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This Rehabilitation Engineering Center provided, for this space in the preceding issue of the Bulletin (BPR 10-32), accounts in brief of 12 different projects. For the present issue, the Harvard/M.I.T. REC has elected to focus on a description of the historical development of a single project, in order to show how "practical aids for the handicapped" come into being as a result of the cooperative efforts of various "informed and committed individuals and organizations."

A TSPS Telephone Console for Blind Operators: Technology Transfer in Action

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Abstract

Microprocessor-controlled braille displays, augmenting standard telephone operator consoles, have enabled two blind operators to perform successfully in a Southwestern Bell Telephone System central office. Technology transfer is being achieved through manufacturing development supported by American Telephone and Telegraph.

INTRODUCTION

Braille displays have been installed in two Southwestern Bell telephone operator's consoles, providing vocational opportunities for blind individuals as TSPS telephone operators. A TSPS (Traffic Service Position System) operator handles most operator-assisted calls (pay phone, collect, hotel, credit card, etc.) but not directory assistance calls. Some 35,000 TSPS operators are employed in the United States.

The standard TSPS console is usually operated with approximately 80 lights or lighted keys (pushbutton switches) and a 12-digit (soon to be upgraded to 14) numeric display for calling and called telephone numbers, time and charges for pay phone calls, and the time of day. The braille display makes all this information immediately available to the blind operator in tactile form. The information is grouped into a series of messages, either in English or accepted telephone industry mnemonics. The message displayed at any given time contains the information which most recently changed. The operator can override the automatic message selection and request a display of any information desired. An electronic "scratch pad" allows the operator to take notes and store any information which may be needed later.

Two blind operators in Little Rock, Arkansas, are using these braille displays, developed and built at the Massachusetts Institute of Technology. Both operators received rehabilitation training at the Arkansas Enterprises for the Blind and are now employed by Southwestern Bell Telephone Company (SWB). They received on-site training as TSPS operators from regular SWB training personnel.

The performance of one of these operators is rated as outstanding, while the other is rated as satisfactory. They work standard shifts, according to their seniority. Very little extra accommodation at the working site has been necessary for either operator.

ORIGIN OF THE PROJECT

At the 1974 Conference on Engineering Devices in Rehabilitation, held in Boston, Massachusetts, a paper on "An Electromechanical Numeric Braille Display: A Familiar Tactile Representation of Electrically Encoded Digital Signals" was presented by an engineer from M.I.T. (1). It reported on BRLCOM-(2), an electronic multimeter with braille output, which used a solenoid-driven braille cell as the output display. These cells were modular and used the standard braille spacing, so that they could be stacked to form braille lines of any length.

These cells had only four dots. Initially, it appeared to be easier (and adequate) to make a four-dot cell, since braille numbers use only the upper four dots of a six-dot braille cell. The braille cells developed for use in BRLCOM were developed under a grant to M.I.T. from the E. Matilda Ziegler Foundation.

An engineer from New England Telephone (NET) who also presented a paper at this conference (3) asked if this technology could be used to provide a braille display of numbers for blind TSPS operators. As a result of that discussion, an engineer from the Massachusetts Commission for the Blind and an engineer from M.I.T. visited a TSPS site in Quincy, Massachusetts, on May 28, 1974(4). Further discussions over the summer led to an informal proposal and a request to NET by M.I.T. to embark on a joint project — to equip a TSPS site for blind operators. Unfortunately, this request came at a time when NET had a surplus of sighted operators and they were unable to justify such a project to aid the handicapped.

SELECTION OF SOUTHWESTERN BELL AS THE INITIAL INSTALLATION SITE

Subsequently, a training specialist at Arkansas Enterprises for the Blind (AEB) had interested Southwestern Bell Telephone Company (SWB) in a project to employ blind TSPS operators. When he received a commitment

from SWB that a blind operator would be hired and trained, he began the construction of a simulated TSPS console. The various lamps would be sensed by a light probe. Since this training specialist was aware of BRLCOM, he felt it would solve the problem of providing numeric data to a blind TSPS operator(5). At AEB's request, an M.I.T. engineer visited both AEB and SWB in September, 1975, to obtain technical information necessary to design the interface between the BRLCOM numeric display and the TSPS console, and to develop a way to transfer the lamp data to a remote display.

In the time intervening between the 1974 conference and the first visit to AEB, the M.I.T. engineer had redesigned the four-dot braille cell into a simpler six-dot full braille cell module and was life testing several modules for use in a paperless braille computer terminal. Twenty of these cells were constructed under a second grant from the E. Matilda Ziegler Foundation (6).

INITIAL AGREEMENT

SWB, AEB and M.I.T. began negotiations to reach an agreement on patents, liability, and other factors. The first draft of the agreement was unsatisfactory and during the period that followed there were several communications among the principal parties and a delay of several months while differences were discussed. Even before an agreement was signed, however, it was decided that the construction would begin with support from several sources. The braille modules would be those previously built with support from the E. Matilda Ziegler Foundation; additional components would be funded by AEB; engineering and technical effort would be provided by the Harvard-M.I.T. Rehabilitation Engineering Center (supported by the Rehabilitation Services Administration), and SWB would assist with information and the commitment to provide employment for a blind TSPS operator.

DESIGN OF THE BRAILLE DISPLAY

While the various problems of the agreement were still being considered, two engineers at M.I.T. approached the adaptation of the TSPS console for use by the blind in two different ways. First, they considered the problem as it was presented to them, namely the addition of a braille numeric display only. Secondly, the entire scope of the problem was considered. At that time the development of microcomputers had become sufficiently advanced to make their use economically and technologically feasible, and the decision was made to use a microprocessor even if only to control the numeric display. However, the power of the microcomputer is such that it didn't make sense to limit its utilization, and the engineers therefore proceeded to work on the complete task of providing almost all information from the TSPS console to a blind operator.

After studying some training material sent from SWB, one of the engineers from M.I.T. went to Little Rock in June 1976, to obtain a better understanding of the operational aspects of the system. It was a real introduction which included operating a live board within one hour of first arriving at the site — leaving the engineer emotionally drained. At the time of this second visit, the hardware interface design was reviewed with SWB engineering personnel. The information gained in these two trips to Little Rock, supplemented by later telephone conversations with SWB engineers and operators, provided the specifications for the system. During the time the hardware was being designed and constructed, an M.I.T. undergraduate student, working on a part-time basis, wrote the essential control program for the microprocessor(7).

INSTALLATION

The first unit was completed before the written agreement was finalized. On February 9, 1977, the three groups involved held an "implementation" meeting, where the roles of each party in the installation, training and ongoing use of the equipment were determined. After the meeting, the formal written agreement was speedily signed.

The initial installation of equipment took place during the week of March 14–18, 1977. The system worked, although numeric display data was not received properly by the microprocessor. The necessary changes were made, and one week later the system was up and running. Shortly after this, the first blind operator began training.

TRAINING PROCEDURES

Two major differences developed between training provided for the blind versus the sighted operators. Since no training materials were available in braille, it was decided that training for blind operators would be done on a one-to-one basis, with the instructor reading the material while the blind trainee made braille notes for later study. (The normal ratio is one-to-six trainees per instructor.) Instead of practicing on a simulated console with paper tape and magnetic tape inputs, the blind trainees used a "directionalized" live console under close supervision. A directionalized board is one for which the calls can be selected so that the trainee encounters the variety of calls recently studied.

The live board training was found to be very effective and the time involved for this phase of the training was essentially the same as that for sighted trainees.

Most of the increased training time for blind operators was attributed to their use of the Register. Usually, the Register is an inkprint file at each operator position containing emergency numbers, rate and routing information, etc. Each blind operaor brailled her own Register, facilitating its use since each organized the contents in

a pattern familiar to her. The braille Register is contained in a 5000-card Rolodex file.

OPERATION

During the early months of operation of the braille TSPS display, Banks or Perkins braille writers were used for taking notes and remembering data. This prompted the M.I.T. developers to conceive and implement a braille "scratch pad" into the system, using the existing braille display, by adding a keyboard and some computer emory and by modifying the microprocessor's control program.

In early January of 1978 a second braille TSPS display was installed and the first unit was modified to include the braille "scratch pad". In addition, the microprocessor computer operating program was updated to reflect features which had been added to the TSPS system since the installation of the first braille system. When first installed, the second system's performance suffered because the TSPS console to which it was connected had much more electrical noise than the console for the first braille display. Necessary design modifications were worked out and installed in both displays during the first week of February 1978.

The first blind operator hired at SWB (in March 1977) was employed by them until May, 1978, at which time she moved to another city. She later returned to Little Rock and was rehired in May 1979. While working as a TSPS operator, her working time (the average time spent per call), a measure of productivity, has been consistently much better than the average for normal sighted operators(8). In February 1979, a second blind operator was hired. Her performance has been at or near the average level for sighted operators. Both operators are currently employed.

THE PACIFIC BELL SYSTEM

At about the time the first M.I.T. system was installed at SWB, a console of a different design for blind TPS operators was installed at a Pacific Bell (PB) TSPS site in Mountain View, California(9). This system, developed by Telesensory Systems, Inc. (TSI), under support from the Sensory Aids Foundation, both of Palo Alto, California, uses voice output rather than braille to provide the TSPS status information and numbers. A second important difference was the respective interconnections to the telephone company switchboards. Whereas M.I.T. and SWB had worked out an arrangement for a hardwire connection between the TSPS console and the microcomputer braille display, TSI had to adapt 12 of their OPTACON(10) cameras to read the numeric display optically. They also constructed an overlay panel for the TSPS console, with individual photoelectric devices to sense the state of each lamp. Two such systems were in use for about one year.

TECHNOLOGY TRANSFER

The success of the M.I.T./SWB program and of the similar program at Pacific Bell (PB), prompted AT&T to consider a follow-up program to produce a commercially available system, to encourage AT&T operating companies to employ blind TSPS operators. A meeting was held in Palo Alto in May 1978, at which personnel from AT&T and Bell Laboratories reviewed the results of the M.I.T./SWB and TSI/PB programs with all parties concerned. A plan to produce a commercial display for blind TSPS operators was prepared.

First, Bell Laboratories developed a TSPS/TIPS (*T*SPS Information Processing System) interface which could serve as a standard interface, satisfying all Bell System standard practices. Then AT&T contracted with TSI to develop a braille/audio display system, combining speech output similar to that used previously by TSI for the Speech Plus™ calculator and the "Talking OPTACON", with a braille output display based on their soon-to-be-released Versabraille. An M.I.T. engineer participated in TSI's initial design work, providing memoranda on the requirements for such a system based on his experience with the Little Rock installation. The M.I.T. engineer also outlined the message structure used in the Little Rock system, and proposed a message structure based on the longer, 20-cell braille display to be used with the TSPS/TIPS display.

The current contract from AT&T is for three units. The first will be delivered to Bell Laboratories for testing and development of operating procedures. The other two will be installed at an operating company for evaluation under conditions of actual use.

Epilogue

This report was deliberately organized to present the historical development of this project to illustrate how practical aids for the handicapped result when informed and committed individuals and organizations work cooperatively, over time, to blend and combine their respective talents. A remarkable constellation of abilities and resources is represented — perception to identify the vocational opportunity; inventiveness to produce the essential hardware and software; diligence to persist in application and training; cooperation to combine different approaches into an optimum system; responsibility in pushing forward when various discouraging organizational and funding problems developed. The project also demonstrates a happy blend of different sources of support. Private foundations funded preliminary, very experimental efforts; Federal resources, principally the RSA, made development possible; and now private industry, small and mammoth, is taking over to deliver the goods on a significant scale, in a cost-effective manner to those handicapped who inspired the efforts in the first place. The blind TSPS operators, who by skill and

energy proved the system practical, share significantly in the success of the project.

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TECHNOLOGICAL SYSTEMS FOR SEVERELY DISABLED PEOPLE

Northwestern University Quad Chair System

The new 24-volt model of the "Quad Chair System" was completed and 600 units have been built for national distribution by a commercial facility. These mobility aids are allowing many severely disabled individuals to return to school, work or other useful endeavors.

The Northwestern University System is programmable to serve the needs of individuals with different degrees of disabilities.

μ-DEC:

The design of μ-DEC (a microprocessor-based distributed environmental control) has been completed. Six units are being fabricated by this laboratory for clinical evaluation. Plans are being completed to have this unit commercially available by mid-1980.

A compatible bed control and television control have been developed to complete the μ-DEC system.

Low-Back Recliner Wheelchair

A low-back recliner with a retractable headrest has been developed for persons with low-level cervical lesions (C-5 to C-7). The unit is added to an E&J Model 3P electric powered reclining wheelchair; the only modification required is standard height backrest uprights, to replace the longer recliner uprights.

In the upright position, this unit allows access to the hand grip for body stabilization during reaching (Fig. 1), yet gives full head and shoulder support when reclined (Fig. 2) for resting and relief of tissue pressure.

Azimuthal Control

Prior to the development of the type 3P (24-Volt) powered wheelchair, an azimuthal control system was designed and tested with the Type 33 chair. Efforts are under way to modify and improve the controller for installment on the newer type chair.

Wheelchair Control Evaluation System

A wheelchair control evaluation system has been developed to facilitate selection of an appropriate controller for the MED Quad Wheelchair System. The evaluation unit consists of a rechargeable battery-operated wheelchair simulator unit which indicates the direction of wheelchair travel via LED display, and a slotted wheelchair lapboard which provides for easy, stable placement of a "Dudley" short-throw joystick or arm disk. This evaluation tool allows a therapist to determine an appropriate controller and simulate its mounting position on a manual wheelchair prior to prescription of an electric wheelchair (Fig. 3).

Evaluation of the system is under way in conjunction with the Rehabilitation Institute of Chicago Occupational and Physical Therapy Departments.

The wheelchair simulator will soon be commercially available. It can be used with several different types of controllers, including sip and puff.

Microcomputer-Based Communication System

Field evaluations of a microcomputer based communication and control system are continuing. Two systems have been constructed and are in daily use by individuals with cerebral palsy. The first system had been installed in a user's home for 2

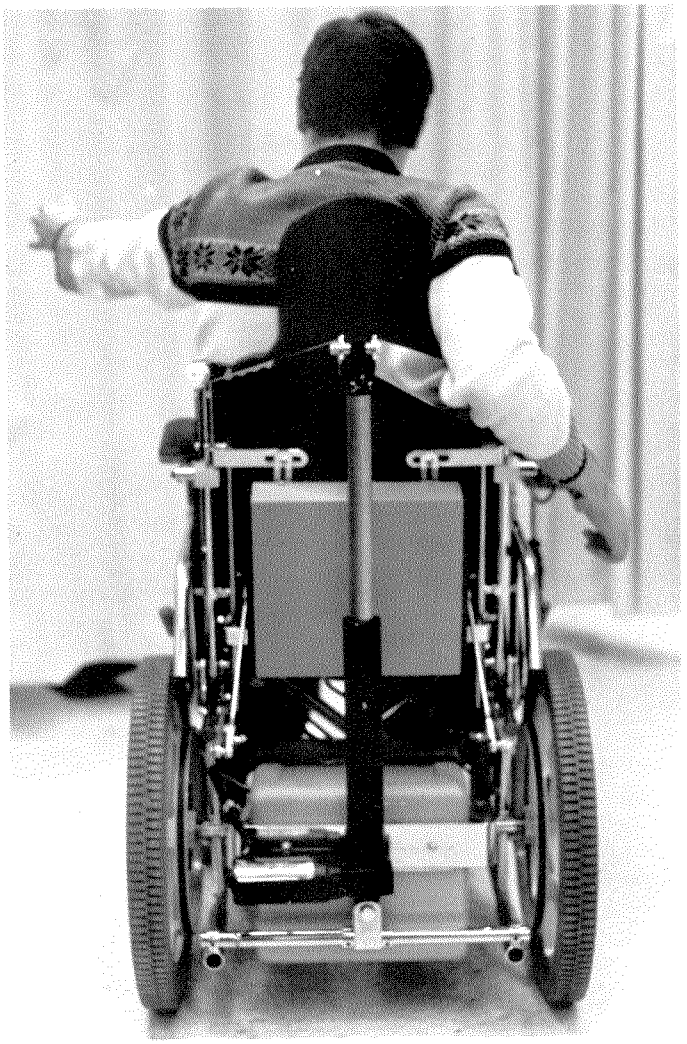

FIGURE 1.
The headrest is fully retracted allowing persons with limited trunk stability to use the hand grip for support when reaching.

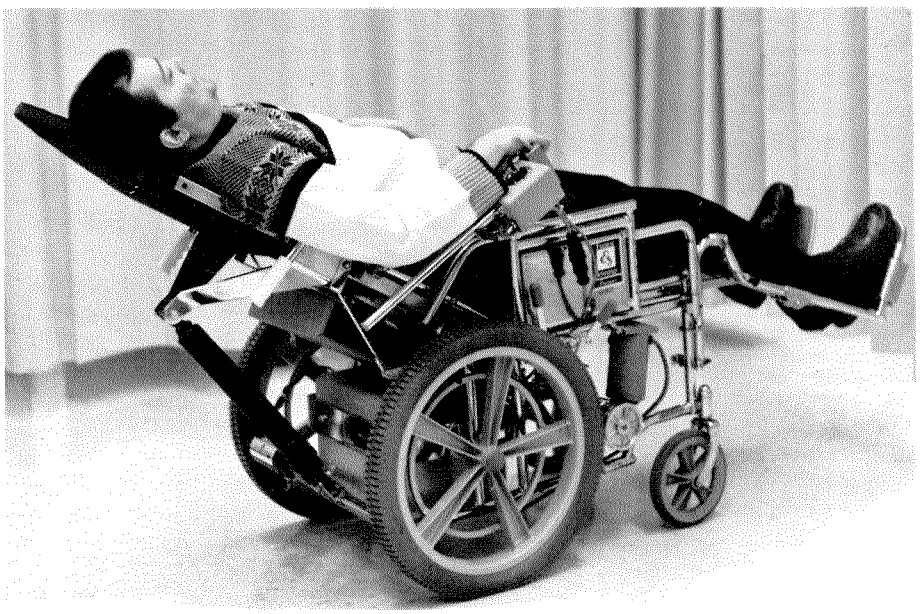

FIGURE 2.
When the backrest is reclined, the headrest slides into position to support head and shoulders.

months as an aid in text generation and information storage and as a telephone controller. This system was then transferred to the individual's work site where it has been in use during the last 2 months.

The other system was installed in a second person's home as a personal communication aid. This system has been in operation for 3½ months and is used primarily for conversational message generation and correspondence.

A third system is under construction to replace a vocational minicomputer-based system used by a volunteer member of the center's staff. Efforts are being made to extend the anticipatory text generation feature of the microcomputer communication system. The impact of this research will be to increase the written communication rate of a severely disabled person.

Communication Aids

A manual spelling board has been developed to be used as an interim communication aid for persons who are temporarily nonverbal or those who are waiting for a more definitive communication device. The spelling board has been designed so that a particular letter can be located by row and column. To maximize rate of letter selection, the letters on the board are arranged according to statistical frequency of occurrence in the English language.

Other developments regarding communication aids include revolving book holders capable of providing access to four books in a minimum of desk space, and specialized controls for operation of electric communication boards.

Eating Aid

An eating aid is being designed to increase eating independence for individuals with limited trunk stability and minimum arm function. Versatility of the components used allow for fitting this aid to the user's functional capabilities and situational needs. Both a standard and a portable design are being developed.

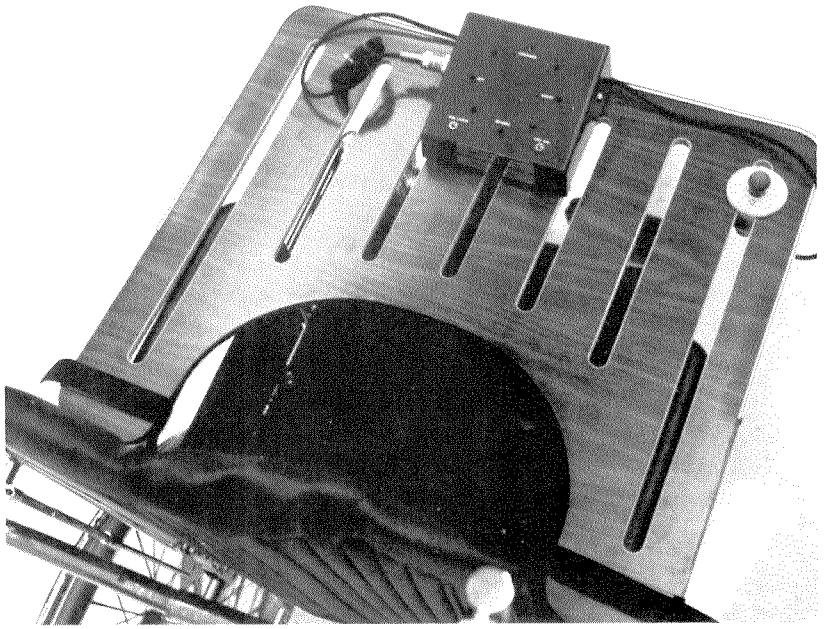

FIGURE 3
Electric wheelchair control evaluation system.

ORTHOTICS

Power Hand Orthosis

The electrically powered wrist hand prehension orthosis from Sweden was evaluated on one C-5 — C-6 quadriplegic patient unilaterally. Patient acceptance of the orthosis was exceptional. His 3-point palmar prehension and activities of daily living were greatly increased, despite moderate to severe spasticity in the upper limbs.

However, the connectors used between the orthosis and controller were too delicate. As a result, the user returned frequently for the repair of the connectors and eventual replacement of one pair.

Shoulder Subluxation Orthosis

This lightweight and cosmetically acceptable orthosis aids in the reduction of shoulder subluxations. The orthosis consists of a polyethylene shell which encroaches on the head of the humerus via a chest and shoulder strap. Patient acceptance has been good and self donning and doffing created no problems.

Elbow Extension Orthosis

This orthosis, constructed of cellulose acetate butyrate and Plastizote foam, is used to reduce elbow flexion contractures. By spot heating in the elbow area, and gradually increasing the amount of extension in the orthosis, elbow flexion contractures are minimized.

