without an error after students push the start button.

The volume of the compressed can is slightly larger than that of the previous one. However, the volume can be reduced even to half of current volume by increasing the power of the motor.

Most of all, the motor power was reduced greatly, and it reduces the cost of the can crusher, and it reduces the total volume and weight of current prototype by removing lots of dead space.

DISCUSSION & CONCLUSION

The project goal, to provide functionally and ergonomically improved working prototype of the can crusher, has been achieved with following improvements. The reduced jamming rate, independent can-loading by the student, automated can-collection, clear view of the crushing process, and the loading signal to inform students when to start another process are verified improvements of the new can crusher.

The functional stability enabled the independent work, and the auto/manual mode satisfied both educational goal and productivity. The students at Rosedale can now recycle cans more independently and cooperatively.

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ROLLER HOCKEY FOR ATHLETES WITH PHYSICAL DISABILITIES

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ABSTRACT

Sledge hockey is a team sport played by athletes with physical disabilities (usually paraplegics) that follows the same rules and structure of ice hockey. In areas where ice rinks and ice times are both limited and expensive there is no way to participate in this sport. A hockey sledge that can be used either on an outdoor court or in a gymnasium was designed, manufactured, and tested. This roller sledge is extremely lightweight, adjustable, functional, and inexpensive to produce.

BACKGROUND

The Sport

Sledge Hockey is a team sport that incorporates the same rules and structure as regular ice hockey in a modified format. Players sit on sledges (a sled like chassis) constructed of a metal frame, a seat and backrest, and two ice skate blades positioned beneath the seat. The front of the sledge has a runner that helps balance the player and allows the sledge to slide the around in an arcing motion. Special sticks are used by the players that allow them to be as efficient as possible while playing. The sticks have a metal pick on one end that allow the player to propel the sledge and a blade on the other end that allow them to control the puck.

Need

The opportunities for people with disabilities to participate in team sports are limited. Considering this, there is a great need for the team sport of roller sledge hockey. Able bodied people roller blade and play roller hockey in the summer, and especially in areas where ice times are limited. People with disabilities should have an equal opportunity to participate in that same type of activity (under the same circumstances.)

No manufacturer of a roller hockey sledge exists. Currently one manufacturer of ice hockey sledges exists in North America. The ice hockey sledge frame being produced is not easily adapted for roller sledge hockey use.

By creating an inexpensive, lightweight roller hockey sledge, people with disabilities will have a greater opportunity to participate in a new, exciting recreational activity / team sport.

DESIGN METHODOLOGY

Four steps were taken to identify the critical sledge design criteria and implement the criteria in a prototype roller sledge design: analyzation of an existing ice hockey sledge, discussion with the manufacturer of the sledge, interviews with participants, and research of the actual game of sledge hockey.

Design Criteria

a. An adjustable, lightweight chassis for easy maneuverability and customized fit.
b. Adjustable wheelbase for balance, speed, braking, and maneuverability.
c. Comfortable, customizable seating.
d. Nonmarking wheels and chassis perimeter.
e. Common materials readily available for replacement and customization.
f. Rubber crutch-like ends to be used for self propulsion.
g. Foot plates for optimal control, balance, and safety.
h. Adjustable strapping in high torsion areas such as the seat and foot plates for safety and control function.
i. Simple, yet very functional overall design for low manufacturing and consumer cost.

ROLLER HOCKEY FOR ATHLETES WITH DISABILITIES

THE DESIGN



Chassis

The roller hockey sledge chassis is constructed of tubular 6061-aluminum. This grade of aluminum was chosen for strength, weldability, manufacturability, and minimal cost. The tubing in the rear section of the chassis is 1" square outer diameter (OD) and the tubing in the front section of the chassis is .75" square OD. Both are drilled accordingly to allow the chassis to be telescoped and set to the appropriate length dependent on the user's needs.

The rear section is 30" long, 14" wide, and is supported by two cross members positioned for structural integrity. The rearmost member is drilled accordingly for seating applications. A section of 3" x 1.25" x .25" 6061-aluminum channel is centered and welded to the underside of the chassis. This is drilled accordingly for customized wheel positioning.

The front section of the chassis is 22" long, 13.75" wide, and is supported by an 8" x 13.75" section of ABS plastic riveted to the underside of the chassis. Two Concept II ™ rowing machine footplate assemblies are attached by cotter pins to 4" pegs that are positioned 8" apart on the extreme front of the chassis. These foot plates are adjustable and free to move from 0 to 85 degrees. The ABS plate acts as a heel rest in this application.

Wheels

To allow for both speed and maneuverability, skateboard trucks and wheels are positioned in the channel. The channel acts as a bumper for the truck axles. This feature keeps the operator from leaning too far to the side and easily tipping the sledge over. The front trucks are 146mm wide and the rear trucks are 166mm wide. This offset in axle width, along with adjustable positioning in the channel, creates a tighter turning radius and a more stable sledge.

The skateboard wheels (4) are 60mm x 80A, clear polyurethane. This larger wheel size and average wheel hardness permits for greater frictional contact on various surfaces, easier control, and longer wear time. The clear wheel keeps the sledge acceptable for gymnasium use because they are nonmarking. Skateboard wheels and trucks were chosen for this application for their strength, availability, and affordable cost.

Seating

A Bi-Unique™ molded monoski seat was used for this prototype. A sling seat can also be attached using the available cross member positioning. The Bi-Unique™ seat was chosen because it is very lightweight, durable, can be heat molded for a custom fit, and is readily available for consumer purchase.

The molded seat offers many more practical features in comparison to the sling seat.

A molded seat is customizable to fit. A sling seat is not customizable and is not as supportive as the molded seat.

A Varilite™ inflatable cushion, which is detachable for sanitary purposes, is used as a back support. A 0.75" thick memory foam pad is used in the bottom of the seat. This grants the user a customized fit, along with padding in case of incidental contact with other roller sledges or accidental tipping.

Sticks

For indoor use, sticks used for self propulsion and puck control are simply modified from the ice version of sledge hockey sticks. The ice picks are taken off the end of the sticks and large crutch tips are fastened on using a removable bonding spray and cloth athletic tape.

For outdoor use, a full size hockey stick may be cut into sections, have street hockey stick blades attached to the ends, and then have the crutch tips attached to the opposite end of the stick. This allows the blade of the stick to wear longer. The crutch tips were chosen for their availability, durability, and low cost.

Other Features

Strapping and belts are used to keep the user in the sledge. The foot plate assemblies have an adjustable strap with a lock slide that keeps the user's foot in the assembly. The seat has a Bodypoint Designs™ positioning belt attached at the hip and midsection area. This positioning of the belt keeps the user snug in the seat and acts as a safety harness as well.

Various braking systems are currently being tested. The most effective system to date is a combination brake / wheelie bar system positioned in the rear of the sledge. This system allows the user to stop the sledge and slightly pop the front of the sledge up of the ground for quick turning applications. This brake / wheelie bar is made of a nonmarking polyurethane (much like the skateboard wheels) and is fastened to the aluminum channel according to the user's preference.

CONCLUSION

This prototype roller sledge is extremely functional and provides people with disabilities an outlet beyond what is presently offered for recreational activities.

The prototype is very lightweight and can be broken into two sections for easy transportation and storage. The chassis is extremely adjustable so the sledge can be used by many different people. This feature makes it very attractive to organizations and schools. All of the components used, such as sticks, wheels, trucks, etc., are common materials and are readily available for consumer purchase. The seating is customizable. Depending on the user, a molded or sling seat can be used.

By designing and manufacturing a roller sledge, another outlet is given to all athletes with physical disabilities. This is an opportunity to give people with disabilities an exciting, healthy recreational activity at an affordable cost (approximately $225 to manufacture).