This orthosis has been used on 3 patients as an alternative to serial casting.

BIOMATERIALS

Two important accomplishments occurred during this reporting period. First, the work in developing methods for evaluating corrosion has been largely incorporated into a pending national standard on corrosion resistance of surgical implant metallic alloys. Second, a viscosity facility has been established which has the capability of measuring such diverse substances as doughing acrylic bone cements and hyaluronic acid.

BIOMECHANICS UNIT

During the last 6 months, work has continued in various areas related to internal joint replacement. Significant progress was made in the areas of knee ligament mechanics, knee orthotics, artificial knee joint component development, and stress analysis of the hip with prosthesis.

Knee Ligament Mechanics

Transducers for measuring the force in ligaments of anatomical specimens (buckle transducers) were used to study the forces occurring in knee ligaments for various knee loads, in both normal knees and in knees with prostheses. The anterior cruciate was of primary interest. The goal of this work was to determine whether an anterior cruciate that was retained during total knee surgery would continue to function in a relatively normal manner. The test results showed that it would. The results also showed that all the ligaments are affected somewhat by the presence of the prosthesis and that this effect is quite sensitive to component placement on the bone. This work will continue towards our goal of an understanding of the influence of prosthesis design and placement on the functioning of knee ligaments.

Knee Orthotics

The work on knee ligaments led to some projects on knee orthoses. In one of these projects, the pistoning force of knee orthoses with various orthotic joints was measured. Strain gages were installed on the side bars of the orthosis, and the bar force measured during knee flexion under force, and under passive flexion. The results showed negligible difference between a simple hinge, a polycentric, a posterior offset hinge, and an optimally placed hinge developed by our center, for flexion under force. Although the last joint gave slightly lower bar force, the difference in bar force due to repeated application of the orthosis was greater than differences between designs. During passive flexion, the polycentric joint gave significantly lower bar force, but the passive condition was not thought to be as important as the loaded flexion.

These results led to design of a new joint which more closely simulates the functioning of the natural knee joint. This joint should give negligible pistoning force during loaded or unloaded flexion, so it shows promise as an improvement over existing joints. This device is now being more fully evaluated.

Artificial Knee Joint Component Development

Results from earlier stress analyses of tibial components and from the knee ligament mechanics work were incorporated in a component design which is being developed in conjunction with Howmedica, Inc., a major implant manufacturer. The component is specifically intended to allow retention of the anterior cruciate ligament. Clinical trials of this component have begun, and although early results are encouraging, long term followup is necessary to determine if this component is superior to other available components.

Stress Analysis of Total Hip Prostheses

The performance of titanium as a hip prosthesis material was evaluated using three-dimensional finite element models. Titanium is thought to be a better material for total hip femoral components because it is only one-half as stiff as the cobalt-chrome alloys used in conventional hip components, and will load the bone in a more physiological manner. It is thought that the undesirable bone resorption in the femur that is seen in long term total hips is due to unloading of the bone by the component. The stress analysis results show that titanium is significantly better than the cobalt-chrome, but that it still loads the bone to only 50 percent of normal. Inclusion of a metal collar at the base of the neck of the component, however, increases the bone stresses to approximately 70 percent of normal. A titanium component with collar has been designed, and prototype models are being manufactured in collaboration with an outside company. Tests will be run with these components to verify the model predictions.

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Restoring Upper-Limb Function through Functional Electrical Stimulation

These studies are the core area of research in the center. The purpose of the project is to develop and evaluate systems employing FES to provide control of paralyzed muscles. The systems developed provide control of lateral pinch and release or prehension and release. Six quadriplegic subjects with C-5 or C-6 level motor function are presently involved in outpatient evaluation of these systems. Patients from spinal injury units at both the Cleveland Veterans Administration Medical Center and Highland View Hospital are involved in these studies. These studies are being performed in conjunction with the VA Rehabilitative Engineering Research and Development program, and the current status is detailed elsewhere in the Bulletin (see "Development of Upper-Limb Orthoses Employing Electrical Stimulation" under VA RER&D Service Programs). The work pursued in the area of functional electrical stimulation is closely allied with that ongoing in the Applied Neural Control Laboratory and the Engineering Design Center at C.W.R.U. In these studies, the feasibility of new upper-limb systems is being investigated, and a radio-frequency powered and controlled implantable stimulator is being developed.

Restoration of Upper-Limb Function through Tendon Transfer

Tendon transfer provides a viable means of restoring motor control to paralyzed limbs. Proper procedure requires that the available muscles for transfer be identified, the potential functional loss due to altered anatomy be established, the properties of the transferred muscle be measured, the resulting new function at surgery be observed, and the post-surgical training and care be carefully followed. Our center has worked in all aspects of this problem in order to provide improved methods of tendon transfer.

The primary emphasis of this study has been on intraoperative monitoring

The activities of the Rehabilitation Engineering Center at Case Western Reserve University are directed toward restoration of function in patients with mobility disorders. Studies are directed toward development of a comprehensive program for restoration of upper-extremity function involving both tendon transfer and functional electrical stimulation. Mobility studies include development of control sources for powered wheelchairs, and evaluation of the therapeutic effects of functional electrical stimulation in gait. In addition, the REC performs community rehabilitation engineering service functions.

of muscle properties during electrical stimulation. To date, measurements have been made for the excursion of 59 upper-limb muscles and the length/ tension characteristics of 42 of these in 40 subjects. Table 1 shows a tabulation of the muscles studied. These studies have enabled us to determine properties of the muscle which are critical in the final result of the surgical procedure. First, excursion measurements provide information on the total physiological range of a muscle. Excursion is obtained by measuring muscle length change while lengthening by pulling on the severed tendon and during shortening while stimulating the muscle. Comparing this measurement with the required excursion enables us to determine whether a muscle is sufficient to provide the desired function. Assessment of length-tension information provides quantitative measure of the proper length for reanastomosis of the tendons. The shape and peak of the curve indicated the length at which maximal force is generated and the force decrement with changing length. Following anastomosis, the desired function can be assessed qualitatively by electrical stimulation of the muscle. This procedure has been used routinely in all of the tendon transfers performed on spinal-cord injury patients over the past 4 years. The results of the preliminary results of this study have been published. (1)

In the next period, these studies, as well as studies of methods of preoperative analysis and post-operative care, training, and evaluation will continue. We are presently using electrical stimulation to retard adhesion formation and strengthen muscle, and biofeedback as a training aid.

TABLE 1
Muscles studied intraoperatively for excursion and length-tension properties

Muscle	Number of muscles studied	
	Excursion	Length-Tension
Brachioradialis	24	18
Pronator Teres	5	4
Flexor Pollicus Longus	2	0
Flexor Digitorum Superficialis (ring finger)	4	2
Flexor Carpi Radialis	9	6
Palmaris Longus	1	0
Flexor Carpi Ulnaris	1	0
Extensor Carpi Radialis Longus	4	5
Deltoid (posterior head)	7	5
Extensor Carpi Ulnaris	1	1
Extensor Digitorum Quinti	1	1
TOTAL	59	42

Therapeutic Effects of FES for the Correction of Gait Abnormalities in Children with Cerebral Palsy

Peroneal nerve stimulation, delivered in synchrony with the patient's gait cycle, is being evaluated as an orthotic and therapeutic aid for the correction of foot-drop in hemiplegic CP children. Evaluation is performed by analysis of gait in conjunction with the Gait Evaluation Laboratory at the Cleveland VA Medical Center. Foot placement patterns, surface myoelectric signals corresponding to ankle flexor or extensor activity, and knee and ankle flexion and extension angles are measured in both legs. At each testing session, gait parameters are measured before, during, and after a 20-min period of walking with the stimulator. Initially, baseline data are collected and the short-term effects of using the electronic peroneal orthosis are evaluated. At this point, the patients take the orthosis home with them for daily use, then come in for evaluation of the long term effects at 2-week intervals for the first month and at 1-month intervals thereafter.

Results thus far, for five patients that have been evaluated, show in all cases that a dramatic and immediate improvement in gait is obtained when the electrical stimulation is in use. Contrary to our expectations, which were based on experiences with stroke patients in this laboratory and on reports from other laboratories with CP patients, the automated dorsi-flexion produced by the direct application of the electrical stimuli is not sustained once the stimulator is turned off. In this regard, no "carry-over" effect has yet been observed despite two subjects having received daily FES for nearly one year.

Preliminary analysis of the data, however, shows that more subtle "carry-over" effects are apparent from chronic use of the FES. These include a reduction in the incidence of "toe-walking" and an increase in heel contact duration and foot-flat duration during the stance phase of gait. EMG data are currently being analyzed to determine if this apparent relaxation of the ankle extensors is due to a reduction in flexor-extensor coactivation, or to increases in flexor activity and/or decreases in extensor activity. Clinical evaluation of all the patients receiving the FES has shown that they remain free of any fixed contractures.

Because of the possible benefits of FES for relief of spasticity, an adjunct study has just been commenced with a separate group of CP children. Such patients receive daily FES from exercise stimulators which cycle on and off automatically while the patient is seated.

Shoulder Wheelchair Control

Studies dealing with control of mobility have resulted in the development of a system which utilizes shoulder position to control the velocity and turning rate of electrically powered wheelchairs. The shoulder position wheelchair controller is intended for C-4 level spinal cord injury persons as an alternative to the conventional contoller for motion impaired individuals.

Figure 1 shows a block diagram illustrating the various components of a conventional wheelchair control system, the shoulder position controller and the training configuration. The system has been designed with a "plug compatible" philosophy. The joystick controller of a conventional proportional powered wheelchair (e.g. the Everest & Jennings "3P" series) is replaced by the shoulder position transducer, a mode switch and the interface electronics package. The interface electronics package is housed in a 6cm x 15cm x 15cm box. It contains the power

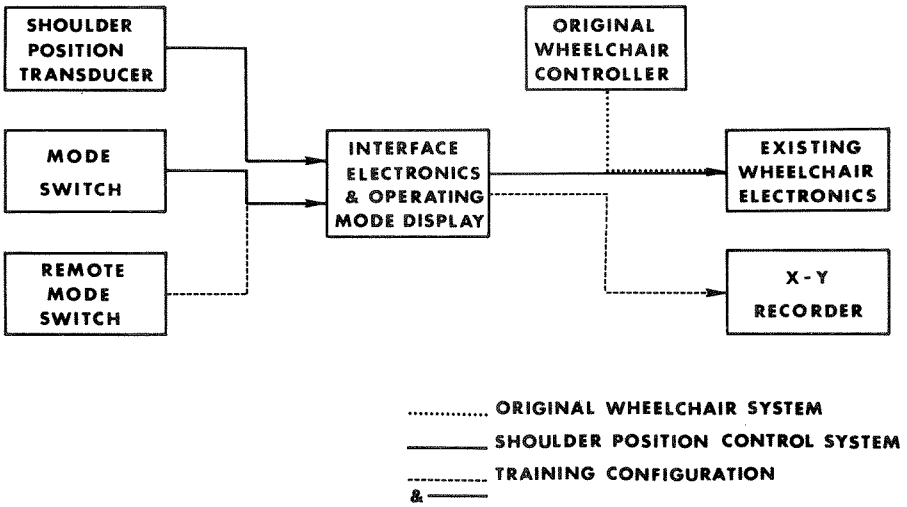

FIGURE 1
Block diagram of the components of the wheelchair system.

switch, operating mode indicator lights, and various connectors for the transducer, mode switch, and output, as well as all the interface circuitry.

The shoulder position transducer is a two-axis device. It is mounted on the user's chest with a harness or double-sided adhesive tape. A sensing arm extends from the transducer body and is secured to the shoulder with tape. The control signals which are sensed are proportional to shoulder elevation/depression and protraction/retraction, relative to the sternum. Two-axis proportional control signals are derived by electromagnetic coupling. The transducer consists of a matrix of sensing coils (fixed to the transducer body) and a single driver coil which attaches to the position sensing arm. The driver coil is excited by constant low-level high frequency current. As the position sensing arm is moved with reference to the body of the transducer, the energy coupled into the sensing coils varies. The differential output-voltage of a symmetric pair of coils is a measure of the single-axis motion. This results in a small, rugged, two-axis position transducer with no parts which will wear out. A mode switch is used to control the idle/active state of the system; this can be a headrest switch, a chin switch, or an EMG switch. On the prototype system, a headrest switch approximately 10cm high is used.

The system simply "plugs in" to the joystick control cable and utilizes the existing wheelchair electronics with out modification. This lends itself to easy interchanging of controllers. A photograph of the system is shown in Figure 2.

Operation of the system is as follows: when the system is in an idle state, the transducer is functionally disconnected from the system, allowing the operator to move his shoulder freely. Activating the mode switch performs two functions: first, it defines the operator's shoulder position upon activation as a zero reference, or null point; secondly, it toggles the system into an active state. Shoulder movement from this null point, which can be anywhere in the subject's useable range of motion, will cause the

FIGURE 2
Subject using the shoulder position wheelchair controller

wheelchair to move. Elevation/depression of the shoulder controls the forward/rearward speed and protraction/retraction of the shoulder controls the turning rate (into the direction of the shoulder motion). The system will remain active with the defined zero reference point until the mode switch is again operated, at which time the system will toggle back into the idle state. The zero point is redefined each time the system enters the active state.

A preliminary training program has been used to train two individuals to operate their powered wheelchairs with the shoulder position controller. Emphasis was placed on actual wheelchair control as early in the training program as feasible. Initially a series of control tasks, with an x-y recorder as feedback, is used to familiarize the operator with the concept of two degree of freedom (two-axis control of the transducer). This also serves to develop an initial skill with the system. Tasks such as range of motion, point-to-point positioning and path following are used. Supervised wheelchair control is conducted after satisfactory completion of tests with an x-y recorder. To date a total of four C-4 level injury persons have used the shoulder position controller with no difficulties. The technique offers advantages such as non-impaired head movement, vision or use of a mouthstick. Since the transducer is worn beneath the clothing, the system is cosmetic. It alleviates the relative-motion problems (chin poking) in rough terrain which are inherent with chin controllers.

Future work involves the development of video training aids to simplify the training task and lower costs, while at the same time they provide the user with motivation and competition (through T.V. games)—and fitting the system to additional patients to continue further evaluations.

Evaluation of Neuromuscular Control in Cerebral Palsy Patients

Patients Services

Studies are being initiated to measure quantitatively the degree of voluntary motor control, and the contributions of muscle stretch reflexes and passive visco-elastic tissues to the total stiffness at a joint in spastic patients. These studies will aid in the diagnosis and followup of spastic patients being considered for corrective surgery and also the CP patients involved in the FES studies. Equipment is being constructed to make measurements of torque, position and EMG signals from both plantar and dorsi-flexor muscles at the ankle joint. These parameters will be measured both under isometric conditions and during imposed rotation of the joint. Studies with patients should begin in the summer of 1980.

The REC is involved in providing both inpatient and outpatient rehabilitation engineering services. Inpatient services have ranged from development of specialized assistive aids to development of a wheelchair control system. Center personnel actively participate in inpatient rounds,home evaluations, and outpatient spinal cord injury clinic and upper extremity prosthetics clinic. In addition, we provide certain job-site evaluation and modification for the Bureau of Vocational Rehabilitation. (In the next period, we hope to expand this component of our center.)

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BACKGROUND

The UT-Rehabilitation Engineering Program was initiated within the Department of Orthopedic Surgery at the University of Tennessee—Center for Health Sciences in September 1974, with financial support from local private sources. The early focus of the program was to provide rehabilitation engineering services to physically handicapped children throughout the Memphis area. A feasibility study award from the Rehabilitation Services Administration of DHEW in July, 1976, followed by a center grant award beginning in April, 1977, permitted the UT-REP to develop applied research and training components and participate as a REC within the DHEW-sponsored network. Subsequent support from RSA and now the National Institute for Handicapped Research (NIHR) has permitted initiation and completion of a number of applied-research projects.

In addition, the center has been able to form additional affiliations and add an adult service component as a result of state support from the Division of Vocational Rehabilitation. The REC now functions as an integral component of the health care system serving the mid-south area.

Concepts and related technical devices for meeting the needs of the young severely handicapped population usually seem to have been developed from a narrow viewpoint and in a haphazard fashion. Rarely has a comprehensive systems approach been taken in which the multiple needs of this population were considered and solutions developed in a systematic

Continued

manner. For example, no system of assistive devices currently exists which will accommodate the changing needs of the young paraplegic as he progresses from infancy into school age activities, on into higher educational settings, and finally into the work world.

Similarly, seating systems are not available that will provide the necessary sitting stability and mobility for cerebral-palsied individuals as they progress from preschool, to school age, on to higher educational pursuits, and finally into the work world.

Other severely involved individuals of educable intelligence are not considered candidates for formal training or vocational habilitation—because they cannot communicate effectively.

Early solutions to problems of mobility, seating, and communication can greatly enhance their potential to receive a basic education, specialized training, independence in activities of daily living (ADL), and ultimately vocational placement.

In general terms, the two core areas comprising the major thrust of the UT-REC supported by NIHR/HEW are (i) seating and mobility, and (ii) ADL independence, with emphasis on the needs of the young congenital amputee, the young paraplegic, and the brain damaged child.

It is our premise that, if a purposeful adult life is to be achieved by an individual with severe disorders of a congenital or childhood origin, physical and vocational habilitation must begin at an early age. To this end, medical, technical, and counseling support must be closely integrated with the individual's educational and life objectives through the developing years into adulthood.

Our founding philosophy has been, and continues to be, that any research project initiated should be based upon a clearly demonstrated clinical need in an area where there is insufficient knowledge and related clinical experiences to satisfactorily resolve the clinical problems defined.

In the clinical area involving physically handicapped children, sporadic efforts by the commercial sector have been the primary source of technical resources for problem solving over the years. The remaining challenges are tremendous. Most creative minds with technical training tend to be overwhelmed by the problems that can be clearly defined, but first-generation solutions can be provided with available clinical and technical knowledge. The major effort that is required at this time is for applied research and development to affect short and intermediate term problem solving, during which time the limits of current knowledge can be defined and realistic plans developed for the initiation of more basic research studies. To proceed otherwise is to deprive the young handicapped population of access to technology which can have a profound and immediate positive impact on the quality of their daily lives.

In summary, it is the core area research focus of the UT-REC to develop concepts and related assistive devices to enhance the life potential of young individuals with severe neuromuscular involvement with emphasis on their seating, mobility, and ADL needs.

ORGANIZATION AND MANAGEMENT

State-wide Program

The establishment of the state-wide Rehabilitation Engineering Program within the University of Tennessee has initially involved two campuses of the University. There is potential for future involvement of other southeastern universities.

The two primary components of the program are the clinical center in Memphis, functioning under the department of Orthopedic Surgery, and the Rehabilitation Engineering Education Program functioning under the department of Engineering Science and Mechanics in Knoxville. The daily operation of the Rehabilitation Engineering Program is the responsibility of the Executive Committee consisting of the medical, technical and educational directors.

Memphis Center (UT-REP)

As previously mentioned, RSA and now NIHR support has been obligated towards the development of applied Research & Development aspects of the clinical program located in Memphis. Programatically, the program is organized in terms of four overlapping areas of activities: research and development, evaluation and research utilization, education, and rehabilitation engineering demonstration unit. To date, RSA/NIHR support has been focused in the first two areas, which will receive the major emphasis in this introductory report. Although areas 3 and 4 have not been officially supported, activities in these areas have been initiated and will be discussed briefly.

The rehabilitation engineering program in Memphis has both medical and technical directors who share the administration of the program. Dr. Robert E. Tooms is the Principal Investigator and Medical Director, and Mr. Douglas A. Hobson is the Collaborative Investigator and Technical Director in the NIHR-sponsored REC. Steps have been taken recently to form an advisory committee, comprising primarily consumers and professionals from the community, which would report directly to the program directors. The program directors work closely with an advisory board, which is made up primarily of individuals representing the agencies responsible for founding the Rehabilitation Engineering Program in Memphis.

COOPERATIVE ACTIVITIES

The program has established affiliations with many hospitals and agencies throughout the Memphis and mid-south area. These affiliations provide a resource pool of professional consultants—and of consumers with diverse physical handicapping conditions, who can serve as research subjects in the clinical evaluation of new concepts and devices. Affiliation with the schools of engineering and special education at Memphis State University provides a ready source of students to participate in center activities. The growing number of private physicians, therapists, school teachers, parents and other individuals interested in the program has been important to the center's development, growth, and integration into the community. Cooperative activities with other agencies support several parallel research projects which are primarily related to the application of rehabilita-

tion engineering technology in the special education classroom.

Of significance was the establishment of a fee-for-service schedule for rehabilitation engineering services for vocational rehabilitation clients. This development resulted from a two year demonstration service project supported by Tennessee Division of Vocational Rehabilitation which was completed in October, 1978. A report on the experience gained during the demonstration project has been published and is available upon request.

Finally, in addition to the cooperative effort with local agencies and other university departments, the UT-REC maintains an ongoing working relationship with staff in approximately ten clinical facilities in the United States and Canada that have parallel research and clinical interests. The exchange of information and/or research prototypes, referral of clients, joint presentations in workshops, etc., are cooperative activities that are carried out as an integral part of the UT-REC effort.

SUMMARY OF CURRENT RESEARCH AND DEVELOPMENT ACTIVITIES

Specialized Seating

This task was conceived to address an urgent clinical need through design and the development of standardized techniques (and related hardware) utilizing currently available technology and industrial practices. Initially, assuming success in the first phases of the task, the second phase of the project was to be to identify any remaining problems that required basic investigation and to initiate studies accordingly. Development of this task has followed that plan, and has resulted in the development of two complementary seating systems; the Modular Plastic Insert System (MPI) and the Foam-In-Place Seating System (FIP). In addition, and as a result of experiences gained with these two systems, a simplified add-on trunk support device termed the Spherical Thoracic Support was also conceived and developed. Finally, a number of "irresolvable" problems were defined and a basic research study developed which addresses the deficiencies in clinical knowledge in the area of specialized seating and positioning for physically handicapped children.

The Modular Plastic Insert (MPI) System was designed for those preadults confined to wheeled mobility who have moderate physical involvement, usually as a result of cerebral palsy. The MPI System comprises a multi-adjustable measuring chair, together with a series of standardized vacuum-formed plastic modules which can be readily assembled and inserted into a variety of wheeled bases (Fig. 1). The measuring chair permits the assessment of the child prior to the provision of a seating system, in order to assist in decision-making and the transfer of vital information from therapy to technical staff.

The second system, the Foam-In-Place (FIP) System, was developed for the more severely involved person. It permits the rapid fabrication of customized foam seating components. The FIP System utilizes two-component flexible polyurethane foam, formed (foamed) directly around the individual while he is supported in the corrected seated posture (Fig. 2 & 3).

The Spherical Thoracic Support (STS) is fabricated from two-component polyurethane foam in standardized molds, and can be attached to any standard wheelchair by use of adjustable hardware which is positioned to provide lateral trunk support as required. The design features a novel spherical joint which allows positioning of the pad to accommodate the contour of the user's thoracic cage (Fig. 4 and 5).

For the MPI system the major effort this past year has been an external evaluation of the system, involving seven clinical centers. Forty units were fitted. The evaluation followed a structured protocol provided to the evaluating clinics. The evaluation data have been compiled, priorities on design refinement have been established, and the results of the evaluation process have been published and

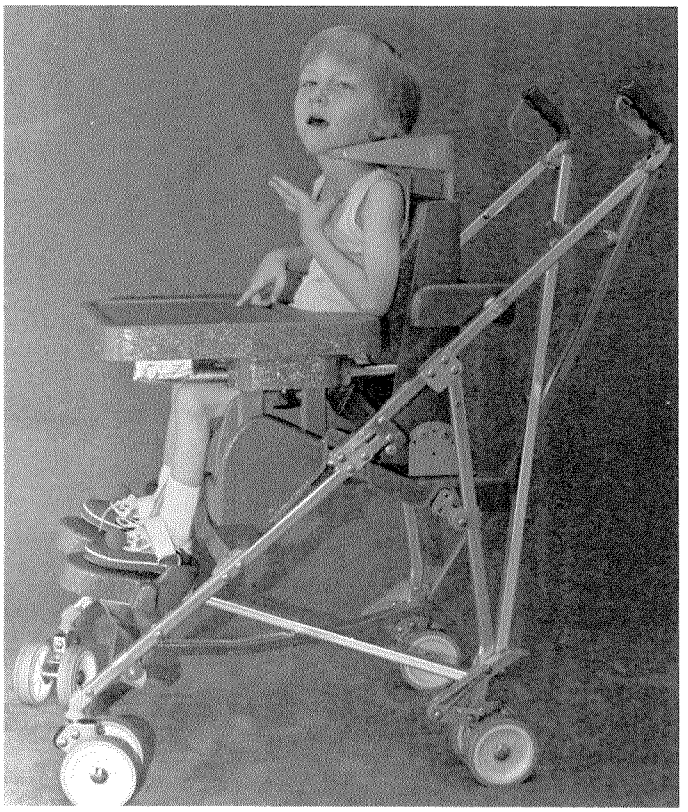


FIGURE 1.
The Modular Plastic Insert System inserted into a commercially available wheeled base (Pogan Buggy).

FIGURE 2.
In the Foam-In-Place process, two-component polyurethane foam is mixed and poured into a mold mounted on a "foaming chair." A latex sheet provides the flexible barrier between the subject and the pressurizing (expanding) foam.

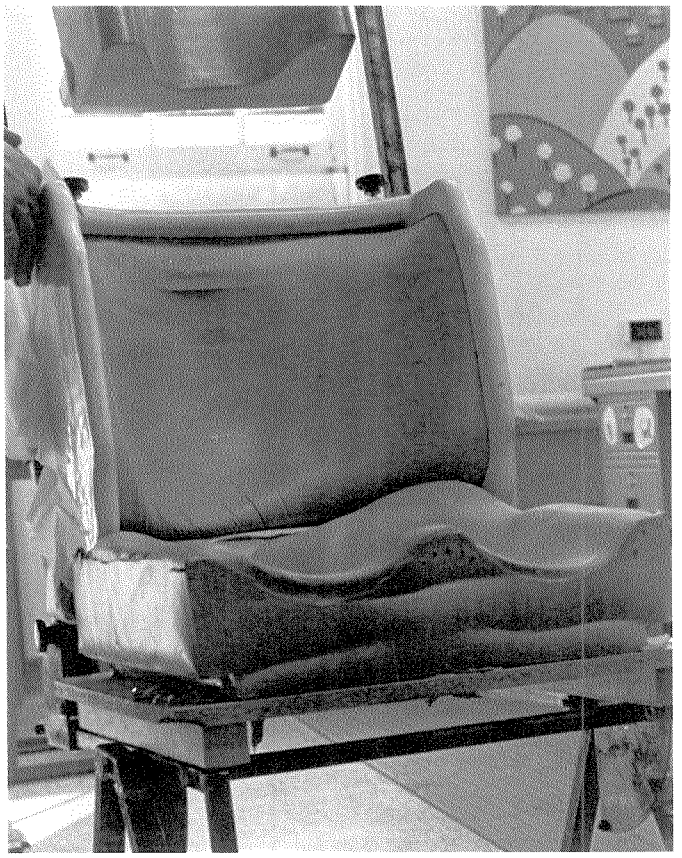
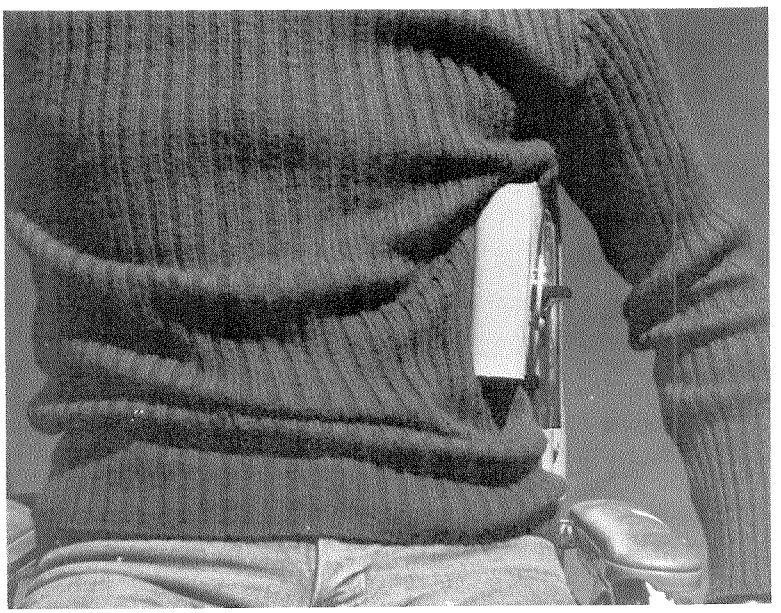


FIGURE 3.
Customized seat and back components can both be quickly made using the "foaming chair." Covering the formed foam with two-way-stretch fabric, and interfacing into the wheelchair, completes the process.

FIGURE 4.
The Spherical Thoracic Support attaches to the posterior upright of all standard wheelchairs with adjusting hardware that permits 3 degrees of adjustment of the support pad. View is downward toward wheelchair seat; attachment is at top left in photo.

FIGURE 5.
The STS provides add-on lateral trunk support for individuals who require support in addition to that provided by the wheelchair.



are available upon request.

The design, development and formal evaluation of the MPI System is now considered complete. Further design refinements to the system will be made with the involvement of a prospective manufacturer, so that any design changes will be compatible with the specific capabilities of the manufacturer.

The major effort with the Foam-In-Place during the past year has been to investigate the potential health hazard that may exist with the use of polyurethane foam, when polymerized in close proximity to a user. The first approach taken was to re-establish contact with the supplier, the Upjohn Company, and seek data compiled by the manufacturer from health hazard studies. The second approach has been to work with the University of Tennessee — Materials of Science Technology Laboratory, where extensive agar overlay tissue culture studies were done on fresh samples of polyurethane foam, polymerized in a manner identical to the Foam-In-Place application with human subjects. Control studies were done utilizing three samples of polyurethane foam materials used routinely in everyday applications (one sample was a commercially available polyurethane wheelchair cushion). The results from the tissue culture tests essentially support the claims made by the manufacturer. Specifically, the tissue culture study indicated that —

1. The toxicity of the polyurethane foam used in the Foam-In-Place application (CPR 1947N) is consistent with the foam used routinely in furniture and commercially marketed wheelchair cushions.
2. The latex film, which provides a barrier between the patient and the foam, is itself non-toxic.
3. Toxicity decreases significantly through time. Comparative studies involving the commercial foam samples and the CPR 1947N formulation were done within a 2-week time period.

The third approach has been to conduct an extensive review of the literature — in particular, to seek information on the toxicity potential of methylene biphenylocyanate (MDI) in comparison to diisocyanate (TDI). The literature clearly states that MDI, which is used as the isocyanate component for the CPR 1947N, has greater molecular weight and significantly lower vapor pressure at room temperature than TDI, thereby reducing the vapor hazard potential which is consistent with commercial applications using foams with the TDI isocyanate component. (Incidentally, the TDI isocyanate system has been the polyurethane system used by prosthetists in prosthetic fabrication for many years.)

The final step has been to conduct an onsite analysis of the vapors present both in the area of the technician and of the subject. These have been done using a mass spectrograph which yields an indication of parts-per-million of specific agents in the air. The preliminary results of this study have indicated that there are no concentrations of toxic agents approaching dangerous levels in the air, either during the mixing by the technician or during the foaming in the vicinity of the subject. As a result of the above testing, our preliminary conclusions are: "With proper recognition of the risk, application of suitable safety precautions, proper conditions of use, and good housekeeping practices, polyurethane and polyisocyanurate plastic materials can be, and many millions of pounds have been, applied with no apparent harmful effects".

A preliminary report on the Foam-In-Place procedure and the health hazards investigation has been compiled and is available upon request.

As previously discussed, the MPI, FIP, and the STS systems have been developed in response to clinical needs that could be addressed through applied research utilizing available technology. These new systems provide benefits in terms of improved comfort in seating, enhanced positioning, and increased mobility. However, before the design of these types of systems can progress towards the resolution of the remaining problems affecting specialized seating, a deeper understanding of the neuromotor responses induced or inhibited by a seating device is required. The effects of body segment positioning, location of external force application, center of gravity orientation, and non-contact external stimuli are of prime importance.

Plans have been laid for the initiation of a basic study to investigate and clarify a number of basic therapeutic principles as they relate to specialized seating.

A second and parallel approach will be to define and verify new variables which inhibit or induce spasticity in cerebral palsy. Specifically, the variables of temperature, noise, light, texture of support surfaces, and the attitude of the body in space will be investigated as to their effect on spasticity in a seated position. Assuming support is provided for this project, it is anticipated that the required measurement instrumentation will be designed and constructed by 1980 year end. Formal trials with research subjects will begin in 1981 and be completed in 1982.

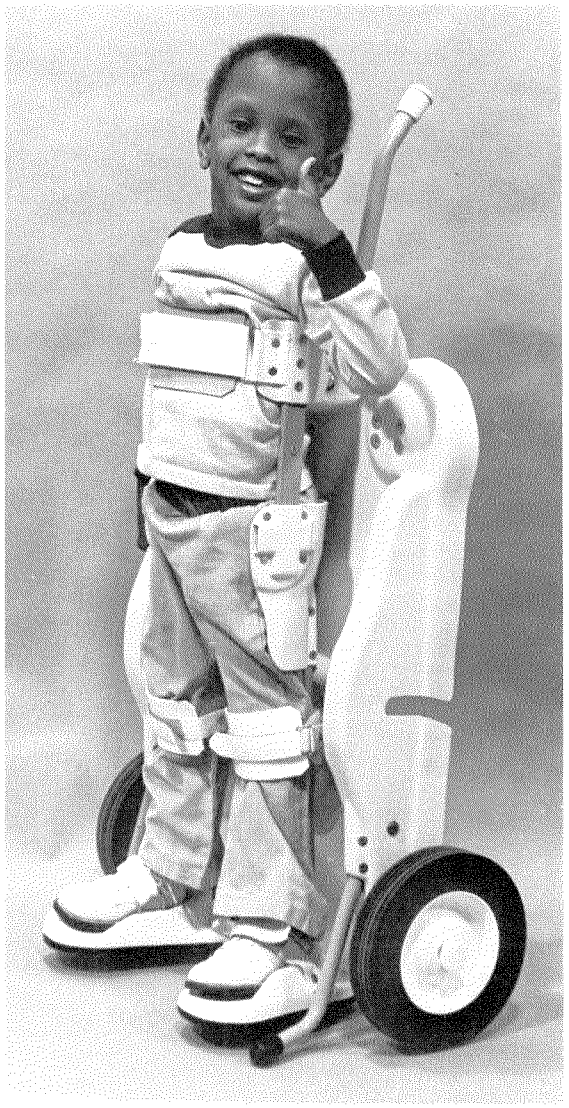
MOBILITY FOR SEVERELY HANDICAPPED CHILDREN

Educational and vocational pursuits are often possible for severely involved non-ambulatory individuals only after they have achieved some form of independent mobility. For the very young, exploration of their environment can be greatly enhanced through simple mobility devices. Other mobility devices can greatly reduce the effort required to transport a dependent child or adult from the home into the community. For others, mobility devices such as powered wheelchairs offer tremendous potential for independence which is so important in educational and vocational pursuits.

In order to address this diversity of needs, this task has been organized in three distinct but related areas of need, each with increased degrees of technical complexity and investment in research and development resources. The three project areas are: developmental devices (short term); transport devices (intermediate term); and powered mobility (long term).

Developmental Mobility

The initial major focus of this task has been to investigate alternate approaches to providing mobility and increased independence for children and young adults born with myelomeningecele. Traditionally, efforts to provide mobility for this population have focused on the full hip, knee,



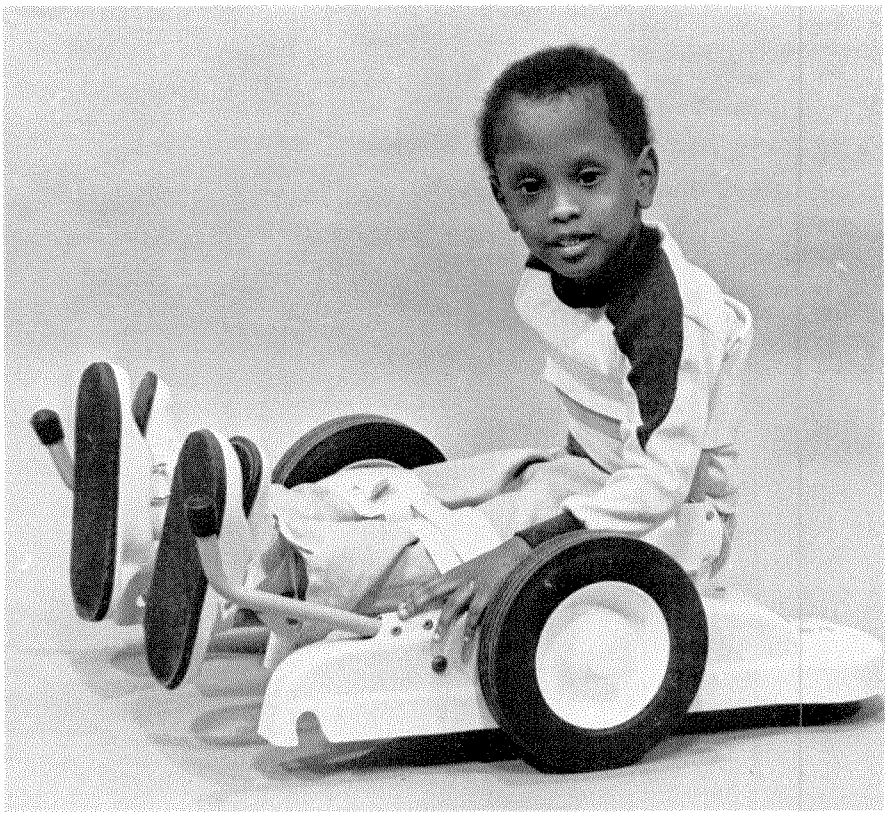


FIGURE 7.
The PUP system also may be used in the seated position to provide indoors mobility in homes and educational settings.

FIGURE 6.
The Plastic Upright Positioner is vacuum-formed in three standard sizes, may be used as an independent body support device, or combined with a wheeled base for greater versatility.

ankle, foot orthoses (HKAO), and ambulation with walkers or crutches. Generally, this approach has been expensive and does not yield an acceptable long term result in that a high percentage of these individuals opt for a wheelchair, either late in the first decade, or early in the second decade in life.

The approach taken has been to define the needs as related to three childhood developmental stages: pre-school, school age or pre-teen, and teenage to adulthood. Initial efforts are focused on the pre-school and school age population. Their specific needs were defined by conducting investigative meetings with clinical personnel; in addition, questionnaires were sent to parents, school teachers, and other professionals in the community.

Phase I - Plastic Upright Positioner

Initial focus on phase 1 has resulted in the design and development of a novel body support and mobility system termed the Plastic Upright Positioner (PUP) for the pre-school age group. The main feature is its simplicity. The design comprises two modules: a body-support module, and a multi-purpose wheeled base module that interfaces with the body support (Fig. 6). Body support components are designed in three standard sizes made from vacuum-formed ABS thermal plastic. The wheeled base is produced in one size in such a manner that it will interface with all three sizes of body modules. The combined body support system and the wheeled base provide a versatile, low cost system for the mobility management of paraplegics (Fig. 7).

Phase II - Sitting/Standing Mobility

Needs assessment studies indicated that the pre-teenage (6-12 yr) population has needs that are significantly different from those of the pre-school child. That is, independent sitting and standing, transferring, hygienic care, and increased mobility are needs that rapidly assume importance when the child leaves the home environment for longer periods of time. As a result, phase II design criteria call for development of a system which will combine the advantages of upright mobility (normally achieved with HKAF orthoses, or the PUP system) with those advantages gained with wheeled mobility such as that provided by a wheelchair. That is, a multi-purpose sitting/standing mobility device. It was felt that the key to success of a multi-purpose sitting/

standing mobility device was the development of an efficient drive system operated by an individual either in the seated or standing position. To this end, a prototype Posidrive System has been developed and incorporated into a standard wheelchair for purposes of evaluation and laboratory testing (Fig. 8).

During the past year, the Posidrive concept has undergone laboratory evaluation in two external facilities. Initially, the Posidrive System was shipped to the Rehabilitation Engineering Center in Charlottesville, Virginia, where extensive energy-consumption studies were carried out. (The results of those studies have been documented and are available upon request.)

In summary, the evaluation study indicated that the Posidrive System is not as efficient as conventional wheel/rim propulsion, and the losses are due primarily to drag and friction in the drive assembly.

More recently, the Posidrive System has been sent to the Tufts New England Medical Center—Rehabilitation Engineering Center for evaluation under laboratory conditions. Results of this second evaluation are expected in the near future. The ultimate goal is to develop an efficient drive system that can be operated effectively in both the seated or standing positions.

Transport Devices

The purpose of this task is to develop concepts and related devices that will address the problems experienced by parents and attendants in transferring older dependent children in family vehicles or in school buses. The initial focus of this project has been on the transfer of children to family vehicles.

The Travel Base concept facilitates the transfer of the child, complete with his seating system, into the family vehicle. The wheel assembly detaches from the seating module for trunk storage after transfer has occurred (Fig. 9). This approach is similar to the commercially available Travel Chair. However, the commercial devices feature a reclined sling seat which does not adequately accommodate many children requiring special positioning. The new Travel Base will accept the MPI, FIP or other custom seating components.

During the past 6 months three of the Mark III designs have been produced and introduced to local field tests. The Mark III design features several design improvements including an adjustable thigh length, anterior/posterior head support, adjustable footrest, and a foot-operated brake. Parent responses are being closely monitored to determine if this

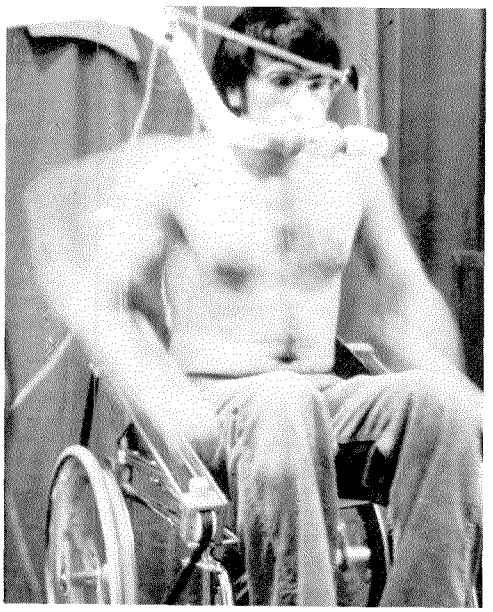


FIGURE 8.
The Posidrive concept for wheelchairs utilizes a positive-drive belt and clutching mechanism to deliver power to the wheels. Energy consumption studies, (shown here) have been conducted to evaluate the efficiency of the drive system compared to direct wheel rim propulsion.

FIGURE 9.
The Travel Chair facilitates the transfer of older children into the family vehicle. Wheel assembly detaches for storage in the car trunk.

unit is ready for wider trials.

Powered Mobility

The purpose of this sub-task is to develop concepts and related devices that will permit individuals who lack the necessary neuromotor function to use the conventional controls to control powered wheelchairs.

Four alternate types of control have been developed, and tested by severely involved individuals requiring independent mobility. These controls utilize the head, the hand, the foot, and a combination of head and hand, to control modified powered wheelchairs. This experience led to the formation of a new approach to powered mobility control for the severely neuromotor impaired.

The conceptual approach now being investigated is based on the fact that many individuals who require specialized wheelchair controls often have requirements to control many additional powered devices in their environment. That is, the concept takes a global view of control, encompassing the control needs of the wheelchair, communication aids and environmental control devices, electronic workstations, etc., and it integrates these hardware options into a system with a microprocessor as the central control module.