ACKNOWLEDGMENTS

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A POOL MOBILITY DEVICE FOR CHILDREN WITH DISABILITIES

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ABSTRACT

Water activities can be mentally and physically beneficial for most disabled children. Pool play can boost confidence and independence while providing the benefits of recreation and exercise. Many disabled children are excluded from independent water play, however, due to the inadequacy of available swim aids. For this reason, Sea Horse was designed to permit many kids with c.p. to safely and independently direct and propel themselves in the water. This motor-assisted craft is built from three modular sections. The mid section includes the power train and seating assembly while the fore and aft hulls provide buoyancy and streamlining. The prototype will be tested in use and design refinements made based on evaluation results.

BACKGROUND

Physical activity in water has been shown to benefit disabled children, including those with cerebral palsy [2]. For example, the water, especially as heated in therapy pools, allows the muscles to relax thereby increasing range of motion. Social interaction with others has developmental value and aerobic fitness and strength may be enhanced as well [2]. However, commercial pool mobility-aids for physically challenged children – typically having the form of modified life vests and innertubes – are sometimes inadequate. They may fail to provide the upper body support needed to keep the child's head above water or ride up on the child and restrict arm, neck, and head movement. Further, present products do not provide a means for utilizing a child's own power and control to propel and steer her/himself in the water. To meet the need for new assistive technology, a modular power-assisted craft has been designed. This project began as a team effort in the Product Design for People with Disabilities course in the School of Biomedical Engineering at U.T. Memphis. It has since evolved into the thesis project described in this paper.

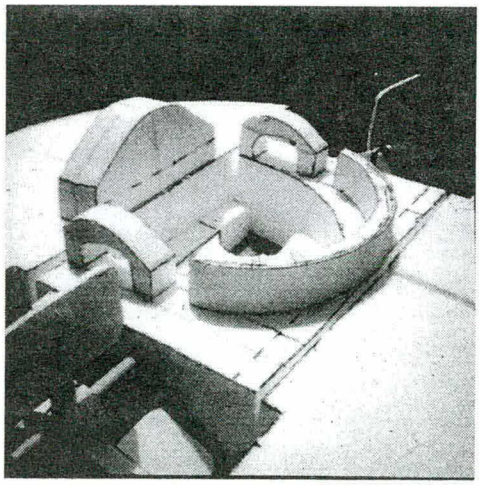

Figure 1

DESCRIPTION-Subsections:

The Hull

Sea Horse is comprised of the mid, fore and aft hulls as seen in the full scale Styrofoam model, Figure 1. When assembled, the craft is roughly 4 ft. long and 3 ft. wide. The fore and aft hulls are mirror images of each other At maximum they are 6 in. thick and ride ~3 in. deep in the water. The mid hull provides the attachment points for seating and the power train while the fore and aft hulls provide most of the buoyancy. Rigidity and mounting points are

provided by a PVC H- frame whose longitudinal members insert in receptacles in the fore and aft hulls to assemble the craft. In cross section, the fore and aft hulls are characterized by tapered lateral lobes for tip stability. The hulls are constructed in the manner of a surf board from fiberglass on foam sculpted in accordance with a set of four built-in polystyrene templates spaced approximately 4 in. apart. Sea Horse's modularity permit's the craft to be quickly knocked down for transportation, simplifies replacement of damaged pieces and makes it easier to accommodate a range of sizes and growth for individual children.

When Sea Horse is in use, the child is typically submerged up to her/his mid-chest so that the experience is more like swimming and less like riding in a boat.

The Paddle Wheels and Triggering System

Sea Horse, as configured for our first user, requires him to make repeated physical effort in order to turn on the motors which drive the two laterally placed paddle wheels (PWs). He will need to kick a padded rectangular plate located behind his feet to trigger a settable period of motor power. The trigger plate is mounted at the end of a vertical telescoping rod via a horizontal hinge to allow it to be placed where it is most accessible to the child or to intentionally increase the work involved in kicking it.

Each PW is comprised of three rectangular paddles made from ABS plastic. The paddles are approximately 6 in. wide, 4 in. radially, and .25 inch thick. Each PW is driven by a DC gear motor to rotate at a fixed frequency of roughly 1/2 a revolution per second. Stall torque is sufficiently low that the PW will stop without causing injury if, for example, another swimmer's limb interferes with its rotation. The PWs will be covered above the water line with clear plastic housings for the safety of the user and to prevent excessive splashing.

Steering is accomplished by differential control of the directions of the PWs, in the manner of a powered wheelchair. The child controls direction by lateral torso lean. When the user wishes to steer right, leaning in that direction switches motor polarities so that the left PW rotates forward and the right PW rotates in reverse. The child sits upright when s/he wishes to stop turning. Our experience with a walker design controlled in this manner suggests that substantial numbers of children with c.p. will be able to master this skill. The amount of lean and the muscular force required can be adjusted by moving the right and left stops built into the back support, and by tightening built-in return springs.

The Seating System

The child is seated in the mid-hull in an adjustable sling seat and four point torso harness with her/his legs protruding beneath the craft. A lap belt can be added for proper pelvis positioning. The back support pad is designed to rotate relative to the stationary backboard via a circular bearing. Careful attention was paid to hull shape and dimensions to allow the child's hands to reach over the sides and splash.

The Power Train

The power for the craft is provided by two permanent-magnet, 12 Volt motors which direct drive the PW shafts. These motors will run on power from a sealed battery, or batteries, located between them. The motors, battery and PWs are mounted on a single chassis which can be lifted out of the mid hull. It also contains the majority of the weight of the craft, as each motor weighs approximately 12 pounds. The motors are air cooled and are sufficiently well sealed to allow them to sustain splashing (as long as they are not continuously immersed). There is no shock hazard.

ANALYTICAL EVALUATION

Many design parameters were considered for this project including fun, safety, cost, size, weight, maintenance, and aesthetics, with

safety given the greatest preference. To achieve this, stability calculations were performed to insure that the craft would be able to right itself without capsizing in the presence of a downward force applied at its edge. For instance, an approximation may be made to determine the minimum width to height ratio needed to maintain stability for a craft. Stability is maintained in a clockwise tip (for example) if and only if the center of buoyancy remains to the right of the center of gravity . Several calculations have been done to determine whether this stability criterion is met by the Sea Horse. For example, the condition for small angle marginal stability for a rectangular block of Styrofoam used for the Sea Horse requires a minimum width to height ratio of .42 [1] . The approximate dimensions of the Sea Horse hull yield a value of over 14 times this requirement, [1]. Further, we know that the pontoon-like shape of the Sea Horse hull makes it more stable than the rectangular shape used in our approximate calculations..

The laws of fluid mechanics also dictate the shape of the craft. The primary contributions of drag in this design are due to the shape drag of the protruding legs and the skin drag of the hull, [1]. For the Sea Horse, the former provides the dominant effect. The horsepower (hp) of the motors, given the inefficiency of the PWs, was selected to be 1/8 hp to overcome the expected drag at an enjoyable speed of ~ 0.5 m/s.

DISCUSSION

The development of this prototype has raised many complex design issues. For example, size must be compromised for tipping stability and faster speeds must be sacrificed for safety. A major problem is the total weight of the craft due primarily to the power train. If the craft could be designed to require less power, smaller and lighter motors could be used. A lighter craft would also aid in getting the craft in and out of the pool. To achieve this goal, drag must be reduced so that less power is needed to propel the craft at the same speed.

For purposes of marketability, the craft must be affordable. The total parts cost of this prototype was approximately $650.00. This amount will decrease with future fabrications as many of the materials may be bought in bulk. The craft must also be aesthetically pleasing to children. The hull will be painted and the top will be made to resemble that of a boat's deck. A craft that looks like a therapeutic device may not encourage use or may discourage the approach of other children in the pool. Therefore, the cosmetic appeal of the Sea Horse will attract children and furnish a vehicle for fun and user friendly pool activity.