The concept takes the modular approach to control, in which the microprocessor provides the essential client/hardware matching and master control, to be interfaced with a variety of peripheral devices depending on the needs of an individual. A prototype unit has been assembled for purposes of demonstrating the potential of the concept (Fig. 10).

A more detailed concept paper has been prepared and is available upon request.

Independence and Activities of Daily Living

The focus of this last task area has been development of techniques and related assistive devices to increase the educational and vocational potential of the young severely handicapped individuals.

Many moderately-to-severely physically handicapped persons are not viable candidates for vocational placement because they have not acquired sufficient independence in the activities of daily living. For example, they are unable to undress themselves, take care of their personal hygiene, leave or return home independently, transfer in and out of a vehicle that can take them back and forth to work, or interface with educational or vocational workstations—all because of a lack of manual dexterity. Varying degrees of these problems often become compounded for an individual, and in total, present a major roadblock to achieving an education or meaningful employment.

This project has focused on one specific sub-task: the development of control interfaces to allow access to modern electronic workstations. The project explores two approaches—one for use in a stationary workstation, and the second for use where portability is required. Recent progress has resulted in the development of the following systems, each of which has progressed to clinical use: a direct-access video keyboard control system, and a direct-access L.E.D. scanner control system.

Direct Access Video Keyboard Control System (DAVK)

The control concepts and hardware do exist that can allow individuals to use environmental control systems using head, or sip and puff, control. However, these control systems are usually based on sequential, or x/y scanning logic, which is slow and not usually appropriate in a competitive job environment.

In summary, this project focuses on

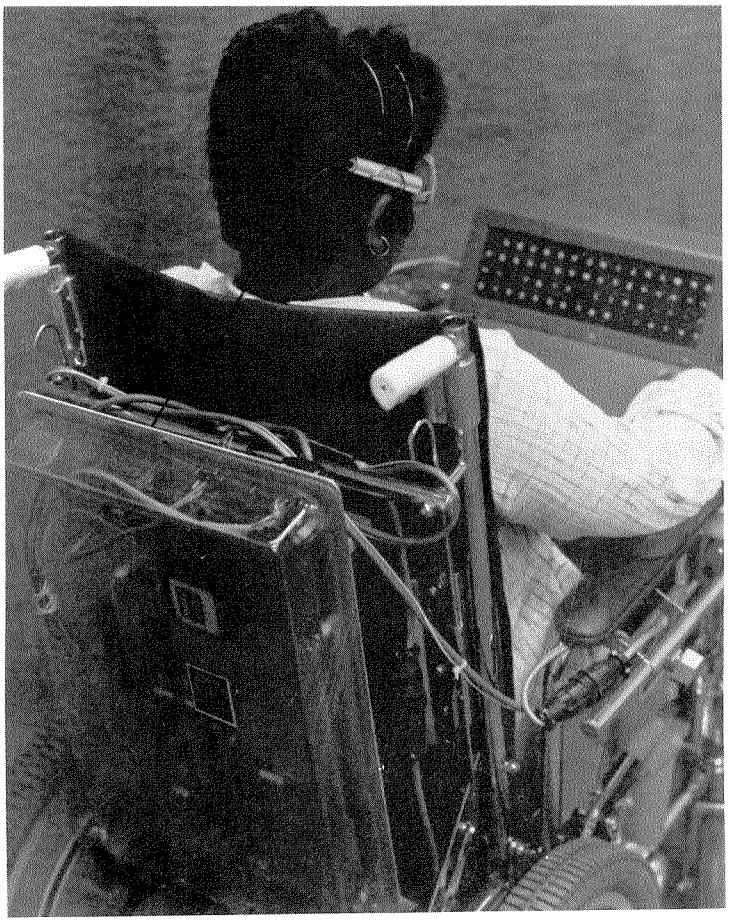


FIGURE 10.
The MK I prototype of the microprocessor control concept, incorporated into a powered wheelchair. Control is achieved by pointing the head-, mounted sensory element at an LED feedback panel.

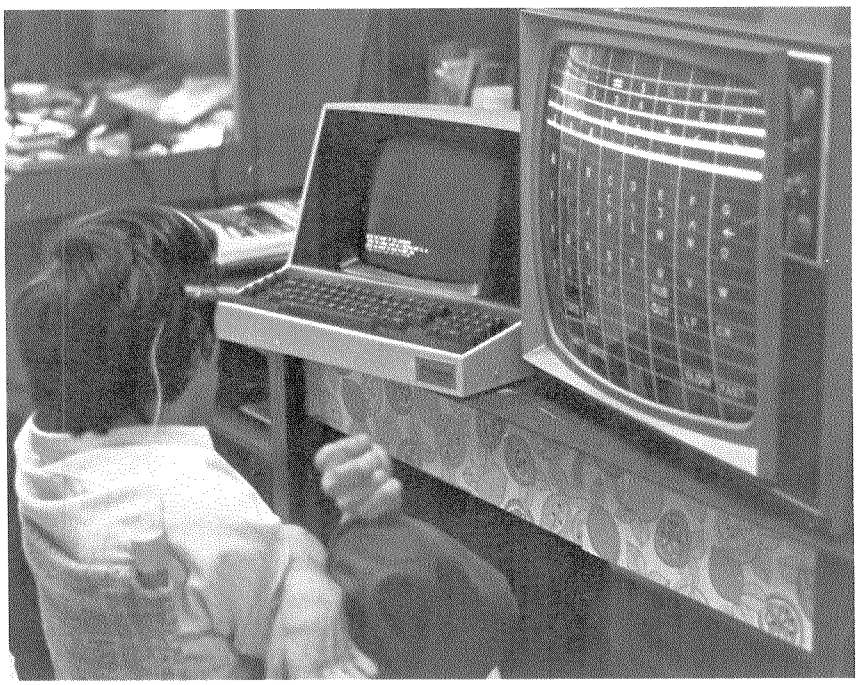


FIGURE 11.
Severely involved athetoid quadriplegic is able to interface with microcomputer using the Direct Access Video Keyboard Control.

the practical control needs of the most severely involved; for example, the severe spastic or athetoid cerebral palsied, the high level quadraplegic, the severely involved post-polio, all of whom are usually rendered non-functional in terms of the manual dexterity required to operate modern electronic equipment.

The concept being pursued is a direct-access control approach utilizing a video monitor and a sensor mounted on the rim of a person's eyeglasses. The user focuses the sensor on the keyboard which is displayed on the video monitor. Holding the sensor a pre-determined time has the same effect on an output device as does manually depressing the key of a keyboard. The objective is to develop a flexible control device that interfaces with a variety of key-operated output devices with secretarial or computing workstations as obvious examples.

A prototype has been developed with the direct input and involvement of a 22-year-old athetoid quadraplegic, who has been significantly motivated to have earned Chartered Public Accountant certification. He now wishes to be able to control a microcomputer system.

The subject has been using this latest model for approximately 3 mo (Fig. 11). Access rate measurements have been taken and will be repeated as his proficiency improves. His current rate of access is approximately 15 characters per minute. Technical details on this project have been documented and are available upon request.

The Direct Access LED Scanner Control System (DALEDS)

The purpose of this sub-task has been to develop a portable head-operated control device that would be compatible with existing control methods in communication and mobility devices.

The Mark II DALEDS system consists of an array of light-emitting diodes (LEDS) arranged in a 5 X 4 X 16 matrix located on a panel mounted on the wheelchair tray in front of the user (Fig. 12). The LEDS are pulsed

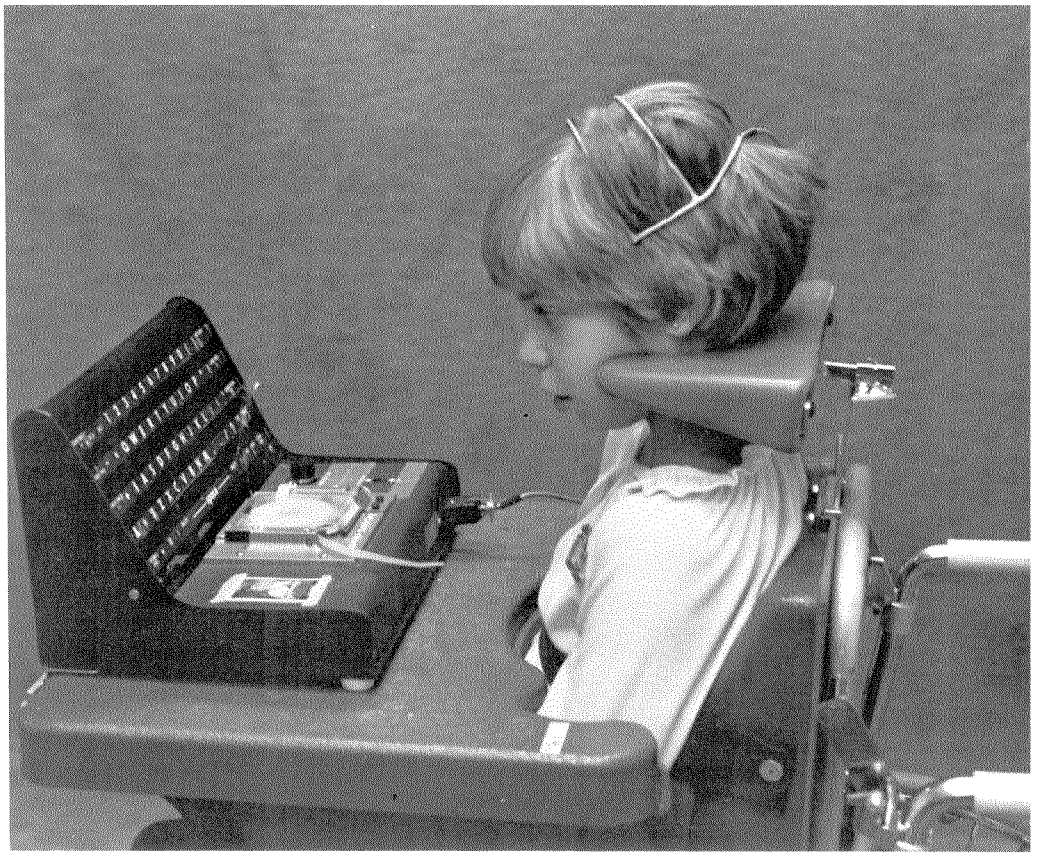


FIGURE 12.
The DALED Scanner device is operated by pointing the head-mounted sensor at the feedback panel. Output may be paper strip or a video monitor display.

one at a time at high current with a very low duty cycle, which gives a short burst of brighter light than normally available from an LED. If nothing intervenes, the system will advance to the next LED and so on until all have been pulsed, then the process will repeat. This all happens many times per second (about 30 times).

If the head-mounted sensor is aimed at the panel, it will "see" the LED in its field of view when it is flashed. The sensor will then send a signal to the system which will prevent it from advancing to a different LED, thus causing all flashes to come from one LED. The pulsed LED will then become brightly visible to the human eye. If the sensor is held on one LED for long enough the system will print or display the character that corresponds to the LED on the panel. The output from the system is either printed on a paper strip (which is the portable mode) or it may be interfaced for display on a video monitor.

The Mark II design has recently become available through the Prentke Romich Company. Continuing design efforts are addressing the problem of reducing the size of the head-mounted sensor and eliminating the need to have a cord running to the head.

In June, 1979, one of our research subjects was invited to the Office of the Secretary of Health, Education, and Welfare, and with the commercial version of the DALEDS control system was able to communicate directly with the Secretary (Fig. 13).

FIGURE 13.
In June 1979, University of Tennessee REC subject, invited to the office of the Secretary of HEW, was able to communicate directly with the Secretary using her commercial-version of the DALEDS.

EVALUATION AND RESEARCH UTILIZATION (ERU)

Research and development activities at the University of Tennessee — Rehabilitation Engineering Program have been under way for approximately 4 years. For the past 3 years, support has come from RSA and the NIHR, with the activities organized within a Rehabilitation Engineering Center. As previously outlined, many of the projects are now resulting in practical devices that have been evaluated locally and are ready for wider field evaluation and marketing. In order to facilitate the transition of local developments into the marketplace, as well as to establish a mechanism to introduce the local community to research and commercial developments taking place elsewhere, an evaluation and research utilization component has been added to the program.

An evaluation methodology has been developed in an effort to expedite the flow of research devices through the research stage and on into the marketplace. During the past year a number of both internal and external evaluation activities has been initiated. A time-evaluation specialist has been added to the staff (half-time) to coordinate the evaluation activities.

The four local developments that have been in process during 1979, several of which are nearing completion, are as follows:(i) The Modular Plastic Insert System, (ii) Spherical Thoracic Support, (iii) The Travel Base, and (iv) the Foam-In-Place Seating System.

The most extensive evaluation to date has been that of the Modular Plastic Insert system. The formal external evaluation of the MPI system began in the Spring of 1978; teams from seven clinical facilities came to Memphis for a 2½-day orientation session on the fabrication, patient selection, and fitting of the MPI system. The evaluation protocol called for the fitting of six MPI systems in each center following the instruction manual provided. A sample of 42 subjects (six persons at each of the seven participating centers) were selected to participate in the external field testing. The evaluation was carried out and completed during 1979. Design shortcomings were determined and priorities established for design refinements. These design refinements to the MPI system are now being completed.

A document has been prepared on the MPI evaluation and is available for distribution upon request.

The other three items listed are currently still under evaluation, and the evaluation protocols are available in draft form.

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INFORMATION RETRIEVAL AND DISSEMINATION

It is becoming increasingly evident that more emphasis must be placed on the effective retrieval, preparation, and dissemination of information. This is particularly important now that the field of rehabilitation engineering is beginning to acquire experiences that can be documented and are in demand by others. Professionals in the field of rehabilitation are looking toward the rehabilitation engineering centers as sources for information, not only on rehabilitation equipment, but also on current research and development activities, alternate solutions to clinical problems, and reference literature. Also, we now look forward to more involvement of students seeking information on rehabilitation sciences as part of their formal education process. Finally, consumers are insisting that they be more informed as to their options, so that they may become more involved in the decision-making process related to their health care. Rehabilitation engineering programs are being looked to as resources for information related to the technical solutions of consumer needs.

Information Retrieval and Cataloging

Information requests of the types indicated above have all been made at the Memphis REC with increasing frequency over the past few years. The developing information file associated with the Rehabilitation Engineering Demonstration Unit has become effective in answering the requests for information related to commercially available equipment.

During the past year the development of a systematic in-house literature retrieval, cataloging, and dissemination system has been initiated. This system will be an invaluable resource for staff, students, and other professionals in the Memphis area. Also, staff from the UT-REC have been involved in the information exchange workshops, including the use of the EIES computer-based information exchange system.

Future plans will focus on the continuing development of the in-house system in terms of cataloging, filing and updating the entries into the system. Depending on the staff resources available and the extent of development of a national computer-based system, the in-house library will be entered onto a computerized cataloging and retrieval system. Every effort will be made to keep the system user-oriented and compatible with any emerging standardized approach.

Information Dissemination

The main forms of information dissemination in 1979 have been presentations at workshops and conferences, and audio-visual materials. Staff have participated as faculty in instructional sessions in five major conferences in which various aspects of the program were presented. An in-depth workshop on specialized seating for children with cerebral palsy was held November 7-10, 1979 at the University of Tennessee Rehabilitation Engineering Center; 40 participants from North America, the United Kingdom and Canada participated. Finally, a 15-minute 16-mm movie was produced during 1979 which conveys many aspects of the activities taking place in the University of Tennessee Program.

This movie, called "A Special Magic", is now available for loan and may be obtained by contacting the Technical Director of the Center.

Rehabilitation Engineering Center
Wichita, Kansas
Cerebral Palsy Research Foundation of Kansas, Inc.
2021 North Old Manor
Wichita, Kansas 67208
Wichita State University, College of Engineering
Wichita, Kansas

Co-Directors: Jack F. Jonas, Jr., John H. Leslie, Jr., Ph. D., Roy H. Norris, Ph. D., and Robert D. Dryden, Ph. D.

INTRODUCTION

The Rehabilitation Engineering Center, Wichita, Kansas, was established on July 1, 1976, under the joint research auspices of the Cerebral Palsy Research Foundation (CPRF) of Kansas, Inc., and the College of Engineering, Wichita State University. The core area of research, as established by RSA, is the development of vocational opportunities for severely disabled persons through engineering.

The CPRF of Kansas provides direct access to the handicapped population through its affiliation with Center Industries Corporation, the Timbers (Independent Living) HUD Project, Infants and Children's Programs, and other client-related activities. Wichita State University, College of Engineering, provides the laboratory and computer facilities which support the engineering research effort. The Cerebral Palsy Research Foundation of Kansas, Inc., and the staff of the College of Engineering (particularly the Industrial and Electrical Engineering Departments) work in unison, to provide the ingredients of a meaningful lifestyle for severely disabled people

through engineering adaptation in the vocational, residential, educational, and independent living environments.

The REC carries out its mandate through cooperative efforts with other agencies such as the University of Tennessee REC, particularly in the area of mobility associated with molded plastic seat inserts for children; and with the National Aeronautics and Space Administration in utilizing space age technology to create vocational opportunities and an independent lifestyle for severely disabled persons.

During the current grant year, the REC initiated a cooperative effort with Louisiana Tech University, College of Engineering, in order to provide expertise and advice to that agency as it seeks to establish a research project in similar areas to that being performed by the Wichita REC.

PERSONNEL

The REC, during the past year, was under the co-direction of Mr.Jack F. Jonas, Jr., and John H. Leslie, Jr., Ph. D., representing the CPRF of Kansas, Inc. Representing Wichita State University, College of Engineering, on a co-directorship basis, were Roy H. Norris, Ph. D. and Robert D. Dryden, Ph. D. Also representing Wichita State University were: Don Malzahn, Ph.D., director of Project I; Don Hommertzheim, Ph. D., director of Project II; Mr. Rajiv Kapur, director of Project IV; Elmer Hoyer, Ph. D., director of Project VII; Allen Schuermann, Ph. D., director of the Economic Comparison Study (assisted by Dong Cho, Ph. D., of the Economics Department); and Mr. Leonard Anderson, director of the Technical and Engineering Staff (assisted by Mrs. Joy McGinness, full-time staff engineer, and Mr. Larry Nitzsche, half-time staff engineer).

GOALS AND OBJECTIVES

The goals and objectives of the REC are to provide a total comfort environment for severely handicapped persons through engineering techniques, hardware, and technology. In order to carry out the core area established by RSA, five projects supported by a technical and engineering staff have been created. These projects are:

Design of Adaptive Devices: (Project I)

This project has the primary objective of providing engineering support service for the placement of severely handicapped persons at Center Industries Corp. and in mainstream work environments in Wichita, Kansas. The project has the responsibility of designing adaptive devices to facilitate placement of severely handicapped persons.

During the current grant year, Project I has been active in improving the results of the test apparatus used to determine the physical capability of severely handicapped persons. This apparatus, called the AMI (Available Motions Inventory), has been refined to the point where the results are accurate in predicting worker capability on the job. A new computer program has been written to interpret the results for vocational rehabilitation counselors and others.

Economic Strategies (Project II)

This project is charged with developing an economic model to determine the economic advantages of employing severely handicapped persons in Center Industries or mainstream employment. This research effort is attempting to develop a mathematical model which will relate all support funding sources,in order to define a situation in which economic benefits to the handicapped person himself as well as state and local funding sources are maximized. In many cases, there are disincentives associated with employment—since a handicapped person loses many welfare benefits when employed. This project is attempting to develop economic strategies to deal with these disincentives, so that the possibility of employment will become a positive motivation for the severely handicapped person.

Workstation Modification: (Project IV)

This research effort is developing human factors data relative to the modification of workstations in an industrial environment so that meaningful work may be performed by severely handicapped persons. The primary research results of this project, during the current grant year, were published in the special summer edition of the Engineering Tech Brief. [a] This extensive publication outlined some of the anthropomorphic data obtained during the course of the last two years in utilizing human factors techniques to design stations for severely handicapped people. Also, energy expenditure studies were documented in the Tech Brief. This project assisted Project I in helping to standardize the Available Motions Inventory test apparatus and provide a logical, meaningful interpretation of the results.

Communication System: (Project VII)

The goal of this project has been to investigate and develop a communications system for the Timbers Housing Project. The following tasks are being performed this grant year:

1. Performing a study to determine what communications functions and personnel analysis functions are needed to better implement independent living while provid-

[a] This is a quarterly publication of the Wichita REC, available free to individuals or organizations working in the field of rehabilitation.

ing aid delivery for the existing core area for the severely handicapped.

2. Designing a modification to available telephone equipment so that this equipment can be used more easily by the non-manual resident. This phase will include necessary modifications to the standard touch-tone phone, speaker phone, and memory dialers.
3. Designing a system employing the telephone (and probably a microcomputer system) to implement the results of the study outlined in 1. This system should be designed to use existing equipment as much as feasible without limiting the expansion desired.
4. Performing a study to determine how this communication-delivery system could be extended to the less-severely-handicapped individuals living in housing units remote from the core area but within Timbers, and possible later extensions to individuals living outside the Timbers housing units.
5. Performing a study to determine what automatic devices are needed and/or available to make secure each living unit as an independent unit. This study must concern itself with items such as automatic door lock/unlock systems, automatic system for calling a central station, and automatic floodlighting of exterior areas.

Economic Comparison of Vocational Rehabilitation Programs in the United States with Other Countries

This research effort was established on October 1,1978, to study the comparative benefits associated with vocational rehabilitation systems in the United States and other countries throughout the world. The research, up to now, has focused on the economic parameters associated with employment at Center Industries Corp., particularly those associated with the Evaluation, Research and Training Unit. Members of the research team visited Australia during the month of June to study the vocational system utilized at Centre Industries in Sidney.

Jack Jonas and John Leslie traveled to Poland in 1978, and obtained some extremely useful information on the system utilized by the Polish government in the development of handicapped workers cooperatives—the research team plans to travel to Poland in the very near future. It is felt that many of the systems utilized in foreign countries in the area of employment can be modified for use in the United States vocational rehabilitation system.