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ACKNOWLEDGMENTS

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Whitaker Student Scientific Paper Competition

1997 RESNA/Whitaker Student Scientific Paper Competition

On the following pages you will find the five award winning papers for the fourth annual RESNA Student Scientific Paper Competition. The student awardee is listed as the first author on each of the papers. These awards are supported through the generosity of the Whitaker Foundation. The purpose of the Student Scientific Paper Competition and Awards is to encourage and promote student participation in high quality research related to the fields of rehabilitation engineering and assistive technology. The competition is intended to encourage students from a variety of disciplines to address issues in the field of assistive technology and submit papers for presentation at the annual RESNA conference. This competition is based on scientific merit of the reported research and is structured to be distinct from and complimentary to the student design competition.

The winning papers in the Whitaker Competition were all presented in a special session at the RESNA '97 Conference. This session provides a unique forum which, in addition to highlighting student research activity, brings together papers on diverse topics for presentation. There were a total of 35 papers submitted for the competition this year, more than ever before. Members of the Student Scientific Paper Competition Committee scored each paper after careful review based on the following criteria.

. General quality of the writing and presentation.
. Clear statement of hypothesis or research issues to be addressed.
. Choice and description of appropriate methodology.
. Presentation of the results.
. Discussion of the results and their significance.

In addition to the five winning papers, the first authors of the two papers listed below were awarded honorable mention. These papers can be found in their respective SIG sessions within the proceedings:

JJ Sarver, BT Smith, R Seliktar
"A Quantitative Analysis of Shoulder Motion Used for Controlling FES Systems in Adolescents with C4 Level SCI."

JP Uhlir, RJ Triolo
"Using Selective Electrical Stimulation of the Quadriceps to Improve Standing in Paraplegia."

I would like to sincerely thank the review committee for this year's competition: Geoff Fernie, Ph.D., Jon Gunderson, Ph.D., Donald McNeal, Ph.D., and Machiel Van der Loos, Ph.D. They faced very difficult decisions in choosing the five winners as most of the papers were deemed meritorious. Very careful consideration was given to avoid any potential conflicts of interest by 1) blinding the reviewers to the authors and their institutional affiliations to the best of our ability, and 2) choosing reviewers who had no association with any of the authors or paper.

On behalf of RESNA I wish to thank the Whitaker Foundation for its support, the judging committee for a difficult job well done, and all the students who submitted papers. I invite students to start planning their research for submission to the 1998 RESNA Student Scientific Paper Competition.

Simon P. Levine
Chair, RESNA Student Scientific Paper Competition

THE AFFECTS OF WHEELCHAIR SECUREMENT POINT LOCATION ON OCCUPANT INJURY RISK

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ABSTRACT

To promote proper wheelchair securement, the ANSI/RESNA Transport Wheelchair Standard currently under development will require that all transport wheelchairs be equipped with four securement points, compatible with belt-type tiedowns. Through computer simulations, the location of these securement points has been found to influence the wheelchair user's response to a frontal crash. This study develops and employs a risk assessment method to compare the crashworthiness of various securement point configurations. Results indicate that securement points located in a zone 1.5" to 2.5" above the wheelchair center of gravity will provide the most effective occupant protection.

BACKGROUND

Recently the ANSI/RESNA Subcommittee on Transport Wheelchairs has agreed that a transport wheelchair must be equipped with four securement points compatible with tiedown securement systems [1]. Wheelchair manufacturers intending to market their wheelchairs as transportable will therefore be required to identify and install appropriate securement locations on each wheelchair model. It has been found through previous studies that the location of these securement points can influence the wheelchair crash response [2]. Based upon these findings it was anticipated that occupant response was also influenced by securement point location. Accordingly the study described in this manuscript was conducted to further investigate this hypothesis.

Automotive manufacturers and consumers have historically sought to compare occupant protection associated with various safety features. Efforts by Viano, et al., and Hackney et al. have addressed the development of a single index or measure that could be used for such comparisons of occupant protection [3,4]. The methods described by these investigators are based upon a comparison of measured biomechanical parameters and kinematic excursions to established human tolerances and limitations. A similar approach, adapted for wheelchair transportation, has been used in this study to evaluate the influence of securement point location on occupant risk to injury.

METHOD

Through the use of computer simulation models, rear wheelchair securement point location was incrementally changed to assess the influence of securement point location on wheelchair occupant frontal crash response. The rigid body model used by this study has been developed using Dynaman software and validated through sled testing to represent a commercially available powerbase [5]. The powerbase, secured using 4-point tiedowns is occupied by a 50th percentile male, Hybrid III, anthropomorphic test dummy (ATD) using an integrated lap and vehicle mounted shoulder belt. The secured forward facing wheelchair and occupant are subjected to a 20g/30mph frontal crash consistent with SAE J2249 WTORS test procedures [6].

Using the powerbase and occupant model described above, a series of simulations were run which incrementally varied the vertical location of the rear securement point, while holding all other conditions constant. Securement point locations spanned a range from 4" below the powerbase center of gravity (CG) located at 11", to 5.5" above the CG. For each of the securement point scenarios, biomechanical measures of the head, neck and chest, along with kinematic values were recorded for comparison to each other and to established injury tolerances and excursion limits. Injury tolerances used in this study were based upon Federal Motor Vehicle Safety Standards (FMVSS) and General Motors Injury

Assessment Reference Values (IARVs) [7,8]. Kinematic limits were as defined by SAE J2249 WTORS dynamic testing performance criteria [6]. The various criteria, listed in Table 1, have been developed to relate Hybrid III ATD measures to injury probabilities in a crash.

Table 1. Injury and Kinematic/Motion Criteria

Injury or Motion Parameter	Equation Variables	Allowable Limit/ Source
Head Injury Criteria	HIC	1000 FMVSS
Neck Flexion	M_{flex}	1681 in-lb GM IARV
Neck Axial Tension	F_{tens}	247 lb GM IARV
Neck Compression	F_{comp}	247 lb GM IARV
Neck Fore-Aft Shear	F_{shear}	247 lb GM IARV
Chest Accel	a	60 g FMVSS
Sternum Compression	C	2" SAE J2249
Forward Head Excursion	Exc_{head}	25.6" SAE J2249
Forward Wheelchair Excursion	Exc_{wc}	7.9" SAE J2249
Forward Knee Excursion	Exc_{knee}	14.8" SAE J2249
WC to Knee Excursion Ratio	Exc_{wc}/ Exc_{knee}	≤ 1.1 SAE J2249

To allow for direct comparison of the various securement configurations, a single index for motion/kinematics and a single index for injury potential were formulated. A Motion Criteria index (MC) based upon equal weighting of kinematic measures with normalization to SAE J2249 dynamic testing performance requirements was developed to compare kinematics of the various crash responses. Equation 1 describes the components of the MC index. Similarly a Combined Injury Criteria (CIC) derived from the weighting of biomechanical measures based upon their injury significance in a crash and normalized to biomechanical tolerances was also developed. Weighting of injury significance to distinct body regions was based upon accident distribution studies from the US and Sweden [3]. Injury significance values from these studies used for weighting of the head, neck and chest are 57%, 14% and 29%, respectively. Following this distribution, the importance of a head injuries can be emphasized due to an increased tendency for permanent disability or death associated with injuries to this region. In the development of Equation 2, describing CIC, each biomechanical measure is normalized to its tolerance value, and multiplied by its associated weighting factor. Where multiple tolerance criteria are defined for a given body region, these values are weighted equally. Biomechanical measures are then summed to arrive at a single combined index value to be used in evaluating overall injury risk.
(Variables used in Equations 1 and 2 are as defined by Table 1.) CIC and MC values can vary from 0 to 1, with higher values indicating a greater risk of associated injury and lower values representing a lesser risk.

$$MC = 0.25\left[\frac{Exc_{Head}}{25.6"}\right] + 0.25\left[\frac{Exc_{Knee}}{14.8"}\right] + 0.25\left[\frac{Exc_{WC}}{7.9"}\right] + .25\left[\frac{(Exc_{WC} / Exc_{Knee})}{1.1}\right] \quad \text{(Eq 1)}$$

$$CIC = \frac{0.14}{4}\left[\frac{F_{axial}}{247\ \text{lb}} + \frac{F_{comp}}{247\ \text{lb}} + \frac{F_{shear}}{247\ \text{lb}} + \frac{M_{flex}}{1681\ \text{in-lb}}\right]_{Neck} + \frac{0.29}{2}\left[\frac{C}{2"} + \frac{a}{60\ \text{g}}\right]_{Chest} + 0.57\left[\frac{HIC}{1000}\right]_{Head} \quad \text{(Eq 2)}$$

RESULTS

Using the biomechanical and kinematic values generated through simulations for each securement point scenario, and Equations 1 and 2, the values of MC and CIC were calculated and are shown in Table 2. A plot of CIC and MC versus securement point location is provided in Figure 1. Values of MC increased from 0.32 to 0.83 as the rear securement point is moved from 4" below the wheelchair CG to 5.5" above the wheelchair CG. Conversely, values of CIC decreased from 0.94 to 0.72 as the rear securement point was raised

incrementally from 4" below the wheelchair CG to 5.5" above the CG.

Table 2. Calculated MC and CIC Values for Varying Securement Point Location

Securement Pt Location Relative to WC CG	Motion/ Kinematic Criteria	Combined Injury Criteria
4" Below	0.32	0.94
2.5" Below	0.33	0.92
1.5" Below	0.36	0.87
0" (At CG)	0.43	0.74
1.5" Above	0.52	0.67
2.5" Above	0.58	0.69
4" Above	0.71	0.69
5.5" Above	0.83	0.72

DISCUSSION

The results of this study evaluating kinematic and biomechanical responses of wheelchair occupants to a frontal crash show that securement point location does influence injury risk. The use of Combined Injury Criteria (CIC) and Combined Kinematic/Motion Criteria (MC) provide a means for comparing various securement point scenarios. Since CIC relates to injury risk integral to the occupant response and MC reflects risks which can be reduced through provision of adequate clear space, an optimization priority should be to first minimize values of CIC. Upon review of Figure 1 comparing injury indices trends to securement point location, it is seen that securement locations just above the wheelchair center of gravity produce the overall most advantageous occupant response. That is, with securement points located 1.5" above the wheelchair CG, CIC is at its minimum and MC continues to increase as the securement point is raised. Based upon these results a "recommended securement zone" located 1.5" above the wheelchair CG to 2.5" above the CG can be defined. Securement points located within this zone will minimize injury risk to wheelchair occupants in a frontal crash.

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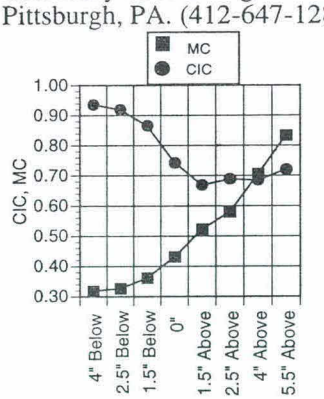

Figure 1. CIC and MC vs. Securement Point Location Relative to WC CG

INTRA-OPERATIVE RECORDING OF ELECTROCORTICOGRAM FOR THE DEVELOPMENT OF A DIRECT BRAIN INTERFACE

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ABSTRACT

This paper reports on our first attempt to record ECoG from the surface of the human motor cortex **during** epilepsy surgery for use in the development of a direct brain interface. We evaluate intra-operatively recorded ECoG in terms of its usefulness for direct brain interface development. Until now, we have recorded only ECoG from electrodes placed for extra-operative clinical monitoring, which were rarely over motor cortex.

ECoG was collected from one subject who repeated two movements. Event-related potentials (ERPs) were identified on 6 of 6 electrodes for the finger contraction and on 5 of 6 electrodes for the pinch movement. These ERPs were used to test a cross-correlation based detection method for a direct brain interface. The best detection accuracy achieved was 100% hits and 35% false positives.

BACKGROUND

A direct brain interface is an interface that detects specific voluntary activities of the brain and triggers appropriate external responses. Most research on direct brain interfaces with human subjects has relied on brain activity observed from the scalp (1, 2). However, electrodes placed on the cortical surface provide increased spatial resolution, frequency resolution and freedom from artifact (3). In recent years, information from the surface of the human cortex has been utilized in the development of direct brain interfaces (4, 5, 6).

Our previous work (4, 5) utilized electrocorticogram (ECoG) collected from the surface of the cortex with electrodes that were placed for long-term pre-surgical monitoring of epilepsy patients. These electrodes were usually placed over the temporal lobe. Subjects performed up to 6 distinct actions over 2 hours. Event-related potentials (ERPs) were identified for several of these actions, usually on a quarter of the electrodes or less (5). A maximum of 1 or 2 actions per subject produced good detection accuracy. The best detection accuracies were on the order of 92% of hits detected with 2% false-positives (5).

The likelihood of recording ERPs and the quality of the ERPs recorded would be increased if electrodes could be placed over motor cortex. Since it is not practical to place electrodes over the motor cortex through the temporal burrholes used for the placement of the pre-surgical electrodes, another means of obtaining access to the motor cortex of conscious subjects is desirable.

Access to the temporal lobe of a conscious patient through a temporal craniotomy is required for intra-operative language mapping prior to resection of cortical areas related to the onset of epileptic activity. Since placement of electrodes over motor cortex is possible through a temporal craniotomy, this procedure provides an opportunity for collection of data particularly relevant to our research. However, the intra-operative data collection environment introduces its own set of restrictions and problems for recording ECoG. This paper reports on our first attempt to record ECoG related to voluntary actions in an intra-operative setting.

RESEARCH QUESTION

The research question examined in this paper is whether data collected under the restrictions imposed by intra-operative data collection can be useful for the development of a direct brain interface. The restrictions imposed by the operating room environment are caused by the interaction of three factors: electrical noise, limited time, and limited access to the subject.

METHODS

The subject for this research was a patient in an epilepsy surgery program who was scheduled for intra-operative language mapping. Prior to surgery, the subject participated in a training session to gain a familiarity with the voluntary actions he would perform during the intra-operative data collection session. In the training session, the subject practiced the actions until each repetition produced a burst of EMG activity about a half second in duration followed by a period of relaxation of at least 4 seconds.

Fifteen minutes were allocated for data collection during the surgery. After the intra-

operative language mapping was completed, the neurosurgeon slid a six-contact strip of electrodes under the cranium over the pre-central gyrus with contact number six placed over facial motor cortex (determined by stimulation during language mapping).

Unfortunately, the reference electrode used for the language mapping was removed along with the rest of the mapping electrodes and the surgeon was unable to replace it prior to data collection. A replacement reference electrode was placed on the arm because of limited subject access, but was moved to the leg when an electro-myographic (EMG) artifact became apparent.

Data was recorded from the electrode strip and from EMG electrodes placed over the active muscle. The subject performed self-paced repetitions of a pinch movement and a middle finger contraction.

The placement of the reference on the leg caused a significant electrocardiogram (EKG) signal to be recorded along with the ECoG. Therefore, the first step in the digital data analysis was to eliminate this unwanted signal by replacing the reference for each electrode with a reference created from the average of the non-adjacent electrodes.

Prior to averaging, the EMG triggers were visually evaluated to eliminate false triggers created by broad-band electrical noise from surgical equipment. The ECoG was then lowpass filtered (cutoff at 2.5 Hz) with a 6th order Butterworth filter, which was applied twice for zero phase distortion. Triggered averaging (with EMG trigger) of the first half of each data set was used to create averages of the ECoG for each data channel from 3.0 seconds before to 3.0 seconds after the trigger. Averages were identified as valid ERPs through the comparison of a pre-activity interval and a peak signal interval (4). The peak-mean ratio (pm-ratio) was defined as the mean of the peak signal interval divided by the 95% predictive interval amplitude calculated from the pre-activity interval. Only averages with pm-ratios greater than 2.00 were selected for cross-correlation.