Development of Devices for the Handicapped in the Work Environment

Among the specific items designed, developed or researched by the REC are the following:

1. The Available Motions Inventory (AMI) system, which has already been used to evaluate the physical capabilities of more than 200 handicapped individuals. Several workstations have been modified using the AMI test results and several physically disabled persons have obtained full-time employment as a result.

The system includes a set of test equipment which can be arranged on a framework allowing the person administering the test to discover and measure the client's capabilities within the context of a wide variety of actual (or possible) workstation configurations. Typical industrial handwheels, cranks, levers and other controls or materials that must be manipulated in the performance of tasks can be positioned as desired.

Results of the tests, recorded as performed, are computer processed to provide an engineering team with data from which they can determine what interface is needed for a severely physically disabled individual to perform a given job task.

The thrust of the REC is to develop systems and equipment that will provide ways of employing the physically disabled. Before such a system may be designed, the design parameters must be specified. The specification of parameters must include both the employee and the job or workstation where that individual will be working. The job parameters may be determined from the existing workstation or may be designed into a new workstation layout. When determining the parameters of a severely disabled employee, not only the skills, experience, and qualifications of that individual, but also the physical capability to perform the tasks required must be considered.

The skills, experience, and qualifications of the potential employee may be found in past records but the physical capabilities must be measured. This measurement would need to assess the individual's capabilities in a work situation and the results should draw a correlation with industries' time standards. The design parameters should include measurement of strengths, rates, and accuracies. The result should be representative of the wide range of industrial jobs available—without attempting the impossible task of duplicating all possible industrial work situations.

The proper administering of the test, along with careful and deliberate interpretation of the results, cannot be the only factor in a decision for placement of an individual: consideration of the client's motivation, emotional and social maturity, and intelligence is essential.

2. **A Spindle Drill Fixture** was designed which, at a very reasonable cost, allows a severely disabled

cerebral-palsied spastic quadreplegic to handle and drill four-pound truck axle spindles.

The individual, when tested, had proved to have right-hand performance well below the 50th percentile level of the ablebodied standard, and the effective work area was only at shoulder height and within 12 inches of the chest. The fixture made it possible for the individual to do the job within this range of motion and strength.

3. **Application of Grasp Pads to increase productivity** in bench assembly operations was studied, acting on an idea seen in the June 1977 issue of Production Engineering magazine. (It was the suggestion of Roy Harrison, of IBM Systems Manufacturing Div. in North Carolina.)

A grasp pad is a piece of foam rubber of suitable size and resiliency, placed on the normal assembly surface. Parts (and tools) placed on the pad instead of the steel surface appear to be considerably easier to grasp.

Because many of the physically disabled who can function only at a bench job (sitting) do not have the grasp dexterity necessary to perform the job tasks at an acceptable rate, the REC developed an experiment that would relate the physically disabled's performance with and without a grasp pad while handling several common items.

The first group tested consisted of seven trainees whose degree of disability ranged from moderate to very severe.

The six items used for the test were as follows:

Tool Check	1 in diameter by .03 in thick
Cleco	⅜ in diameter by 2 in long
Washer	½ in diameter by .04 in thick
Nut	¼ in by 20 thread
Rivet	3/30 in diameter by 5/16 in long
Wire	20 ga. by 3 in long

Only the trainee's preferred hand was tested. Each of the trainees was required to pick up, move, and release 10 parts of a given item. Each subject was tested with and without a grasp pad (on a steel work bench) for all six items. (The pad provided compression of 25 percent with a 25-lb load.)

The use of a grasp pad appears to improve performance in almost all cases. The increased performance was greater for the item most difficult to pick up. Further and even more remarkable, the most severely handicapped trainee showed the greatest increase in performance.

Based on these results, the most severely handicapped trainee was set up with a grasp pad while packaging tool checks for a production run. This resulted in an actual performance increase of 435 percent. The effects of this simple idea may prove to be quite substantial for the future employment of the physically disabled.

Other Devices Briefly Noted

Space limitations permit only brief mention of some other successful devices, such as the rather simple holding devices which help a moderately involved girl who has cerebral palsy to assemble propane gas torch nozzles. Her output exceeded that of an ablebodied workers not using the fixtures developed by the Center's technical and engineering staff for this girl.

In another example, the Center staff adapted a 32-ton punch press for use by a one-handed operator, while retaining compliance with OSHA regulations for safety. The operator uses a separate pedestal-mounted one-hand trip. The regular two-hand control, or automatic mode with guards, are still used by other operators of the press.

At the request of the Kansas Power and Light Co., the REC staff investigated means to make wall-mounted thermostats more easily read and manipulated by elderly customers. It was determined that any adaptations that would benefit the elderly would also benefit certain disabled individuals. Three different prototypes were developed and are currently being evaluated by Kansas Power and Light.

An example of an extremely simple device is a simple extension to a water hydrant key. By increasing the torque, the extension made it possible for a young man with reduced strength in hands and forearms to water the lawns and trees without assistance, in carrying out his groundskeeping job at a local hospital.

REC engineer Leonard Anderson made it possible for another young man with cerebral palsy to operate a push-type power rotary mower, by suggesting a simple "dead man's switch". A bicycle caliper brake handle and brake cable was installed on the mower handle, and connected to a spring-loaded spark grounding switch. (This employee could have operated the mower safely without the device, but the safety switch satisfied his employer's anxiety, so that the employee was permitted to carry out a job activity he wanted very much to do.

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Rehabilitation Engineering Center Moss Rehabilitation Hospital — Temple University — Drexel University Philadelphia, Pennsylvania 19141

Gordon D. Moskowitz, Ph. D., Director, V. Theerasakdi, M.D., Medical Director, and Dolores Scott, Administrative Assistant

This report is a followup on the research and development reported in BPR 10-32, Fall 1979, issue.
Recent accomplishments of this center include:

1. **Availability of the Clinical Prototype of the Force Line Visualization System.** The system which provides visualization and measurement of floor reaction forces (normal and shear) during locomotion and standing has been adapted for manufacture and sales by Valley Instrument Co., of Exton, Pennsylvania. Equipment should be available for purchase during 1980. The selling price will be approximately $15,000 for the total system (force plate and display). The display will be available separately in the event that a laboratory already has a compatible force plate system. A report fully describing the application and structure of the laboratory system has been prepared and is available through this center.

2. **Application of Electromyographic Pattern Recognition Techniques to Control Above-Knee Prostheses.**
As previously described and demonstrated here, a prosthetic control classification scheme is realizable through EMG of hip musculature. During this last year the knee actuator has been designed and satisfactorily simulated. Construction of the EMG-controlled prototype actuator will be begun shortly. The essential difference between this system and others is that the system designed here is neither preprogrammed nor passive, but is active and under the full control of the user.

3. **Tests on a High-Reliability Peroneal Functional Electrical Stimulation (FES) Unit.** A ten-subject technical reliability study is nearing completion. Twenty-five improved FES units have been fabricated and tested. These units have already been tested on nine subjects with very satisfactory results. The redesign was undertaken to obviate the problems of malfunction due to lead breakage, circuit failure, etc., on previous units. Other groups can purchase peroneal FES units fabricated at this center. (At this time, there are no U.S. firms which manufacture these units).

4. **Continuation and Extension of the Clinical Gait Analysis Service.** This service offers the expertise of this center's locomotion laboratory to the orthopedic and physiatric community. The service has been in operation for 2 yrs and has been instrumental in the planning and assessment of therapeutic procedures. The clinic has been consulted on difficult referrals from the Moss Hospital Orthotics and Prosthetics Clinic (49 patients). During this last year the Arthritis Clinics at Moss and Einstein Hospitals have started to refer arthritic patients (6) with locomotion problems for pretherapy and posttherapy evaluation. Earl Marmar, M.D. (orthopedist) has joined Thomas Cook as Medical Director and Director, respectively, of the gait analysis service. Continued operation of this service will provide additional information on the effective utilization of locomotion laboratories. Ultimately a manual will be prepared for dissemination describing the operation and use of a modern clinical locomotion laboratory.

5. **Support for Stair Descent Research.** Partial grant support for the project on the effect of altered sensory input on stair descent has been obtained from NINCDS/DHEW. This 3 yr grant will enable this center to better pursue this study, which is directed at elucidating the problems encountered by the brain-injured during stair locomotion.

6. **Evaluation of the Gait Mat.** Development of the gait mat has been completed this past year and it is now in clinical evaluation at Moss Hospital. This mat is a relatively inexpensive clinical device for obtaining measures of gait useful to the orthopedist, orthotist, prosthetist and physical therapist. The parameters that can be measured include foot position and timing of foot falls. Duplicates of the device will be fabricated and placed for outside evaluation. Plans for external evaluation are now being formulated. NIHR will be contacted before placement.

7. **Establishment of a Formalized Outpatient (Client) Rehabilitation Engineering Service for Pennsylvania.** A 3 yr contractual arrangement has been made between this center and the Pennsylvania Bureau of Vocational Rehabilitation (BVR) to provide engineering services through client counselors to their severely disabled population. The arrangement follows 2 yrs of an ad hoc demonstration clinic offered to BVR clients.

8. **Growth and Expansion of the Rehabilitation Engineering Service.** The service which includes inpatient, outpatient, and consulting capability, has been made available throughout Moss, Temple, and Einstein Hospitals. In addition, the service has provided contract services to numerous private and public agencies at no expense to the REC budget. The interest in and usage of the service over the last year has been impressive, as the project statistics indicate. A grant proposal is planned to support the inpatient service similar to the grant supporting outpatient (client) engineering services (item 7 above).

9. **Establishment of an Adaptive Seating Service.** As a result of this center's involvement in the evaluation programs of two special seating systems, developed at the REC at the University of Tennessee, we are now able to use the equipment to provide special seating devices and consultation through the Seating Clinic operated by Moss Hospital.

10. **Continuation of the Publications Office.** Five new titles have been added to the publications list offered through this office. This brings the total number of publications offered to fourteen. The titles added this year include:

a. "Wheelchair Workshop II - 1978"
b. "Evaluation of the C.A.R.S.-U.B.C. Knee Orthosis"
c. "A Technique for Force Line Visualization"
d. "Flexible Brim Above-Knee Socket of Polypropylene"
e. "Manual for an Ultralight Below-Knee Prosthesis," 2nd edition.

It is the aim of this service to provide and assist others in providing publications, films, and slide presentations that will be useful in dissemination of the results of the program.

Ambulation Energy Meter
Responsible Investigator - T. Cook, M.S.

A tri-axial accelerometer was mounted appropriately to measure accelerations of the approximate center of gravity during gait. Computer programming was completed to sample the data and to calculate external mechanical work in each plane and the total work per unit distance walked. Initial data collection efforts focused on the validity, reliability, and sensitivity of the measurements obtained from this instrumentation scheme. Validity was examined by comparing external mechanical work as determined by the accelerometers with that calculated from the locomotion force plates. Reliability testing on a group of ten normal subjects was completed to examine the expected variability of the derived measures for test-immediate-retest, intraday and interday test conditions.

Sensitivity of the measures derived from this instrumentation was examined by testing patients with various pathologies under different conditons. These tests typically were a comparison of a patient's gait while wearing an orthosis to the patient's gait without the orthosis or a comparison of an amputee's gait with different prosthetic configurations. Within minutes after collecting the data, computer-generated graphs display the mechanical energy in each plane and the total body energy as a function of time for each stride.

Work on the development of a clinical version of this instrumentation has been delayed because the computer scientist involved in the project has left the center. Additionally, because of the relative newness of this gait measurement parameter, further demonstration of its usefulness seems appropriate before a substantial effort is expended to produce a clinical device. Consequently, the laboratory technique will continue to be used as part of a gait analysis service and as part of the study of alignment and control principles. Following this additional experience a decision will be made regarding the development of a clinical version of this instrumentation.

Instrument for Clinical Analysis of Gait
Responsible investigator-D. Taylor, B.S.E.E.

The feasibility model of the instrument (portable 13 ft. long walkway with associated electrical and electronic equipment) has been completed and is being used clinically in order to obtain an initial evaluation. The accuracies are those anticipated by the design resolution of 1.5 cm in the space domain and 20 ms in the time domain.

The clinical personnel involved find the instrument easy to use and the resolution to be adequate. Step length, velocity, stride length, and cadence are easily calculated from the printed recore.

Because the device records only the times of initial floor contact under the foot, it does not provide the information for calculating swing and stance times. In order to obtain the latter parameters, the time to the end of floor contact must be acquired.

Modifications and additions to the instrument are proposed in order to construct a second unit which will add switch release times to the printed record and thus permit swing-stance times to be obtained as well as the step-stride lengths and velocity-cadence parameters. The feasibility of adding a microcomputer to the instrument will be investigated. In addition to performing calculations for velocity, cadence, and other gait parameters, a microcomputer should be able to replace at least some of the present electronics which are internal to the device.

A clinical evaluation study is now being planned.

Cervico-Ocular Reflex (COR) Effects on Eye Stability During Active and Passive Movements
Responsible Investigator—W. Freedman, Ph.D.

During the past year experiments have been completed on twelve normal adults. The data have been analyzed and the results have been accepted for publication in ACTA Otolaryngologica. Project objectives have been accomplished with the following results:

Summary of Results:

1. The cervico-ocular reflex (COR) in humans was measured while the subjects (n=10) stood on a rotatable platform in a dark room with the head fixed by a stationary biteplate. Eye movements were measured in response to active and passive rotations about a vertical axis.

2. The COR gain (i.e., horizontal eye movement/amplitude of body rotation) was as large as 22 percent at low frequency of body rotation (0.025 Hz). With increasing frequency (e.g., at 0.4 Hz) the gain decreased to about 2 percent.

3. The phase angle of the eye movement ranged generally between -80 to -240 deg with an average response around -180 deg.

4. During active rotation, the COR response was similar to the responses measured during passive body rotation.

5. The principal conclusion is that in normal adult humans, the COR does not aid in stabilization of the image on the retina during passive or active body rotations in the same manner as the vestibulo-ocular reflex (VOR).

It has been determined in the previous set of experiments that the COR and VOR do not work together to produce retinal image stability. Rather the eye movements caused by head rotation (VOR) and body rotation (COR) generally oppose one another. An experimental method has been devised which will allow joint excitation of the COR and VOR as well as separation of effects from the recorded eye movements. The experiments require computer control and data analysis.

Clarification of Alignment and Control Principles for Lower-Limb Orthothics and Prosthetics
Responsible Investigator—C. Pritham, C.P.O.

Last year this project was entitled, "Studies Involving Alignment of Above-Knee Prostheses." It was proposed that some 40 above-knee amputees be studied in the gait laboratory to assess variations in alignment and to examine the correlations between alignment and gait performance. The second phase of this proposed project was to produce controlled malalignments in several patients in order to further elucidate alignment principles.

Although the details of the gait analysis scheme were formulated and carried out on several patients, it is felt that the gait lab resources are best utilized to clarify alignment and control principles on a broader basis, namely, in regard to shoe modifications, ankle-foot orthoses, and AK and BK prostheses. Consequently, effort was re-directed to accomplish the broader objectives as stated above.

Development of Myoelectric Knee Control for AK Protheses
Responsible Investigator—G. Moskowitz, Ph.D.

A model of the actuator was derived, and the entire thigh-actuator-shank system was simulated on a digital computer. The system was treated as a pair of rigid links pivoted at the knee center with shank mass concentrated at its CG (Fig. 1). The hip was subjected to displacements (X_H Y_H) and the thigh to rotation (Θ_T) as would occur during normal locomotion. The controller was programmed to provide input to the actuator such that a normal torque profile would be produced at the knee. Results of the simulation are presented in Figure 2, where "actuator length" is as defined in Figure 1. The simulation has been extended to include non-gait situations. X_H, Y_H, and Θ_T have been provided by Radcliffe (1).

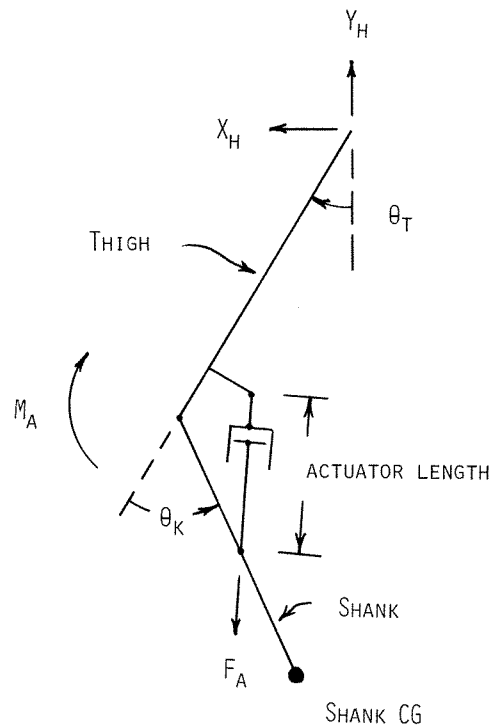

FIGURE 1
Schematic of Thigh Actuator Shank System for simulation study.

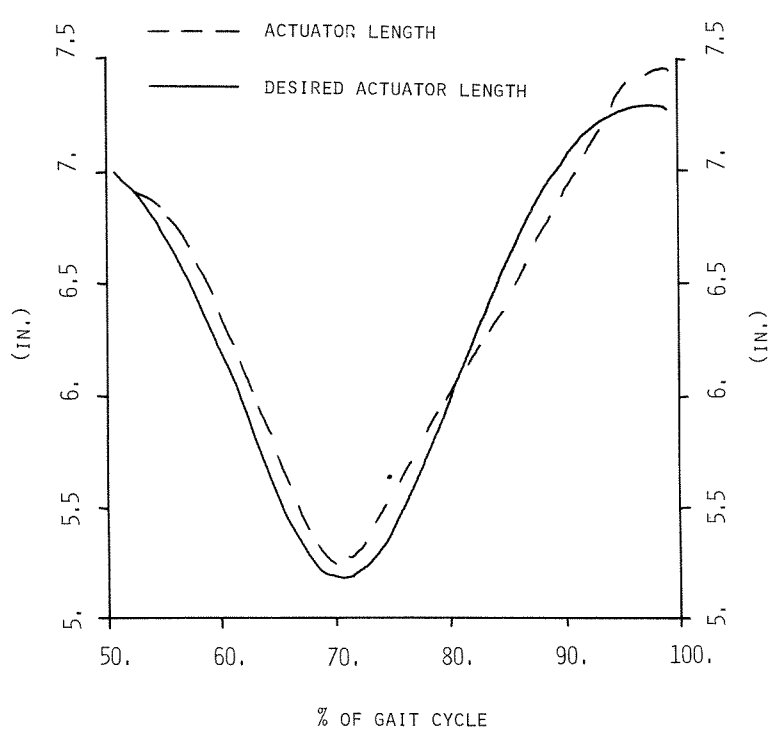

FIGURE 2
Desired actuator response vs. simulated response.

Simulation studies indicate that the design employing an actuator and controller as described above will provide appropriate damping torques and limited active torques under voluntary control of the amputee.

References

1. Radcliffe, Charles W.: Biomechanics of Swing Phase Control in Prosthetic Knee Mechanisms. 1st Intl. Congr. Prosth. Tech. and Func. Rehab., 275-286, Mar. 1973, Vienna.

New Projects

Lower-Limb Prosthetic Components
Responsible Investigator—C. Pritham, C.P.O.

There is a widely perceived need for a suitable lightweight above-knee prosthesis for geriatric patients who are potentially functionally limited. A number of developments in the U.S. and abroad show potential in meeting this need. It is proposed that an effort be made to explore the possibilities. Objectives of this project are:

a. To design and fabricate a lightweight constant-friction single-axis knee with optional manual lock of endoskeletal design.

b. To modify an existing design of a polycentric knee.

c. To obtain and informally evaluate a British-designed knee.

d. To explore the feasibility of using foamed-in-place soft cosmetic covers with the above and with other endoskeletal prostheses.

e. To obtain and informally evaluate British-designed commercially available thermoplastic soft cosmetic covers.

f. To explore the feasibility of using a commercially available brush-on urethane elastomer as a prosthetic skin.

Instrument for Clinical Observation of Weight-Bearing in Locomotion
Responsible Investigator—D. Taylor, B.S.E.E.

The temporal patterns of vertical force against the walking surface during locomotion contain information which can be utilized in the description of pathological and normal gait. An increasing interest in establishing locomotion laboratories at hospitals and rehabilitation facilities is a reflection of the growing interest by clinicians in obtaining measures to characterize human gait. Few clinical facilities, however, can afford to purchase and install the expensive force plate assemblies which are commercially available, or the expense of designing and fabricating these assemblies and the associated electronic instrumentation. As a result, only a limited number of rehabilitation facilities are capable of obtaining and utilizing this basic parameter of locomotion.

The objective of this project is to design and construct an economical semi-portable walkway capable of recording and displaying vertical force patterns at a cost of about one-tenth that of conventional instrumentation. The instrument should be easy to use and possess sufficient accuracy and reliability to serve most clinical purposes. The device will make this basic phenomenon of gait available to a much broader range of clinicians than at present.

Studies in Functional Electrical Stimulation
Responsible Investigator—N. Mayer, M.D.

This project seeks to demonstrate that the delivery of functional electrical stimulation (FES) in advance of a desired movement behavior will facilitate that particular movement behavior. Specifically, we plan to study the relationship between cutaneous electrical stimulation and lower-limb unloading (i.e., transfer of body weight to the other limb) in neurologically normal subjects and patients with upper-motorneuron syndromes. Subsequent studies under this same project will examine the feasibility of utilizing a body-weight-activated foot switch to trigger functional electrical facilitation at the initiation of swing-phase and unloading of the stance-phase limb. The ultimate goal of the project, therefore, is to develop a two channel electrical stimulation unit which will help to control the entire swing-phase by facilitating the initiation of swing-phase and limb unloading during preswing and initial swing, using cutaneous stimulation of the plantar surface of the foot as well as controlling ankle position during mid-swing and terminal swing using the already verified direct peroneal nerve stimulation. Objectives of this project are:

a. To establish reaction time and unloading rate responses to electrical stimulation applied to the plantar surface of the foot in normal subjects and patients with upper-motorneuron syndromes.

b. To determine the locus of total body weight distribution during stance phase of patients with upper-motorneuron syndromes.

c. To develop a two channel electrical stimulation unit to test facilitation of the initiation of swing phase along with direct motor nerve stimulation to control mid and terminal swing portions of the gait cycle.