ERP templates developed from the first half of the data for each action were cross-correlated with the ECoG from the second half. A detection was identified when the cross-correlation statistic exceeded an experimentally determined detection threshold. An identified detection was considered a 'hit' if it was within one second of the time at which a movement occurred (as recorded by EMG onset). The detection threshold was selected to maximize the difference between the percentage of movements detected (hit percentage) and the percentage of incorrect detections (false-positive percentage).

RESULTS

The subject performed 25 repetitions of the pinch movement with the reference electrode on the arm and 50 repetitions with it on the leg. Ten of the repetitions were eliminated because of electrical noise, leaving 65 usable repetitions of the pinch movement. Only 44 repetitions of the finger movement (reference on the leg) were performed because of intra-operative time limitations.

The averages of the ECoG for each of the 6 electrodes are shown in Figure 1. Six of 6 averages for the finger movement and 5 of 6 averages for the pinch movement contained ERPs with a pm-ratio greater than 2.00.

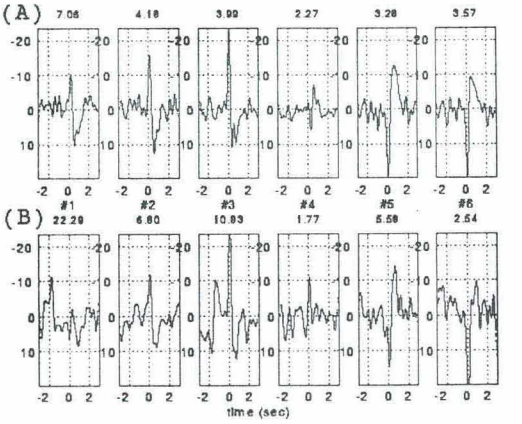

Figure 1: Averages from the first half of data sets with pm-ratio shown above each. (A) finger contraction, (B) pinch movement.

Electrode	Finger Hit %	Finger False%	Pinch Hit %	Pinch False %
#1	96	45	87	39
#2	82	26	83	61
#3	96	33	100	56
#4	100	51	—	—
#5	100	38	97	50
#6	100	35	97	48

Table 1: Detection accuracy on electrodes containing ERPs for both movements. ERPs from the first half of the data sets were cross-correlated with ECoG from the second half.

ECOG RECORDING

Table 1 shows the performance statistics for detection using cross-correlation of ERP templates from the first half of the data set with ECoG from the second half. The best detection achieved for finger contraction was 100% hits and 35% false positives. The best detection for the pinch movement was 97% hits and 48% false positives.

DISCUSSION

The 15 minutes of intra-operative time available for data collection were sufficient for the subject to repeat two voluntary actions for a total of 119 repetitions. The familiarity with the actions which the subject gained in the training session eliminated the need to explain the actions during surgery. Therefore, all available time could be spent in equipment setup and repetition of the actions.

ERPs were identified in ECoG from a much higher percentage of electrode locations than had been achieved with extra-operative data collection. The detection accuracy for the finger contraction was considerably better than for the pinch movement. However, even this accuracy does not approach the degree of accuracy achieved with the best extra-operative data.

A possible reason for the lower than expected detection accuracy is the EKG from the placement of the recording reference. Although the average reference removed the EKG contaminant, it could not compensate for the decreased dynamic range available for representation of the ECoG that resulted from recording the larger EKG signal. The presence of the EKG in the recorded data required that the 8 bits available for the digital data representation cover a 600 microvolt range to accommodate the EKG signal, instead of the 150 microvolt range required for ECoG.

CONCLUSION

The intra-operative data collection methods reported here proved sufficient to record ECoG related to two distinct actions in an extremely short data collection session. The ECoG from a high percentage of the electrode locations proved to contain identifiable ERPs for one or both actions. The quality of the ECoG was reduced by the inadvertent recording of EKG. However, the quality of the ERPs related to the finger contraction was still sufficient for detection accuracies of 100% hits and 35% false positives which provides a good starting point for further refinement of the detection methods.

This case shows clearly that data collected under the restrictions imposed by intra-operative data collection will be useful in the development of a direct brain interface. As experience is gained in the intra-operative data collection process, the quality of the data should improve. An increase in the number of actions or the number of repetitions of each action performed may also be possible. Intra-operatively recorded ECoG will better enable us to address questions about the location and distribution of ERPs related to specific actions and help to define the methods best suited to accurate detection of these ERPs — steps which are vital to the development of a direct brain interface.

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QUANTITATIVE ASSESSMENT OF BELOW-KNEE AMPUTEE GAIT

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ABSTRACT

With the recent advancements in energy-storing prosthesis technology, the quantitative assessment of below-knee amputee gait is becoming more critical as a tool for comparative understanding of prosthesis function. The inverse dynamics approach common in the literature contains limitations in the application to amputee gait. These limitations are assessed and an improved method is outlined.

BACKGROUND

Of the more than 50,000 amputations performed in North America annually, over 90% involve the lower limb (1). The design of prosthetic foot and ankle components was changed considerably in the mid-1980's with the advent of energy-storing prosthetic feet, now known as Dynamic Elastic Response (DER) feet. DER prosthetic feet are designed to store energy through mid-stance in a leaf spring arrangement and then return that energy at toe-off to assist the amputee with limb advancement. This technology has met with contrasting opinions in the literature regarding clinical effectiveness. As more designs surface each year, a definitive assessment of the clinical effectiveness of DER feet gains increasing importance.

Inverse dynamics has been the primary analysis model used in amputee gait analysis to estimate the net mechanical power and work required to move the body through a gait cycle (2). When gait analysis is performed on the below-knee amputee, markers are placed on the prosthesis and adjustments are made in the software for the center of mass and inertial characteristics of the prosthesis. However, Prince et al. have recently pointed out the incorrect assumptions of inverse dynamics when applied to ankle-foot devices: the model assumes a rigid foot articulating about the ankle, and there is no accounting for the energy dissipation and recovery in the viscoelastic material of the cosmetic cover (1). This research will represent the first quantification of these limitations in an effort to improve the analysis techniques.

RESEARCH QUESTIONS

What are the limitations of present below-knee amputee gait analysis techniques, and what specific improvements might be made?

METHOD

The DER foot used for the study was the Carbon Copy High Performance (HP) foot (Ohio Willow Wood, Mt. Sterling, OH). This foot contains three carbon-fiber deflection plates for energy storage.

Materials testing was performed at the Ohio State University Mechanical Testing Laboratory on the HP foot A custom device was designed to couple the inverted pyramid on the prosthetic foot to the MTS machine. The foot was aligned into maximum plantarflexion of 11° with respect to the pylon coupler, allowing for forefoot contact with the base of the MTS machine and subsequent deformation of the foot upon crosshead lowering.

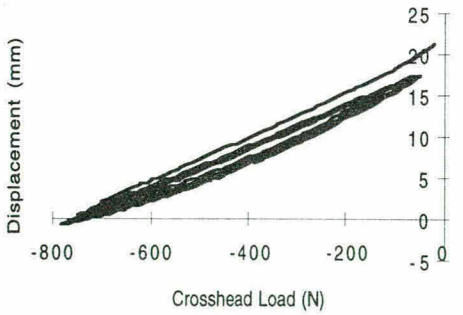
The foot was loaded to a maximum of 800 N, based on recommendations for fatigue

testing by Toh, et al. (3) and results for vertical propulsive force in Arya, et al. (4). In order to determine the presence of hysteresis or viscoelasticity, the foot was loaded cyclicly between 10 and 800 N, at 0.5 Hz. Load vs. deflection curves were obtained. A Philips PMX portable x-ray unit (Philips Medical Systems, Shelton, CT) was positioned in front of the MTS machine to record medial-lateral images of the foot at various stages of deformation. A known reference length bar of 11.76 cm was positioned in the field of view to normalize varying degrees of magnification. The MTS machine revealed slight fluctuations in the set loads of no more than ±4 N. Images were recorded at these approximate loads: unloaded, 200 N, 300 N, 400 N, 685 N (approximating body weight), and 800 N. The films were digitized and processed using the public domain NIH Image program[a] to obtain deflection angles at incremented vertices along the length of each deflection plate.

RESULTS

Figure 1 shows the load-deflection curve for the foot under cyclic loading between 10 and 800 N.

Figure 1: Cyclic Loading of Carbon Copy HP Prosthetic Foot



Once a consistent cycle is reached, the loading-unloading cycles in Figure 1 form a loop, showing the presence of hysteresis in the foot structure. Representative energy loss in the hysteresis loop for a single cycle was 1128.31 N-mm. This figure is 14.9% of the input energy.

Figure 2 shows the NIH Image result from loading the foot to 800 N, with incremented vertices superimposed on the deflection plates. These vertices were used to track the angle of deflection throughout the loading increments.

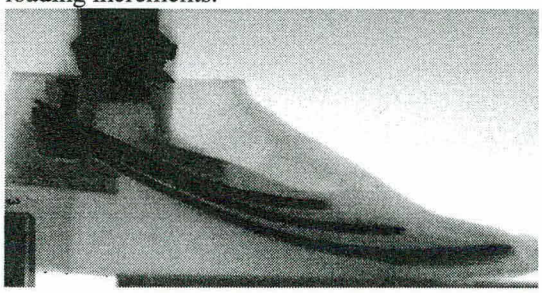
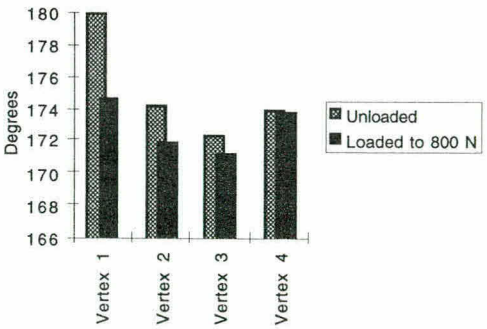


Figure 2: Digitized X-ray of HP foot loaded to 800N

When compared to the image for the unloaded foot, measurement of angle at the vertices superimposed on the large plate shows that deflection occurs along the length of the plates as in cantilever beam loading, as shown in Figure 3. Similar results were obtained for each plate at each loading increment.

Figure 3: Large Plate Vertex Angles



Furthermore, the image in Figure 2, at maximum deflection, shows that the "ankle joint" center of rotation assumed by inverse dynamics is actually the only rigid portion of this DER foot.

DISCUSSION

Hysteresis in the foot structure confirms the presence of energy dissipation with each cycle, most likely due to the cosmetic foam cover. Energy dissipation is not accounted for in the inverse dynamics approach. Its presence in the gait cycle can result in erroneous conclusions regarding energy stored and returned by the prosthetic foot. As this factor is prevalent in the literature as a means for comparison of different DER feet, this represents a serious inadequacy

The x-ray imaging technique has not been used previously in the literature, and provides insight into the deflection characteristics of individual plates inside the foot. Figure 3 confirms that bending does not occur at a focused vertex, as in the ankle joint center assumed by inverse dynamics. Instead, overall bending accumulates along the length of the deflection plates. In gait analysis, an improved link segment model would allow for a changing center of rotation throughout the gait cycle and would require more complex geometry in the shank segment for accurate moment calculations.

This research confirms that errors are present when inverse dynamics techniques are applied to DER prosthetics studies, both in the calculation of moments and in the measurement of energy. The research is part of a larger study in which a custom algorithm incorporating Prince's power flow technique (1) will be applied to gait analysis of unilateral trans-tibial amputees wearing the HP foot. The gait analysis phase of this research will assess an improved analysis model utilizing an independent measure of force from the ground reaction vector to more accurately assess the energy storing capabilities of DER feet. The improved technique will be compared to results from standard inverse dynamics, demonstrating the outcome of the quantified errors. Additional material testing will be used to develop a computer model of the HP foot, validated by gait analysis. With the improved energy return analysis, the model can be modified to better serve the energy and frequency requirements of different patient populations.

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[a] NIH Image written by Wayne Rasband at the U.S. National Institutes of Health and available from the Internet by anonymous FTP from zippy.nimh.nih.gov

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MULTI-LEVEL COMPRESSION APPROACH TO SIGN LANGUAGE TELEPHONE

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ABSTRACT

While digital video transmission and video conferencing methods have improved significantly over the last few years, the transmission of sign language for individuals who are deaf via this medium still remains a problem. Desktop video teleconferencing systems accommodate the bandwidth limitations of both analog and digital (ISDN) telephone channels by reducing the frame rate, while preserving voice quality and only minimally degrading image quality. Sign language transmission requires fidelity to movement (consistent and high frame rate), and requires reasonable image quality only in the areas around the hands and face.

This paper presents a multi-level compression approach which uses a newly developed technique to identify the hands and face from the remainder of each video frame. This allows for a very lossy, high compression of most of each frame, while retaining the visual quality necessary to identify hand shapes and read facial expressions. By taking advantage of this additional compression and eliminating the speech signal, enough bandwidth is recaptured to allow an acceptable frame rate that maintains the fidelity of human movement necessary to represent sign language.

BACKGROUND

More than 750,000 people use sign language as a first language in the United States. Remote communication via sign language however, is very limited. TDD, or Telecommunications Devices for the Deaf, is a common means of communication. Here, each party has a keyboard on which they can type and have the output appear at the other end. Similar systems are also available with communications taking place over the Internet. The drawback to these systems is that users can only express themselves in type-written form. In addition to being slower than either natural speech or sign language, the reliance on typed text presents a serious limitation to many native signers whose English spelling and grammar may be limited. For a native signer, expression in sign language is exceptionally robust, allowing for emotion and other suprasegmental information.

A more ideal solution would allow users to view a video screen and actually see the other person signing. Today's video conferencing standards and the networks they must be carried on are inadequate for transmitting intelligible sign language. In order to transmit video over common media such as the Plain Old Telephone System (POTS) and ISDN, offering approximately 28.8 kbps (kilobits per second) and 128 kbps respectively, compression algorithms were developed to reduce the number of bits needed to represent the data. Galuska et al (1992) show that the bandwidth needed for real time full video transmission is significantly greater than the bandwidth available on common networks.

In order to allow deaf individuals a means of communication by signing over these common networks, compression algorithms needed to be implemented to severely reduce the amount of data being transmitted. Galuska (1990) used a luminance valley detection algorithm to extract edge information from a signer. By sending only "outline" information, an acceptable frame rate was obtained and the intelligibility of the communication was found to be acceptable by Harkins et al (1991).

Walsky (1995) showed that although the signal content of movements used in sign language are in the range of 2-3 Hz, predicting a frame rate of 4-6 frames per second. An actual frame rate of 10-12 frames per second is required for a person to perceive smooth biological movement. This defines the lower limit of frame rate for a video teleconferencing system useful to deaf signers.

Most compression algorithms used today have a priority scheme such that audio quality is preserved, then image quality, and finally frame rate. These algorithms, when used over ISDN networks allow realistic frame rates in the one-half to 4 Hz range (less for POTS) when there is extensive movement as there is in signing. The priority scheme for intelligible sign language transmission is frame rate followed by image quality with audio being of no importance.

RESEARCH QUESTION

By changing the priority scheme for compressing video data for transmission, is there a way to achieve high enough movement fidelity without compromising intelligibility? By using a robust skin identification algorithm and a multi-level compression algorithm, compression can occur such that 10-12 frames per second can be achieved over an ISDN network without compromising image quality on important regions of the image. (i.e. face and hands)

METHOD

The approach used to segment the images into skin and non-skin regions is robust in that it can accommodate variations in skin pigmentation in a single subject, as well as differences in pigmentation across multiple subjects. This approach is also relatively insensitive to complex backgrounds and varying illumination. A more detailed explanation of this algorithm is discussed by Saxe and Foulds (1996).