An Examination of Gait Function Following Intrasynovial Knee Injection
Responsible Investigator — T. Cook, M.S.

This project concerns a basic descriptive study of the biomechanical aspects of gait performance prior to and following intrasynovial injection of arthritic knee. The investigation will include measures of overall gait function as well as specific measures of the forces and motions associated with the involved knee joint.

The objective of this project is to describe the changes, if any, in selected gait parameters following intrasynovial corticosteroid injection of the knees of arthritic patients. The selected gait parameters include bilateral measures of: step length, step time, rate of vertical loading, peak vertical load, vertical impulse, and knee excursion.

EVALUATION

Functional Electrical Stimulation Responsible Investigator—N. Mayer, M.D.

A reliability study is currently being pursued on the new FES unit fabricated at the Rehabilitation Engineering Center. It has been proposed to study 10 patients using this new unit for a period of 6 mo of daily usage. Patients have been encouraged to utilize the unit on a fulltime basis during the day as a swing-phase control orthosis. At the time of writing of this report, 9 patients have been selected for study. Six patients are actively engaged in using the units. One patient entered into the study for 2 weeks but dropped out because she could not manage the application of the unit. Two patients have been selected and have agreed to participate in the study and will be activated shortly so that their data are not included in the subsequent report. To this point, 550 patient days of use have been logged using 7 different FES units. During this time period, 11 problems have been brought to our attention, including 6 problems with the foot switch, 3 problems with electrode placement, and 2 problems requiring a change in the battery. In addition, one patient had one complaint of having developed cramps in his thigh and calf which were transient and were treated symptomatically. There is a question as to whether these cramps were related to the FES treatment. (At the time, the patient was also involved in a special muscle exercise program conducted elsewhere.) Patients entered into this study are also being investigated with respect to their walking speeds. Data with and without FES are being collected and will be compared to repetition of the data collection at the end of 6 mo. These data are not available at this time since the patients have not completed the full 6 mo on the study. One patient did not use the unit for 10 days during very hot weather because she indicated to us that she was uncomfortable wearing the unit during this hot period.

Education and Dissemination

Training Films on Locomotion Responsible Investigator—T. Cook, M.S.

The educational film on normal human locomotion has been edited and will be ready for distribution by the end of the grant period. Eight copies of this film have already been requested by various institutions and a copy will be submitted for showing at various scientific meetings during the next year.

Planning was begun on production of a locomotion film on above-knee amputees and preliminary footage was taken on several patients. This footage will be combined with that taken as part of the project on "Clarification of Alignment and Control Principles," and disseminated as part of the results of that project.

Dissemination of Information on Sensory Feedback Devices Responsible Investigator—C. Leiper, R.P.T.

For several years the development and evaluation of sensory feedback devices has been one of the major projects of this center. The possibility of utilizing knowledge of muscular activity and body movements as precise and repetitive sensori-motor performance information has greatly expanded with the development of biomonitoring technology. This type of performance information, known as biofeedback, sensory feedback therapy, and augmented sensory feedback,has been used to redirect aberrant movements with the intent of developing long term functional improvement of neuromuscular control. Sensory feedback is a response oriented approach to treatment through which objective performance information related to a specific motor task is presented to provide a comparison of the actual performance with the intended performance. The information can be presented via the visual, auditory, or tactile sensory pathways.

Several measuring and monitoring systems have been designed at this center to provide immediate, consistent, and continual feedback of performance:

a. *The Limb Load Monitor* (LLM) was designed to provide auditory information related to the amount of weight bearing in the lower limbs and is used in ambulation training for patients having hemiparesis or amputation.

b. *The Knee Angle Monitor* (KAM) provides auditory feedback regarding the position of the knee and can be used as an adjunct when increasing the range of motion at the knee joint or in developing motor control during standing and walking.

c. *The Palatography Unit* was developed to provide visual feedback related to the position of the tongue on the palate. It is used during speech therapy for dysarthric or hard of hearing patients.

d. *The Head Position Monitor* (HPM) is utilized by children having cerebral palsy to indicate and encourage the upright posture of the head. Feedback is an auditory signal and/or the operation of toys or TV when the head is positioned correctly.

e. *The EMG Monitor* provides auditory or visual feedback regarding the electrical activity generated by a muscle and is utilized in many central and peripheral nervous disorders for specific muscle retraining.

Of these devices, the LLM, the KAM, and the EMG Monitor are currently produced by this center in small quantities. The LLM has undergone extensive field trials and external clinical evaluation. The KAM has been clinically tested by one external evaluator (IRM at New York University) and a current center project is expected to provide guidelines for clinical use based on an internal clinical trial.

Dissemination of information regarding the application of the devices has primarily consisted of progress reports in the center's annual report, lecture-demonstration by therapists, physicians, and engineers to professional associations. Publications have been limited.

Within the past year promotion of the devices, especially the LLM, has been increased to include advertisements placed in the Physical Therapy Journal and demonstration via an exhibit booth at the national meeting of the American Physical Therapy Association.

Knowledge and experience in the development and application of sensory feedback devices, especially those related to force or position feedback, is relatively rare. Investigators at this center have been among the leaders in the field. Increasing numbers of therapists are receptive to the use of feedback information within rehabilitation programs and are requesting information and workshops. Therefore, it is proposed to continue the dissemination activities of the therapy personnel in an active manner over the next 2 yrs.

Patient/Client Services

Rehabilitation Engineering Services
Responsible Investigator—
G. Moskowitz, Ph. D.

Engineering rounds at Moss and Temple were initiated in January 1979. Since that time a total of 77 patients with 113 problems were seen by the engineering team and 131 solutions have been recommended (Table 1). Approximately 31 percent of these problems were in the area of activities of daily living 23 percent related to home evaluation including access inside and outside the house as well as equipment modification in the home, 15 percent were related to mobility with the majority of these problems relating to wheelchair ambulation, and 12 percent of the problems were in the area of communications. The vast majority of cases referred for engineering evaluation had disease of the central nervous system. The four most common disease categories were craniocerebral trauma, spinal-cord injury, peripheral neuropathy, and multiple sclerosis.

An area of major interest in this project is to establish the domain of rehabilitation engineering problems with particular regard to the type of personnel necessary for providing such services. We have taken a team approach towards problem solving because it was anticipated that the engineering service delivery model for handicapped patients would be similar to the medical rehabilitation model which also revolves around a team approach. The primary engineering team consists of a rehabilitation engineer, a physician, a physical therapist, and a rehabilitation nurse. Additonal resources available to the engineering team are a transportation specialist (with a background in occupational therapy), an orthotist, occupational therapist, and a number of engineering center personnel with skills in mechanical and electrical engineering. In

TABLE 1
Engineering rounds: for 77 patients with 113 problems, 131 possible solutions were recommended. The percentage column indicates that 31 percent of the problems involved activities of daily living.

Solutions of Problems	No. of Solutions	%
Activities of Daily Living		
a) Orthotics	5	
b) Adaptive Devices	31	31
c) Prosthetics	0	
d) ECU	5	
Mobility		
a) Locomotion Aids	6	
b) Wheelchair Ambulation	10	15
c) Seating	3	
Home Evaluation		
a) Access House	27	23
b) Equipment Modification	3	
Communication		
a) Non-Vocal Communication Devices	8	
b) Vocal Communication	1	12
c) Call Systems	4	
d) Electronic Communications	3	
Transportation		
a) Personal Licensed Vehicles		
1) Operation	4	
2) Access	4	9
3) Modification	4	
b) Public Vehicles		
1) Access	0	
Work Site Evaluation		
a) Access	2	7
b) Equipment Modifications	7	
Architectural Barriers in Public Places		
a) Access into Building (PL504)	0	0
b) Public Thoroughfare	0	0
c) Public Rest Rooms	0	0
Other		
a) Inappropriate Referral	0	3
b) No Solution	4	

reviewing the case histories problems and solutions for the past 6 mo, it was apparent that the recommended solutions for patients referred to the Rehabilitation Engineering Service required team problem solving in the vast majority of cases. Contributions from health professionals as well as engineering staff were required to generate an appropriate solution for the handicapped patient. For the solutions generated, 67 percent required team problem solving, 29 percent of the solutions required specific engineering problem solving over and above the contribution of the engineer to the team problem solving.

A grant contract was signed with the Pennsylvania Bureau of Vocational Rehabilitation. This grant will support the outpatient function of the service and will also provide funds for this center to purchase an advanced adaptive van to be used to assess, train, and evaluate severely disabled persons who wish to acquire driver status.

The service has continued to expand, through purchase and other means, the rehabilitation engineering equipment demonstration collection which has been of enormous value as a concomitant to the engineering service. This REC has shared its equipment experiences with other participants in the REC/REDU program.

Clinical Gait Analysis Service
Responsible Investigtor—T. Cook, M.S.

During the past year a total of 49 patients have been evaluated as part of the Clinical Gait Analysis Service. Twenty-two patients were referred from the Moss Hospital Orthotics and Prosthetics services. Nineteen patients were below-knee amputees, one was an above-knee amputee, and two were patients with orthotic devices. Six patients were evaluated from the Rheumatology Service. Thirteen patients were referred from the A.I. Dupont Institute in Wilmington, Delaware, and eight patients were referred from a variety of sources including the American Oncologic Hospital, Thomas Jefferson University Medical Center, and the Hospital of the University of Pennsylvania.

Table 2.
Patients tested as part of the clinical gait analysis service and the type of measures obtained on each patient.

Measures	Foot Contact Events	Joint Kine-matics	Ground Reaction Forces	Forceline Visualiza-tion	Myoelectrical Activity
Orthotics-Prosthetics Service:					
19 BK	19		19	4	
1 AK	9	1	1	1	
2 Orthoses	1		1	2	1
Rheumatology Service: 6 Arthritis	6	4	6	4	1
Dupont Institute: 13 foot problems	13		13		
Other:					
2 Musculo-skeletal			1	2	1
6 CNS problems	4	4	3	6	5

In each case an effort was made to select those measurements most pertinent to the patient's problem. Table 2 shows a breakdown of the kinds of measurements and the patient for whom they were made.

In all instances, an attempt has been made to maintain close contact with the managing physician to ensure that the information supplied by the gait analysis service is understandable and relevant to patient management. To date, physician cooperation has been good and several area physicians have visited the laboratory to gain a better appreciation of the type of service which can be provided.

Patient Client Services

Adaptive Seating Service
Responsible Investigator—C. Leiper, R.P.T.

Over the past 2 yr, REC personnel have been involved with certain evaluation activities in the area of special or adaptive seating and wheelchair systems. At the same time an interest in developing a clinic team to recommend appropriate wheelchair prescriptions, was developed by Dr. Spencer of the Moss Rehabilitation Hospital Pediatric staff. REC personnel became involved as consultants in this clinic operation through their knowledge of special techniques used in the evaluation programs. In effect this clinic is an attempt to document the need for a special seating service to accommodate those persons requiring adaptation of commercial items or design of special systems.

In addition to participation in the Wheelchair Clinic, personnel have been involved with the transfer to Elizabethtown Hospital of the fitting chair for the Molded Plastic Insert technique. This hospital already has an active adaptive seating program and was anxious to utilize the new technique.

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Ann Arbor, Michigan 48109

J. Raymond Pearson, M.Sc., M.E., Director

Primary research efforts at the University of Michigan Rehabilitation Engineering Center (UM-REC) focus on the driving of personal licensed vehicles by persons with disabilities. Core areas of this endeavor are

1. the assessment of performance capabilities of persons with physical disabilities,
2. investigations of physiological and psychological factors affecting driver performance,
3. the development of a working clinical model for extended service delivery, and
4. innovative approaches to the design and development of adaptive devices and systems for vehicles.

The following reports on progress in the area of the design and development of wheelchair compatible vehicles.

At the present time, vans are the only vehicles commercially adaptable to accommodate the driving needs of persons who are too severely disabled to use conventional passenger cars equipped with hand controls. Although modified vans serve the needs of some drivers in this group well, the needs of others would be better served by conventional passenger cars if they were suitably modified. A suitably modified passenger car would offer obvious advantages to owners: because the initial and operating costs are lower than those of vans, the cars will fit into ordinary residential garages, and there is a psychological advantge to driving a vehicle essentially like that driven by most able-bodied drivers.

The development of a suitable powered wheelchair and compatible

FIGURE 1.
Driver seated in a simulated vehicle-compatible wheeled chair in the Dodge Omni. This prototype chair is for a passenger-door entry concept.

passenger car poses many problems as evidenced by the fact that previous efforts in this direction have not been commercially successful. A satisfactory wheelchair-modified car combination should satisfy the following important criteria:

1. The overall system must be reasonably simple, less costly than a van conversion unit, and highly reliable. These factors tend to go together. Fail-safe features must be incorporated into the equipment whenever possible. (One important safety feature in such cars might be a CB radio which is operable by the driver from any position where a malfunction might be encountered in or just outside the car.)
2. The vehicle modification should leave the vehicle operable by an able-bodied driver and reconvertible to "standard" when traded in for a new model. Any modifications should encroach minimally upon the utility of the vehicle and leave it so that the driver can take one or more passengers with him. Likewise, some, and preferably all, cargo space should be left intact.
3. The special wheelchair should not only serve for use with the automobile but should also be useable as a regular electric wheelchair. Ideally, the added features built into the chair to make it compatible with the car would enhance its value for other purposes.
4. Aesthetic and psychological factors must be satisfied. These include making the mode of entry and egress for the special wheelchair as inconspicuous as possible.

Cars with front-wheel drive provide a more nearly flat floor for any desired movement of a wheelchair inside the car. It is also evident that cars of the future will be smaller than past American designs. Furthermore, the recent introduction of "hatch-back" models appear to indicate a design feature that will probably be available on many cars. The first American automobiles to combine these features were the Chrysler Horizon and Omni models. The Chrysler Corp. donated two Omni vehicles to the UM-REC for these studies. The initial effort in the design and development of wheelchair-compatible vehicles has concentrated on the utilization of these vehicles, and two prototypes of wheelchair-compatible compact vehicles are being developed to complement the vans that are commercially available.

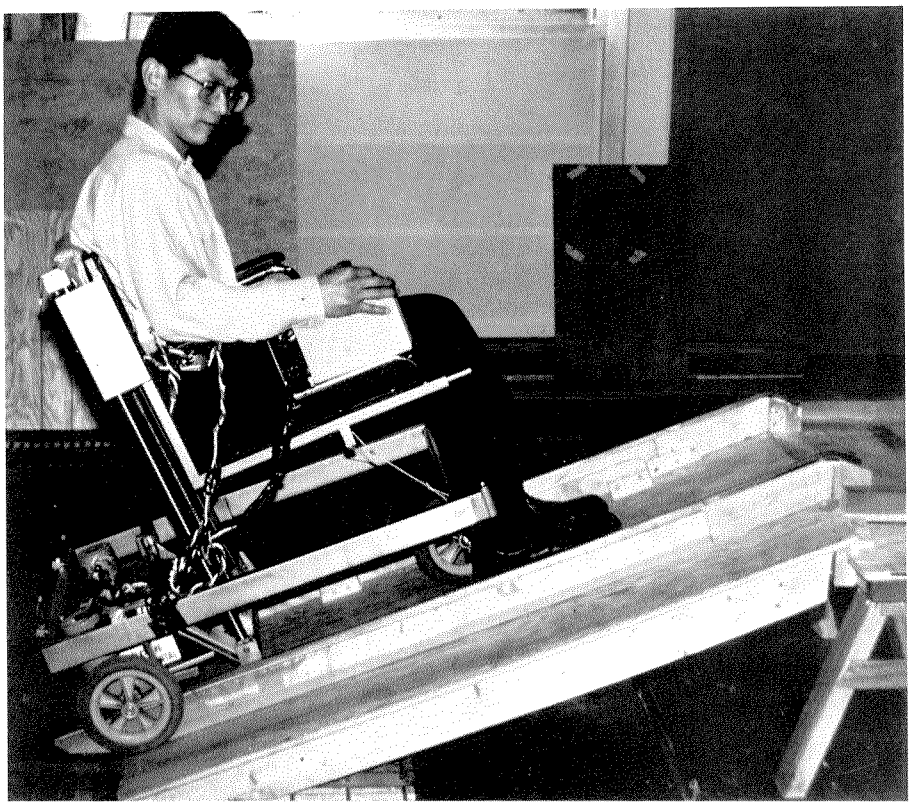

FIGURE 2.
Prototype vehicle-compatible wheelchair.

One of the Dodge Omnis was modified by Creative Controls, Inc., in Troy, MI, a subcontractor of the UM-REC. Modified door hinges allow the passenger side to swing nearly 180 deg, thus improving wheelchair access to the curb side of the vehicle. The gearshift control console was removed from the floor and installed next to the steering column. The floor has been leveled completely for easy access by a wheeled vehicle, and a power-operated parking brake actuator was installed. A small low-silhouette wheeled chair has been fabricated for ramp or lift entry through the curb side door (Fig. 1). This chair was constructed in the proper driving configuration for entry and egress studies and does not raise and lower to provide normal wheel-chair position and function— this unit was not intended for general use.

This particular Omni car was also equipped with sensitive servo brake and throttle controls to enable drivers with severe disabilities to operate the controls. The actual chair, with a provision for raising it to the floor level of the car where it can be maneuvered by the available mechanism, has not been developed. When completed, this prototype would require removal of all regular interior car seats but might permit a folding seat for one passenger in the rear. The luggage space in the trunk area would remain intact.

A prototype wheelchair was built for the UM-REC by Sarns, Inc., of Ann Arbor (Fig. 2). Initially, the plan provided a smooth rolling surface to support the chair weight, with the rack and pinion for propulsion only.

Because of clearance problems, the weight-supporting rollers were eliminated—preliminary indications showed that this might be satisfactory. This unconventional practice undoubtedly increases friction and wear of the rack and pinion. If this proves to be objectionable, the weight-supporting rolling members can be restored. Standard cog belt components with sprockets for climbing wheels, and the mating rubber belting bonded to the ramp surfaces, proved unsatisfactory because overlap between engagement of successive teeth could not be obtained. However, a special rack and pinion provision (Fig.3) would enable the chair to climb a relatively steep ramp with positive traction (important for possible rain and snow) and with adequate power from the "automatic low gear"feature.

This chair incorporates the necessary provisions of lowering and tilting the seat so that rear entry into the vehicle can be made within the available vertical opening of the hatchback. Tracks and lateral guides inside the car for bringing the chair forward and into driving position, and a suitable restraint system in the driving position, have not yet been developed. Other mechanical details must also be refined if an acceptable level of reliability is achieved. This system leaves the front passenger seat of the car undisturbed but eliminates most of the previously useable space for rear seat passengers and trunk cargo storage (Fig. 4).

A third approach will involve providing a chair with adjustable seat height to be attached to the inner surface of the passenger door of a 2-door sedan when the door is fully opened (Figs.5-7). With the chair seat thereby held in a fixed position by the car door, actuating the "chair lowering" provision would result in retracting the chair wheels. In this position, the car door could be powered closed, thus bringing the chair and its passenger into position for driving the car from the right side with special controls somewhat similar to those used for driver education vehicles. Preliminary investigations indicate that a simple, lightweight, attractively styled three-wheel chair similar to the general concept of the AMIGO wheelchair could probably be developed to accommodate the needs of persons with severe disabilities who are presently unable to drive. Such a chair could be small enough to fit within the door opening of a standard 2-door car body.

FIGURE 3.
Wheelchair drive with coaxial wheel and rack pinion. The small pitch diameter of the latter increases traction output and enables the chair to climb the steep slope.

FIGURE 4.
View from the rear of a wheelchair-compatible vehicle. In this particular vehicle, the driver's seat was temporarily replaced so that the car could be driven by an able-bodied driver. The front passenger seat remains intact but the entire back seat and all of the cargo space were eliminated.

FIGURE 5.
Modified AMIGO wheelchair design concept. The simple powered, steerable, front wheel with steering input would be adapted to the strength and range of motion of the driver.

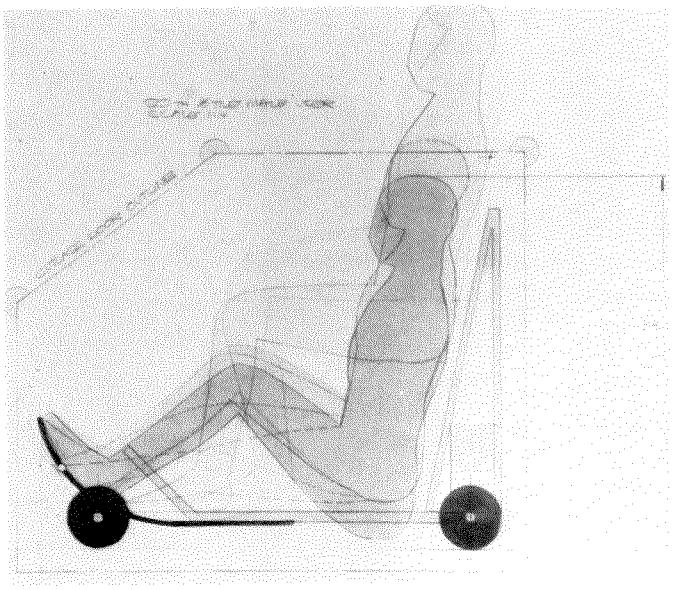

FIGURE 7.
Drawing from a feasibility design study of a modified wheelchair with the occupant passing through the door opening of a typical wheelchair-compatible vehicle.