Swain and Ballard (1991) showed that color histogram intersection is an effective method for color-based segmentation. This technique, based on the RGB color space is, however sensitive to ambient lighting conditions. This straightforward histogram matching technique was used by Ahmad (1994) and robustness problems were addressed in Saxe and Foulds (1996).

Unique Contribution to Skin Detection

A modified approach, developed by the author and based on color histograms is employed for this algorithm. The HSV (Hue, Saturation, Value) color model was introduced to account for differences in lighting within a single frame as well as across multiple frames. The HSV values correspond to wavelength, excitation and illumination respectively. Hue and saturation, invariant to changes in illumination, are used construct the color histogram and provide a robustness to illumination. Iteration was introduced to allow for tighter thresholds to be set, thereby enhancing the segmentation from complex backgrounds.

An initial region of skin chosen by the subject is used to create the Control Histogram and initiate the algorithm. Each patch in the image is intersected with the control patch to create a first level of segmentation. Next, a new control seed is automatically chosen from the segmented patches and the iteration continues.

The image, represented in RGB form is converted to HSV using an algorithm from Foley et al (1992). Hue is represented as an angle (0-360 degrees) and saturation as a real number 0 to 1. The histogram's two axes (hue and saturation) are discretized into N x M bins. Each of the bins in the histogram are initialized to zero. A given patch's histogram is populated by incrementing the value that represents each pixel's hue and saturation values (i.e. HIST[hue,sat]).

To segment the image, the algorithm compares each patch from the image with the control patch. The match score is the number of instances in common between two histograms C and I. A hit, signifying that two patches match, occurs when the match score is greater than some threshold value.

After the first iteration, which makes use of the initial region of skin chosen by the subject, the algorithm must make a "smart" choice as to which control patch to use for the next iteration. By limiting the selection to only patches that were found in previous iterations, the algorithm will likely choose a patch that is similar to the initial control, however different enough to account for small variations in a subject's skin pigmentation. When the selected control seed generates no new hits, the algorithm assumes the detection is complete. Several results are shown in the figures below.

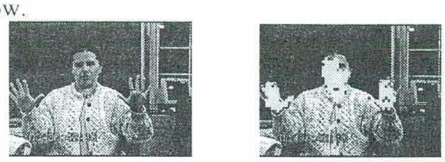

Figure 1: Original and segmented images.

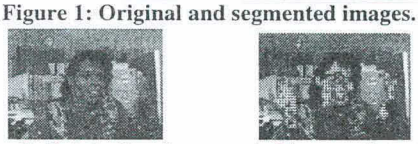

Figure 2: Original and segmented images detecting a person with darker skin pigmentation.

Two level image compression

Using the skin detection algorithm, it is possible to segment each frame into skin and non-skin regions. Since sign language intelligibility is partially dependent on the recognition of hand shape and facial expression, those regions of this image can be compressed moderately, preserving their recognition. The remaining non-skin region can be compressed to a much higher degree, thus gaining an overall increase in frame compression.

THE EXPERIMENT

Experiments have been performed with images captured on a Sun Sparcstation 20, with the two-level compression accomplished using MATLAB's Image Processing Toolbox.

A segment of a videotaped session was processed off-line. Each frame was segmented into skin and non-skin regions. The percentage of pixels representing skin was calculated. A JPEG compression technique, based on the Discrete Cosine Transform, was applied to the image with

modest compression for skin regions, and high compression for non-skin regions.

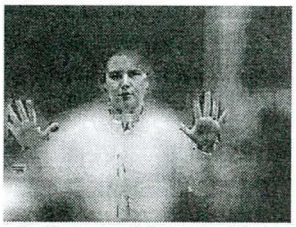

Figure 3: Processed image with two level compression, leaving hands and face sharp.

RESULTS

The goal of this project is to provide an acceptable frame rate of 10 frames per second without damaging image quality to the point of unintelligibility. In order to transmit 10 frames per second over an ISDN network, the maximum data rate would be in the order of 1600 bytes per image. Several image sizes, compression ratios and color levels were tried in order to achieve this goal. Table 1 summarizes some of these results, showing the image size in pixels, represented in color or grayscale, the number of bytes needed to represent the multi-compressed image and the expected frames per second over an ISDN network. This information was generated for the single video frame shown in Figure 3. The image contained the subjects face and two hands. Approximately 10 percent of the image was detected as skin.

Image Size	Color	Bytes	FPS
320 x 240	color	3349	4.8
320 x 240	grayscale	3267	4.9
160 x 120	color	1404	11.4
160 x 120	grayscale	1367	11.7

Table 1: Results for multi-compression algorithm.

A frame rate of 4 to 5 frames per second can be achieved over the POTS by showing only skin regions with no background. Continuous video sequences have also been tested on a frame by frame basis with very similar results. In multiple frame sequences, user interaction for the skin detection algorithm is required only by the initial frame. Subsequent frames use the histogram from the previous frame as an initial control. Multiple frame examples will be shown on videotape and are also available from the world wide web at http://www.asel.udel.edu/gesture/. These include both finger spelling and American Sign Language examples.

DISCUSSION

It is apparent that the current network infrastructure that links homes together is not nearly capable of delivering real-time, full sized, color video to home computers. Current video conferencing systems cannot deliver the necessary frame rate to transmit sign language intelligibly. Edge detection systems have been produced that maintain high fidelity and provide intelligible communication, however, users have not widely accepted these systems. Such special purpose compression requires expensive non-standard hardware.

The approach presented in this paper adds a computationally efficient segmentation technique which can be adapted to existing teleconferencing standards. The new JPEG standard provides for multi-level compression of regions within an image and is readily adaptable to the skin segmentation algorithm. Other image compression algorithms such as MPEG, H.261 and proprietary methods, are also usable.

This research potentially allows commercially available video teleconferencing systems to offer a cost effective option that accommodates the needs of sign language users.

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ADAPTIVE SHARED CONTROL OF A SMART WHEELCHAIR

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ABSTRACT

The NavChair Assistive Wheelchair Navigation System (Levine, et al., 1990) is being developed to reduce the cognitive and physical requirements of operating a power wheelchair. This paper presents experimental results evaluating the NavChair's method for automatically allocating control between the wheelchair and its operator.

BACKGROUND

The NavChair Assistive Wheelchair Navigation System (Levine, et al, 1990) is an adaptive shared control system being developed to provide mobility to those individuals who would otherwise find it difficult or impossible to use a power wheelchair due to cognitive, perceptual or motor impairments. The NavChair shares vehicle control decisions with the wheelchair operator to reduce the motor and cognitive effort of operating a wheelchair.

The NavChair prototype is based on a Lancer power wheelchair [1] augmented with an IBM-compatible 33MHz 80486-based computer and an array of 12 sonar sensors. During operation, the NavChair system interrupts the connection between the wheelchair's joystick and wheel motor controller. The user's indicated path of travel, the wheelchair's immediate environment, and current task requirements are used to determine the control signals sent to the wheelchair motors, and hence, the direction and velocity of the wheelchair (Jaros et al, 1993).

The NavChair provides task-specific navigation assistance in the form of several distinct operating modes, each of which distributes control differently between the wheelchair and the operator. Currently, operating modes are implemented for collision-free travel in open environments (General Obstacle Avoidance mode), passage through doorways or between closely spaced obstacles (Door Passage mode), and navigation guided by hallway walls (Automatic Wall Following mode).

The presence of multiple operating modes necessarily creates the need to choose between them. One alternative is to make the wheelchair operator responsible for selecting the appropriate operating mode. While this may be an effective solution for some users, it would present unreasonable demands on others. Instead, a method for the NavChair to automatically select the correct operating mode on its own has been developed (Simpson et al, 1996).