Advantages of a Right-Hand-Side Design

This right-hand-side system may be substantially simpler, and hence more reliable, than the other two approaches. The remainder of the vehicle interior would be unencumbered, so that the full passenger and luggage complement can be carried. Other advantages of using the right side are that the left side is left unaltered for use by able-bodied drivers, and the normal steering wheel and column are not in the way of the driver with a disability. Entry and egress with this system could be accomplished in a rather ordinary and inconspicuous manner. The primary modification to the car involves considerable strengthening of the door and its hinges. This process may necessitate removal of the window elevating mechanism with the window remaining permanently closed.

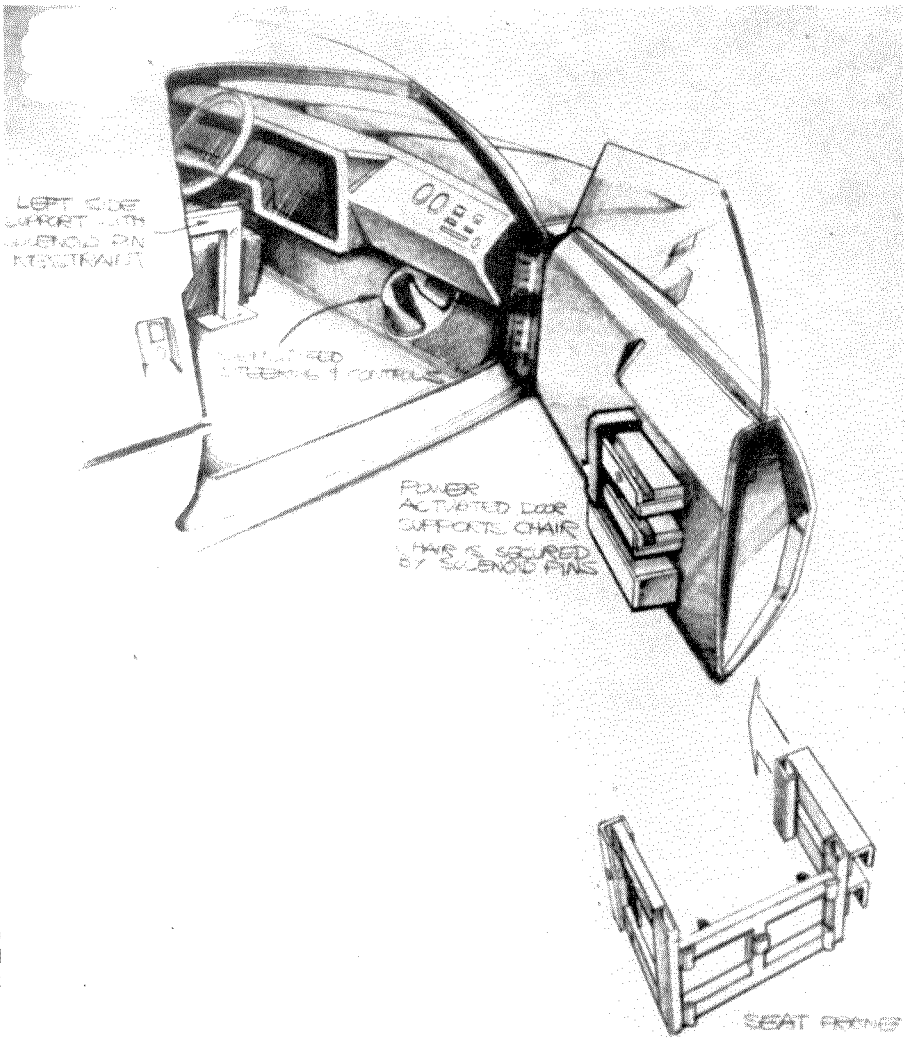

FIGURE 6.
Wheelchair-compatible-vehicle concept. Wheelchair brackets will engage counter brackets on door that suspend chair from door as wheels rise to clear sill. Powered door will swing car door into place. Front wheel of chair will engage slotted truncated cone connector to vehicle steering system.

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James B. Reswick, Sc., D., Project Director

The work in functional electrical stimulation (FES)is the primary core area of the REC at Rancho Los Amigos Hospital. The work is carried on by the Neuromuscular Engineering Group directed by Bruce Bowman, M.S.

Probably the most noteworthy progress in neuromuscular engineering during 1979 relates to the successful transition of rehabilitation engineering technology to near-commercial production and distribution.

Cyclic Electrical Stimulation

The application of lateral surface cyclic electrical stimulation to the treatment of idiopathic scoliosis continues to show exceptionally promising results. Followup results of over 50 patients at Rancho and 12 in Sweden confirm that in selected cases the progression of scoliosis curvature is stopped while in some it is reduced. The device responsible is the ScoliTron ™ manufactured by MedGeneral of Minneapolis, Minn. This unit is based on Rancho REC research and development and is the subject of a joint pending patent application.

Cyclic stimulation has become a standard treatment method in the Rancho Stroke Service for both upper and lower-limb involvement. Based on Rancho REC designs and specifications, the StimTech Corporation of Minneapolis, Minn., has supplied 100 prototype cycling stimulators to the Rancho REC. These stimulators will be provided by the center to selected groups in the United States and in Tunisia, as part of a multicenter evaluation program sponsored mainly by the U.S. Veterans Administration.

Pathokinesiology

The Rancho REC Pathokinesiology Department, co-directed by Dr. Jacquelin Perry, M.D. and Daniel Antonelli, M.S., selects from among its activities for this report two techniques which have now matured following several years of development.

One is the finalization of EMG quantification as a reliable, effective and efficient means of identifying, in a person with normal neural control, the relative intensity of muscle action during events of interest. While development of this approach evolved through progressive stages, this is the year that established quality and practicality were proved. It was applied with confidence to three complex studies, all of which resulted in clinically pertinent and logical findings.

The intensity of quadriceps muscle action was proved to be significantly less during straight leg raising than with isolated knee extension in approximately half of the subjects, indicating that this is an unreliable way to seek quadriceps strengthening. Action of the single and two-joint hip extensor muscles was distinctly diffferent during stair climbing and walking, implying a correlation between functional potential and the patient's pattern of paralysis. Response of the shoulder muscles to proprioneuromuscular facilitation proved to be less selective in either timing or intensity than is commonly taught. The natural conclusions are that either the therapist must be more selective in the use of these techniques, or mass strengthening is the primary therapeutic objective.

in pathokinesiology has been the compilation of an age-defined data base of normal values for energy costs of walking. Through serial studies, they now have reference data of approximately 20 males and 20 females for each of the basic age groups: child (6-12), teen (13–19), adult (20–60), and geriatric (over 60). This provides a reliable baseline for judging the significance of the many types of chronic disability.

These two accomplishments are an excellent example of the rewards of close engineering and medical collaboration to solve difficult clinical tasks.

Project Threshold

Project Threshold is really two separate but interrelated projects: Model Home and Client Services. The Model Home is one of three Rehabilitation Equipment Demonstration (RED) Units established as experimental models in the United States by the National Institute of Handicapped Research, for the purpose of assisting the disabled in obtaining the most appropriate rehabilitation equipment to serve their needs. The Rancho RED Unit has become fully operational in 1979 as an independent Living Evaluation Center. It is used extensively in the California State Department of Rehabilitation Client Services Program, and is also heavily used by the Occupational Therapy Department of Rancho Hospital for evaluation of Los Angeles County patients. Only minimal progress as an equipment evaluation center has been made due to lack of funding, but with new supplementary funding specifically for the RED Unit, evaluation, information exchange, and training will be intensively developed.

Client Services Program

The Client Services Program that is block-funded by the Department of Rehabilitation of the State of California is operating at full capacity with a substantial waiting list. To date, 114 referrals from state counselors have been serviced. A report entitled "Project Threshold—A Model System for Delivery of Rehabilitation Engineering Services" was published in April, 1979, and distributed widely. This report shows how one type of effective system may be organized, and it further gives client cost data. Additional copies of this report are available from Rancho's REC.

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Evaluation of Electronic Self-Help Devices for Severely Disabled Patients

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Evaluation of the unique (and comparatively expensive) Bard-Carba transducers (radio frequency, infra-red, etc.) reveals little or no advantage over conventional transducers for operation by persons with high-level SCI or muscular dystrophy. The Possum Link PSU-2 and Commutron ENCO-IV have not been preferred by any diagnostic population. Evaluation of new vocational aids has not revealed new page turners or typewriter systems recommended for general use by individuals who can proficiently use a mouthstick. Three page turners (MED-Brusse, GEWA, Bard-Carba R-2) are recommended for applications where the prospective operator cannot utilize a mouthstick, or where the volumes to be read are of dimensions which only these devices can handle.

Continued evaluation of mobility control systems indicate that the MED System, and the Du-It (Romich, Beery & Bayer, Inc.) each perform reliably and warrant general recommendation for operators who require modified mobility controls. The Du-It provides especially good flexibility for retrofitting onto existing frames and can be utilized with 12-V or 24-V motors. Regarding the shortthrow chin controllers of the respective systems, the Du-It requires considerably less overall attendant intervention than the MED because of the contrasting supporting structures (MED, rigid arm, vs Du-It, harness). Only the MED pneumatic control has been available for testing; the Du-It pneumatic is scheduled for evaluation in the near future. Overall results with the MED pneumatic have been good, with most individuals considering the primary disadvantage to be the inability of the system to permit slowing of the chair without bringing it to a full stop.

Several consumer products are currently undergoing initial evaluation as environmental and/or vocational aids. These include the BSR/Sears Control System, Royce Freedom Dialer, Rapidial, and Teleconcepts Memory Dialer. All have application for out-of-bed operation by many persons with severe physical disabilities. Each of these push-button style units is operable by persons with high level quadriplegia via mouthstick or universal cuff assisted methods—depending on level of lesion. They are also operable by persons with various other disabilities (such as muscular dystrophy or cerebral palsy) with or without some type of mechanical assistance.

Three different brands of powered door openers (Stanley Silent Swing, Power Access, Besam) have been installed and are under evaluation; a fourth (Keane Monroe) is being installed. Product data on the Keane

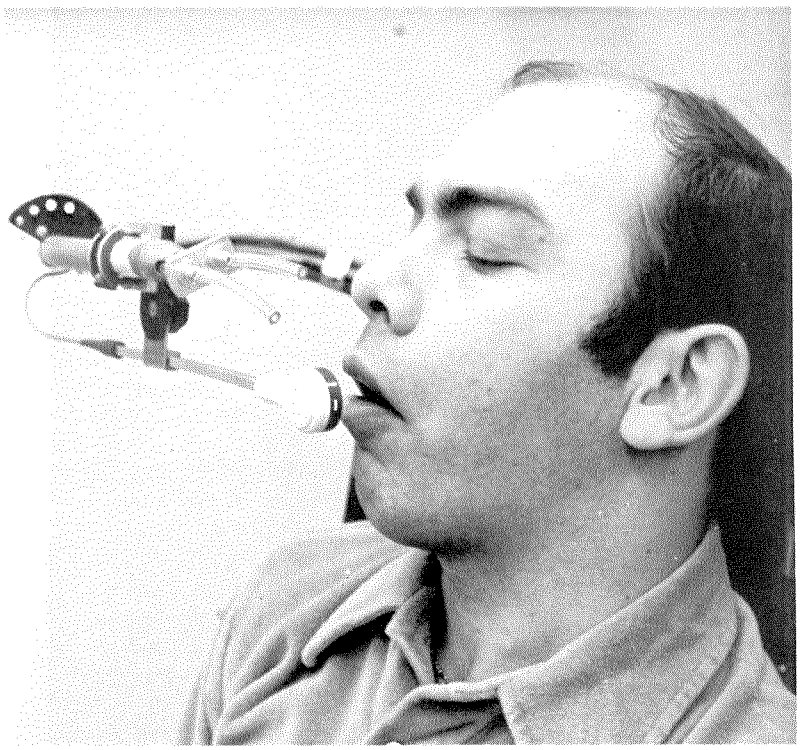


FIGURE 1.
Precise mouth-to-microphone distance must be maintained when noise-cancelling microphones are used with VRS (voice recognition systems).

Monroe suggest that it may have fewer disadvantages than have been noted in the others.

Clinical Evaluation of Voice Control for Rehabilitation Aids for the Severely Disabled—by Persons with and without Speech Impairment

Three studies have been undertaken to obtain data on various aspects of voice input for control of standard rehabilitation aids. A user-adaptive isolated speech recognition system has been utilized to obtain data on recognition, operation, and user acceptance by a spectrum of speakers including persons with spinal cord injury, muscular dystrophy, cerebral palsy and Friedreich's ataxia. Results thus far indicate that good recognition is obtained by motivated disabled users when the controlled aid or device does not induce stress in the user

Speakers with mild to moderate dysarthria are potential candidates for voice control. Speakers with severe dysarthria may be candidates but a small inventory of available commands may limit application. Additional effort is required to develop better means of maintaining the position of the microphone with respect to the disabled speaker (Fig.1)

The basic speech recognition system used in the IRM voice control had proven operable by experienced ablebodied speakers in industrial installations with error rates of 1-to-2 percent. It was therefore anticipated that similar results would be experienced by disabled speakers. However, a review of the results of our original studies, which were directed toward an evaluation of the application of the voice control systems rather than quantitative assessment of speech-recognition error rates, revealed overall error rates that were considerably greater. Studies have shown that very low error rates are essential for voice input to be readily accepted by users (1).

It is encouraging to note that voice recognition systems accomodate a wide range of intellectual abilities and speech impairments. No boundaries regarding intellectual levels have been noted for levels varying from significantly below age level through very superior. Mild to moderate dysarthria and scanning speech have not proved to be contraindications for voice control. Within the limitation of a limited number of commands, severe degrees of dysarthria can be accommodated.

Analysis of our clinical studies indicate that recogniton problems result almost exclusively from an inability to maintain the proper microphone position (see Figure 1) or operator stress elicited by specific aspects of control of the peripheral devices. Follow-on studies are devoted to developing adequate training programs that will minimize the role of stress in the utilization of voice control systems.

(1) Martin, T.B.: Practical Applications of Voice Input to Machines. Proc. of IEEE, Apr. 1976, pp 487-501.

Study of the Impact of Electronic Assistive Devices on the Quality of Life of High-Level Quadriplegics

The impact of electronic assistive devices, i.e. environmental contol systems (ECS), etc. on the day-to-day living of high level quadriplegics (C-3—C-5) has been studied. Twenty male quadriplegics (7 ECS users and 13 non-users) were interviewed using Activity Pattern Indicators (APIs), Bell Adjustment Inventory, Locus of Control, Multiple Affect Adjective Checklist and McClelland's adaptation of the Thematic Apperception Test. Thus far it has been found that ECS users make greater use of adaptive devices to function more independently and with minimal assistance; users are more active (i.e., they participate in more activities). As expected, users spend considerably more time in educational activities than non-users, while non-users spend significantly more time in passive recreational activities in residence than users. (Fig.2 and 3). We have, thus far, concluded that environmental control systems have a positive impact on the lives of users and that patient acceptance of these devices should be promoted. Patients should be exposed to them as early as possible in their rehabilitation programs, and home planning and equipment procurement should be accomplished prior to discharge, so that patients and their families do not become acclimated to a less safe and efficient manner of functioning.

An assessment protocol of both intrapsychic and behavioral measures is recommended as a comprehensive and systematic way of evaluating both the short term and long term effects of the utilization of assistive devices.

An Electrical "Know-How" Manual for the Severely Disabled and their Families

Many new electronic assistive devices for the disabled are appearing on the commercial market. These devices offer increased functional ability for the very severely disabled individual. They appear particularly suitable for persons with high-level spinal cord injury—who are being seen in increasing numbers.

With the introduction of powered wheelchairs and their storage batteries, environmental control systems, and the associated peripheral devices, many questions are posed with regard to safety, installation, maintenance, and repair of electrical appliances.

A manual is being written to acquaint the handicappd patient, members of his family, and attendants with enough basic electrical information to enable them to use electricity in the homes with safety and respect. We are trying to answer questions which are asked over and over again: how to charge a lead-acid battery; how to repair a frayed cord; how to choose a properly rated fuse; how long an extension cord to use; how does the ground lug prevent electrical shock, etc.

The manual is in three sections:

1. Basic Theory of Electricity (what it is; what it does; how it does it; safety);
2. "How To" (basic tools for making minor repairs; how to replace a receptacle; how to utilize an adaptor; how to choose a properly rated fuse; etc.); and

MEAN FREQUENCY OF ACTIVITIES IN MALE E C S USERS (7) AND NON-USERS (13)

FREQUENCY = INCIDENTS/WEEK

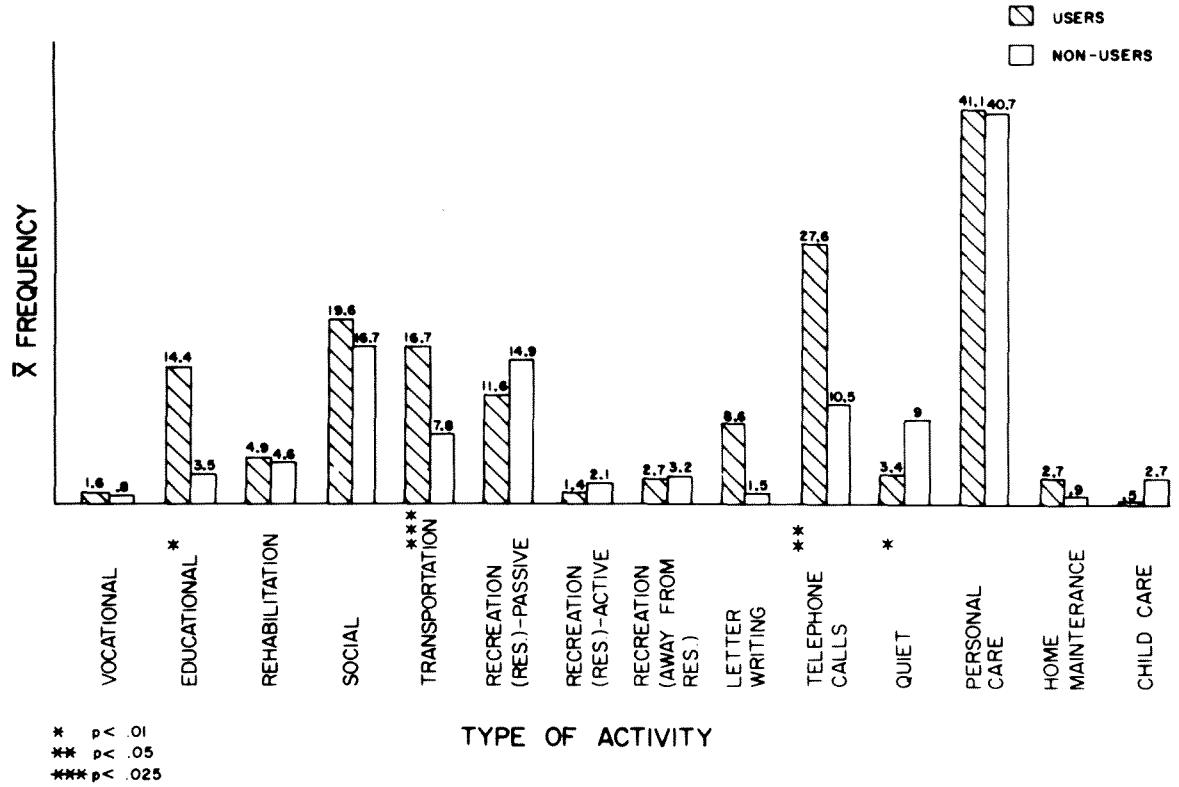
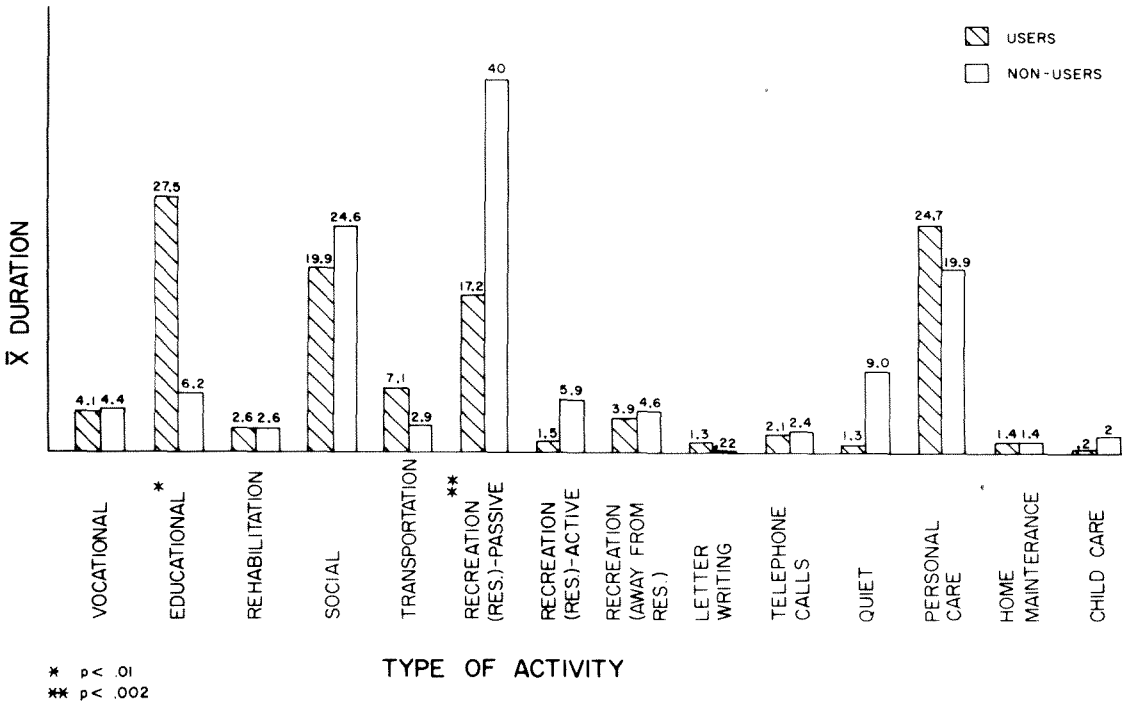


FIGURE 2.