AUTOMATIC ADAPTATION IN THE NAVCHAIR

The NavChair uses a probabilistic reasoning construct known as Bayesian networks (Charniak, 1990) to make its adaptation decisions. Bayesian networks can be thought of as a means of organizing information to allow the convenient application of a form of Bayes' theorem:

$$P(\mathbf{H}|\mathbf{e}) = P(\mathbf{e}|\mathbf{H})P(\mathbf{H})/P(\mathbf{e})$$

where, in our applications, $\mathbf{H}$ represents the NavChair's operating modes, $\mathbf{e}$ is the set of observations, $P(\mathbf{e}|\mathbf{H})$ is the probability of observing the most recent evidence given a particular operating mode, and $P(\mathbf{H}|\mathbf{e})$ is the probability that a particular operating mode is the most appropriate operating mode given the available evidence.

Figure 1 shows the Bayesian network currently used by the NavChair. Each node (oval) in the network represents a probabilistic variable and each arc (arrow) represents a probabilistic relationship between two variables (i.e., an arc from node A to node B means that the value of P(B|A) can be specified). As shown in the figure, the NavChair's network makes use of the NavChair's location within its global environment and the identities of objects in its immediate surroundings to make adaptation decisions.

The NavChair's location is tracked within a topological map, and is represented as a vector, each element of which is the probability of the NavChair being in a particular location (room, hallway, etc.) specified within the map. So, if there are three locations specified by the NavChair's internal map, the NavChair will represent its location as a three-element vector

of probabilities in which the largest element will correspond with the most likely location of the NavChair. Within the Bayesian network, each location has its own set of probabilities as to how likely each operating mode is in that location. For example, within a particular narrow hallway, wall following and door passage mode might be considered more likely (and thus have higher probabilities associated with them) than general obstacle avoidance (which would have a correspondingly lower probability) whereas the opposite could be true in a spacious room.

Objects in the wheelchair's proximity are identified from the same sonar signals that the NavChair uses to avoid obstacles. Currently, the NavChair has methods for identifying both walls and doors, which are used to calculate the probability of a wall being to the side of the NavChair and a door being in front of the NavChair. Both of these probabilities are used as input for the Bayesian network.

During operation, the NavChair constantly updates the probabilities associated with its location and the presence (or absence) of doors and walls in its surroundings. Every time these values change, they are fed into the Bayesian network and a new decision regarding the most appropriate mode for the wheelchair is made. If the decision to change operating mode is made, the values that define the new mode (what behavior to exhibit, the chair's maximum speed, how close the chair can approach obstacles) replace the values that defined the previous operating mode.

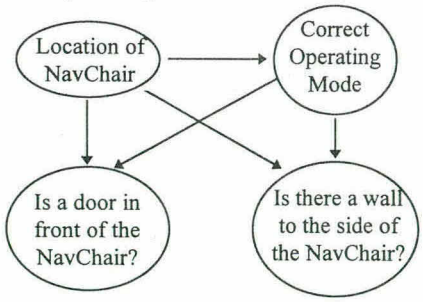

Figure 1. Bayesian network used to make adaptation decisions in the NavChair.

Experimental Methods

Eight able-bodied subjects (5 male, 3 female) ranging in age from 24 to 35 years participated in this experiment. Subjects were randomly divided between two experimental conditions distinguished by whether the NavChair (Automatic Adaptation condition) or the experimenter (Wizard of Oz condition) made adaptation decisions.

Each subject performed fifteen trials of the navigation task shown in Figure 2. The experimental task was chosen to require the NavChair to make several transitions between operating modes in order to achieve optimal performance. As can be seen in Figure 2, the navigation task was divided into four distinct areas. The "ideal" (as determined by the experimenter prior to the experiment) operating mode for each area of the task environment is shown in Figure 2.

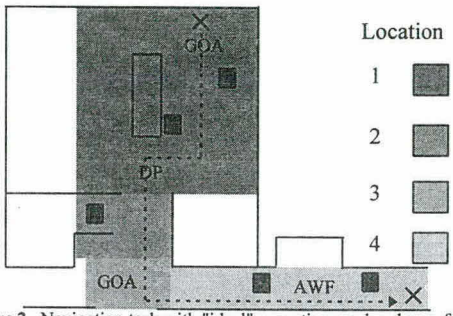

Figure 2. Navigation task with "ideal" operating modes shown for each area. GOA = General Obstacle Avoidance; DP = Door Passage; AWF = Automatic Wall Following

In each trial, subjects started at the same location and navigated to the same target location by the same path. During each trial, the NavChair recorded data separately in each of the four areas to allow a task-specific analysis of the performance measurements. The performance measures recorded during the experiment are shown in Table 1. Subjects were given a maximum amount of time to move through each of the four areas of the task. Only those trials in which the subject successfully navigated all four areas within the allotted time were counted as successfully completed.

Performance measures for each subject in each of the four areas were averaged across all fifteen trials. These averages were compared with one-way ANOVAs (each ANOVA corresponding to a different performance measure and area). A significant difference was defined as one whose p-value was less than .05.

Results

The results for the experiment for all four areas are shown in Table 1. Collision measures

(front, side or back) with a value of 0.00 for both conditions are omitted from the table. No learning effect was observed for any of the performance measures.

By most measures there was very little difference between the two conditions. In particular, neither automatic adaptation nor Wizard of Oz caused any failures to successfully complete the task. Wrong decisions in area 4 was the only measurement found to have a significant difference between conditions. Although these differences were not significant, the Wizard of Oz condition did allow the chair to maintain a higher average speed (except in area 3), move through areas in less time (except in area 4), and maintain a greater distance from obstacles.

Measure	Average Auto. Adapt.	WOz	Area
Wrong Decisions	1.18	0.00	1
	0.00	0.00	2
	0.47	0.00	3
	1.38	0.00	4
Speed (mm/sec)	390.38	412.49	1
	229.00	244.83	2
	605.30	585.33	3
	689.74	712.58	4
Time (sec)	30.97	24.36	1
	15.00	12.10	2
	6.90	6.97	3
	12.09	13.15	4
Min. Obst. Clrnc. (mm)	538.72	522.23	1
	268.91	287.21	2
	813.51	818.26	3
	454.90	465.64	4
Side Collisions	1.00	0.50	1
Back Collisions	0.25	0.25	1
Success	100%	100%	N/A

Table 1. Results from experiment averaged across all subjects within each condition.

Discussion

The NavChair's automatic adaptation mechanism must meet several design criteria (Simpson et al, 1996), the most important being that the method must make the correct operating mode decision as often as possible. In this experiment, the NavChair's automatic adaptation mechanism compared favorably the "optimal" adaptation mechanism, namely an expert human making adaptation decisions.

Another important criterion is that the NavChair avoid frequent mode changes, which could lead to an uncomfortable ride for the operator. The NavChair's adaptation mechanism contains built in controls that limit the frequency with which it can change modes, which limit the possibility that it will rapidly switch between different operating modes.

Decisions must also be made in real-time. In this experiment, the automatic adaptation mechanism did not interfere with normal operation of the wheelchair. In particular, the low number of collisions and lack of failure on any trial both imply that the NavChair was able to devote most of its computational resources to providing navigation assistance to the operator rather than making adaptation decisions.

Conclusions

The NavChair's automatic adaptation mechanism represents a viable solution for the NavChair's adaptation needs. The adaptation mechanism satisfies the specified design criteria by making correct adaptation decisions, maintaining ride comfort, and minimizing the use of computational resources. Additional experiments have also been performed which demonstrated similar results when the NavChair was operated by voice control. This approach to automatic adaptation is also being applied to other assistive technologies. A recently completed experiment demonstrated the ability of a different Bayesian network to make adaptation decisions for a one-switch row/column computer access system (Simpson, et al., 1996).

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Manufacturers

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