FIGURE 3.

MEAN DURATION OF ACTIVITIES IN MALE E C S USERS (7) AND NON-USERS (13)

DURATION = HOURS/WEEK



3. Appliances commonly used in the home—
   a. room heaters, air conditioners, hair dryers, electric toothbrushes, vaporizers, humidifiers, etc.
   b. precautions for their safe operation; utilization of ground fault indicator receptacles; how to avoid overloading existing wiring, etc.

Braking Systems for Powered Wheel-Chairs for the Severely Disabled

Powered wheelchairs for use by persons with quadriplegia and other severe neuromuscular disorders must have a reliable braking system which is easily operated, and whose operation is readily understood by the driver. The system should utilize standard parts to facilitate repair or replacement when necessary, and should be adaptable to any style of powered wheelchair. The need for a suitable braking system has become even more compelling because of the great increase in the number of spinalcord injuries in the U.S. Spinalcord injury affects approximately 175,000 in the U.S. About 6,500 new injuries occur yearly. Most patients are under 30 years of age and 60 percent are quadriplegic (1).

A multidisciplinary team (consisting of physiatrists, occupational therapists, rehabilitation engineer, driver training instructor, behavioral scientist, and disabled consumers) at IRM has concluded that the optimum braking system is one which operates in a manner analogous to that of an automobile—especially since almost all of our patients were drivers prior to their disabling accident. Thus the system which we propose is one in which—

1. The brakes are applied only as required by driver and are independent of any auxiliary parking brake.(the brakes are not set when the motors are not energized);
2. Braking action is proportional; and
3. Brakes are not connected to the driver controller, and are controlled by a separate switch (or transducer).

The salient features of our system differ from the requirements of a braking system as suggested by Stout (2).

We have developed two separate braking systems:

1. **Mechanical Brake System** - This system utilizes drum type-friction brakes in which the friction brake bands are connected to a pair of actuating solenoids through flexible cables. Two separate drums are required, one for each of the rear drivewheels. The solenoids utilize an efficient two-coil design in which one coil develops the high initial pull, the other holds the load in position. The highpower coil pulls the load through the required stroke distance.

The solenoid plunger then actuates a micro switch which switches the high power coil out of the circuit leaving a separate low current drain coil to hold the load in position. Details of this system are shown in Figures 4,5,6, and 7.

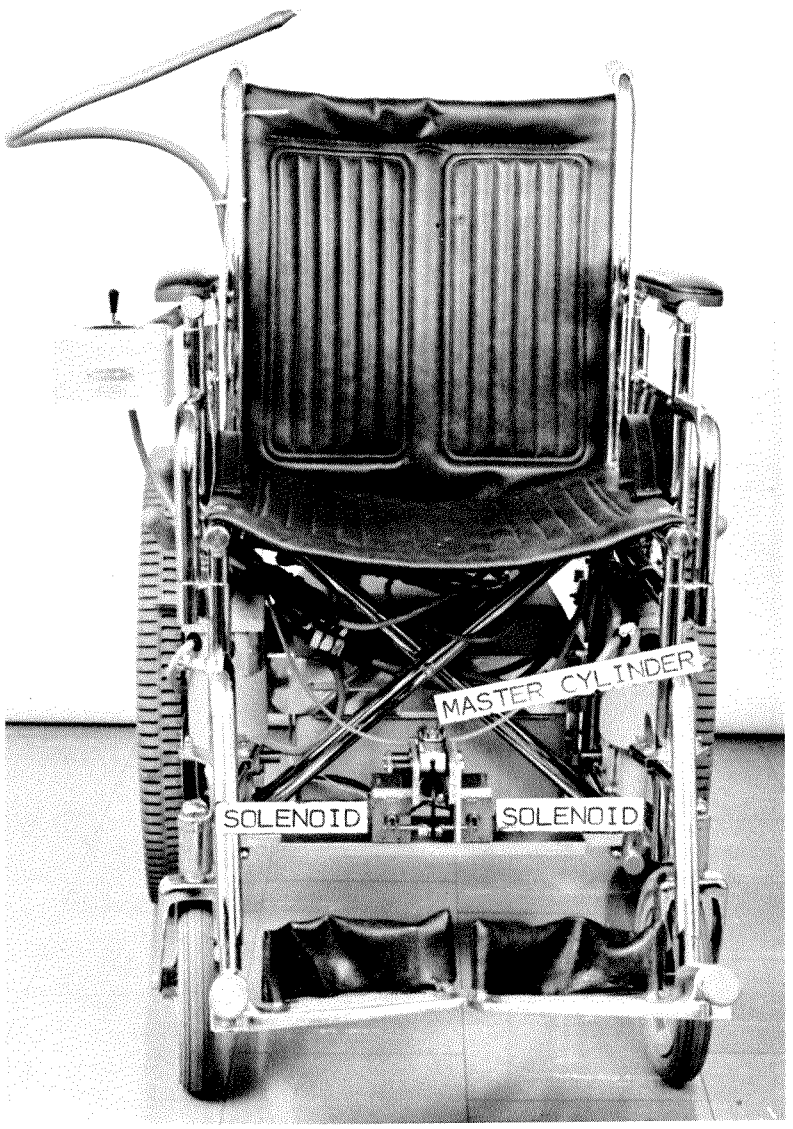


FIGURE 4.
E&J Model 32 powered wheelchair equipped with IRM braking system.

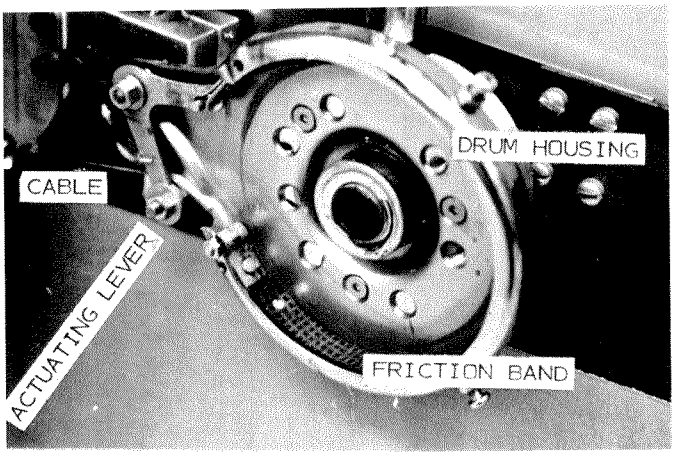


FIGURE 5.
Disassembled mechanical brake showing friction band, drum housing, actuating lever and cable.

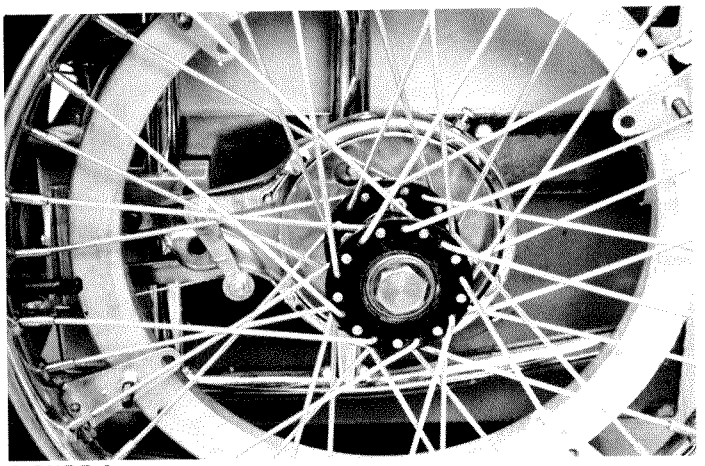


FIGURE 6.
View through spokes of drivewheel showing mechanical brake assembly.

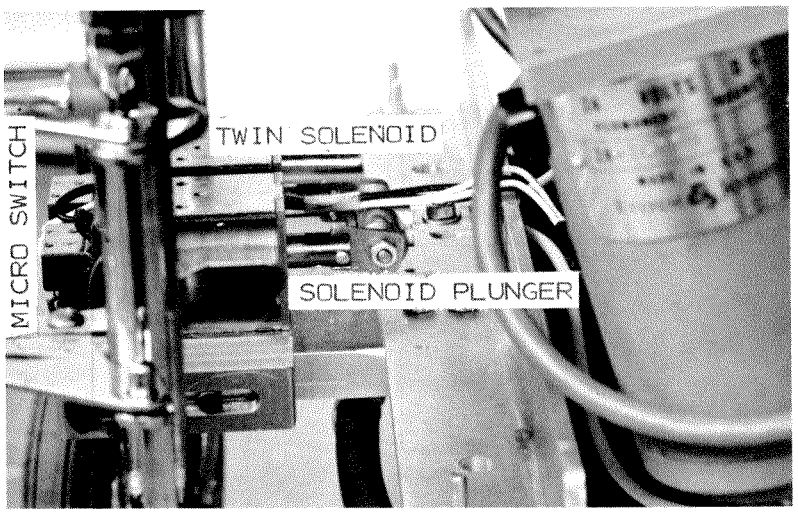


FIGURE 7.
Twin-solenoid assembly, showing position of Microswitch which switches solenoid coils from high power to low power after brakes are applied.

2. **Hydraulic Brake System** - This system utilizes caliper disc brakes which are actuated hydraulically from a master cylinder. The master cylinder force is produced by the solenoids previously described. Two separate sets of brakes are required as for the drum brakes. Details of this system are shown in Figures 8, 9, and 10.

Evaluation

The hydraulic braking system outperforms the mechanical system. On upward and downward terrain with a slope of 15 deg (2.7 feet rise (or fall) per 10 feet of horizontal travel) an E & J Model 32 powered wheelchair equipped with these brakes and carrying a 175 pound driver was able to stop and hold without slippage.

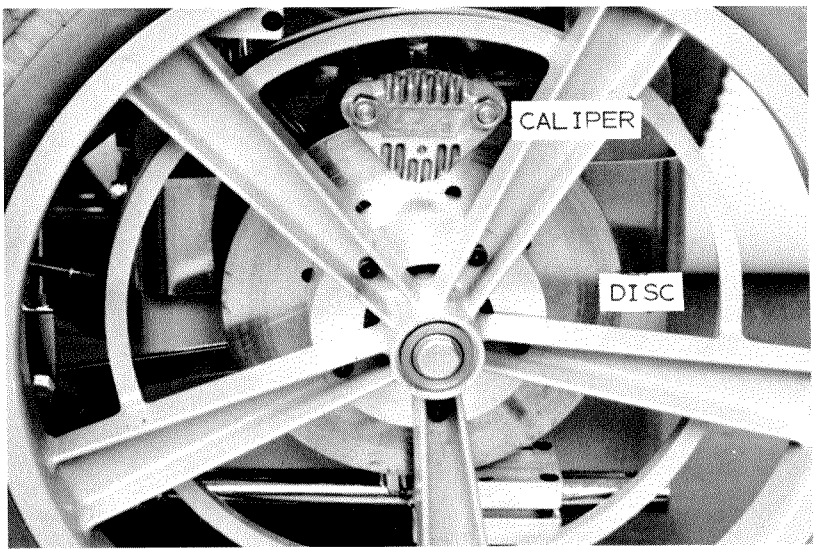


FIGURE 8.
View through spokes of drivewheel showing brake assembly.

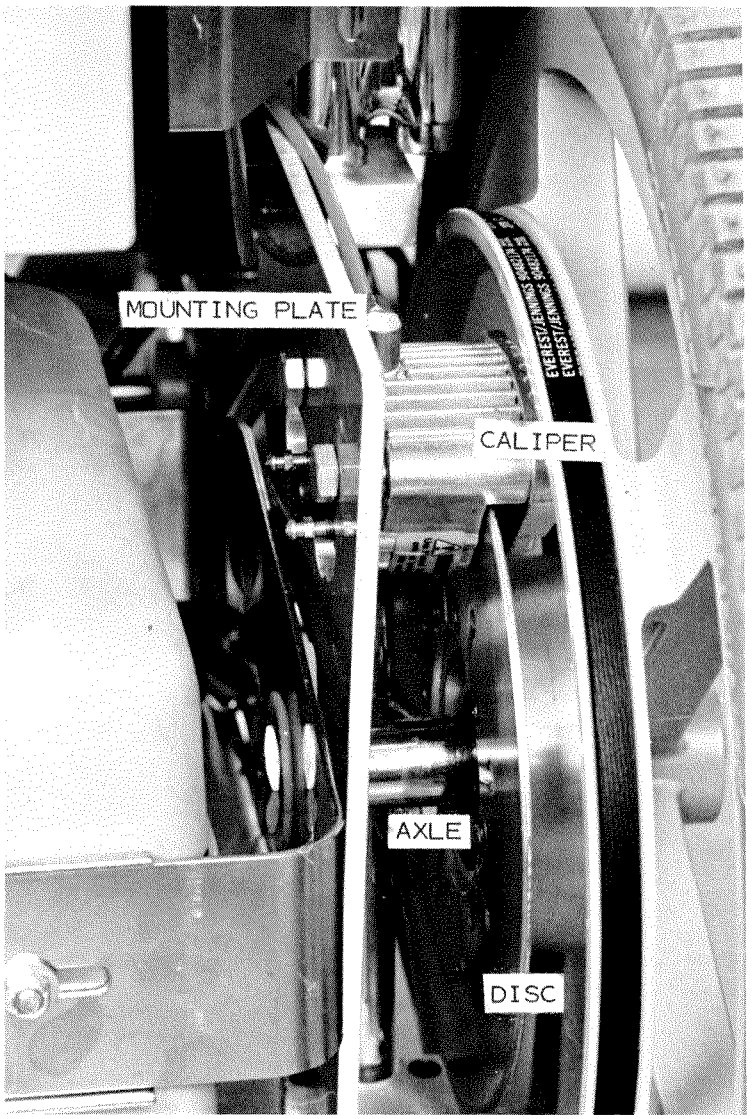


FIGURE 9.
Detail view of hydraulic brake assembly, showing method of mounting onto powered wheelchair.

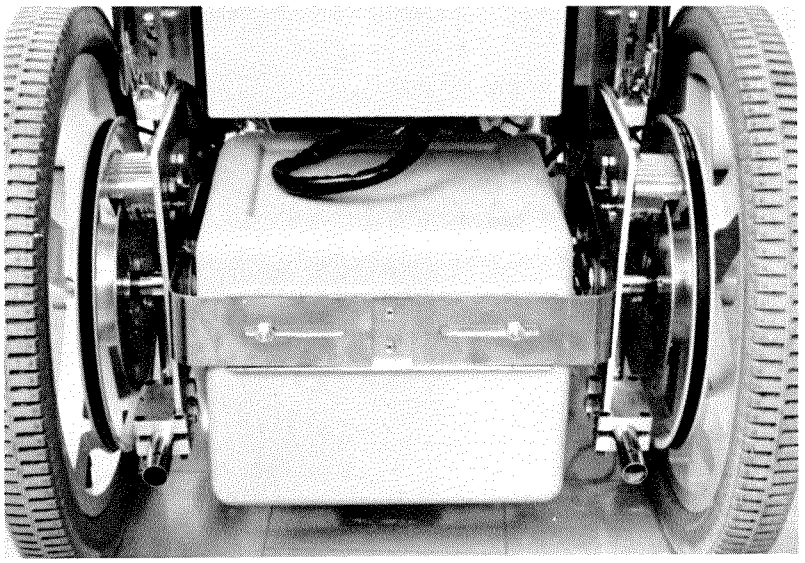


FIGURE 10.
Rear view of E&J Model 32 powered wheelchair equipped with IRM hydraulic disc brakes.

The brakes can be operated either from the pneumatic (puff and sip) control or by voice control. Both prototype systems and details of the ongoing development program are described in "Braking Systems for Powered Wheelchairs for The Severely Disabled" submitted for presentation at the Interagency Conference of Rehabilitation Engineering, June 15–20, 1980, Toronto, Ontario, Canada.

References:

1. Wheelchair-II, Report of Workshop, Dec. 1979, Rehabilitation Engineering Center, Moss Rehabilitation Hospital, Philadelphia, Pa. 19141
2. Youdin,M., G.H. Sell, T Reich, M. Clagnaz, H. Louie, and R. Kolwicz: A Voice Controlled Powered Wheelchair and Environmental Control System for the Severely Disabled. XII Interna tional Conference on Medical and Biological Engineering, Jerusalem, Israel, August 1979.

Evaluation of Functional Performance of Devices and Instruments for the Severely Disabled

Conventional door locks (which require the user to insert a key into the lock and then turn it to either lock or unlock a door) and conventional doorknobs are not usable devices for severely disabled persons. We have evaluated electrically operated locks that utilize a code which is entered into the lock via a set of pushbuttons and others that have a coded card that serves as the "key". All of these require either too much finger dexterity or do not provide adequate security—i.e., in the case of the push button arrangement it is too easy for a stranger to observe the combination. We are now evaluating electric door locks that are operated from a radio frequency transmitter/receiver. One such combination permits the selection of as many as 102 code combinations of the users' personal choice. The door to our Independent Living Laboratory has been equipped with such a lock. The lock is also wired to a "Power Access" door opener so that the unlocking operation also triggers the door opener. The door immediately opens; remains open for a preset interval; then closes. We have mounted the transmitter on a powered wheelchair and it is operable from the "puff and sip" or voice control. The transmitter is also operable from a standard

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manual switch. The door lock can also be operated with a key, so that an attendant or other household resident does not require a transmitter.

The problems with the present system (aside from cost) are:

1. The system does not provide an electrically operated "dead bolt".
2. In the event of a power failure, it would be necessary for the user to have someone unlock the door with a key. Even if the lock were modified so that it would revert to the normally unlocked position when power fails, it would still require someone to open the door by turning the knob.

We believe that this system should be further investigated because of the security which it could provide for a disabled person living in an urban area.

The transmitter/receiver systems described above are also being evaluated in our Independent Living Laboratory for their ability to provide "free ranging" control of environmental control systems. In one of our installations the user can operate all of the peripheral devices (see BPR 10-32, FALL 1979, pp 264-265) from the puff and sip control while moving about in a powered wheelchair. (The operating radius is approximately 50 ft.)

The results of our evaluations of these radiofrequency transmitter/receivers will be used to formulate specifications to cover these particular applications.

Information Dissemination

Reports and demonstrations of the results of the research carried on at the IRM REC are given regularly to hospital staff, patients, patients' families, and visiting health professionals. Patients and consumer groups are encouraged to visit the Independent Living Laboratory where they have an opportunity to try new assistive devices, and to learn where to obtain (and how to install in their own homes) the many devices undergoing evaluation and/or development. Periodic lectures are given to civic groups and other health service groups.

The following is a partial list of formal lectures and/or papers delivered since the Fall 1979 report:

1. A lecture on Environmental Controls was presented within the Aids to Independent Living Instructional Course at ICRE, Atlanta, August, 1979.
2. A lecture on Environmental Controls was presented at a joint meeting of the New York Vocational Evaluation and Work Adjustment Association and the Hudson-Taconic Chapter of the New York Occupational Therapy Association at Helen Hayes Hospital, Haverstraw, New York, October 1979.
3. Numerous lectures on Environmental Controls and Voice Controlled Instrumentation were presented at various in-house postgraduate courses, including the Advanced Rehabilitation Methods Course and various OVR Counselor Workshops.
4. Lecture on Instrumentation for the Severely Disabled at the United Hospital Fund Meeting, Plaza Hotel, New York, N.Y., November 13,1979.
5. Lecture on Instrumentation for the Severely Disabled on radio show "Science Talk" with New York Academy of Science, July 6, 1979, New York, N.Y.
6. Presentation on Voice Controlled Powered Wheelchairs at the Wheelchair Symposium, Goldwater Hospital, New York, N.Y., May 17-18, 1979.
7. Participation at the Interagency Conference on Rehabilitation Engineering, August 26-31, 1979, Atlanta, Georgia.
8. Presentation of invited paper on "Instrumentation for the Severely Disabled", XII International Conference on Medical & Biological Engineering, V International Conference on Medical Physics, August 19-24, 1979, Jerusalem, Israel.
9. Presentation of paper "A New Concept in the Design and Utilization of Environmental Control Instruments for the Severely Disabled.", IEEE, The Conference of the Engineering in Medicine and Biology Society, October 6-7, 1979, Denver, Colorado.

The following papers are among those which have been submitted for publication:

1. The Impact of Electronic Assistive Devices on the Quality of Life of High Level Quadriplegics: Joelle Couniotakis, M.A., M.Ed., Wayne Gordon, Ph.D., Heiner Sell, M.D., and Carol Stratford, O.T.R (Archives of Physical Medicine.)
2. Voice Control: Clinical Evaluation by Persons with Severe Physical Disabilities—With and Without Speech Impairment: Carol Stratford, O.T.R., Ruth Dickey, O.T.R., Muriel Zimmerman, O.T.R., Myron Youdin, M.E.E., and G. Heiner Sell, M.D. Interagency Conference on Rehabilitation Engineering, June 16-20, 1980, Toronto, Ontario, Canada.
3. Braking Systems for Powered Wheelchairs for the Severely Disabled: Myron Youdin, M.E.E., Theobald Reich, M.D., G. Heiner Sell, M.D., Henry Louie, A.A.S., Mario Calgnaz, B.E.E., and Robert Kolwicz. Interagency Conference on Rehabilitation Engineering, June 16-20,1980, Toronto, Ontario, Canada.

Training Films

A pilot film showing the operation of the Mark I Voice Controlled Powered Wheelchair and Environmental Control System for the Severely Disabled has been completed. Planning has also been completed for the production of a 10 minute color film of the Mark II system. This latter film will be available on loan to interested REC centers. ■

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Lawrence A. Scadden, Ph. D., Project Director, and J.A. Brabyn, Ph. D., Associate Director

Vocational Rehabilitation Engineering

Innovative instrument design, and adaptation of existing equipment, have facilitated the employment of a number of blind persons and cleared the way for future employment of others.

A major project during this reporting period has been research and design work on automotive test equipment, so that blind persons with technical ability can enter the increasingly important and sophisticated field of automotive repair. Equipment designed or adapted by this program to date includes an alternator/generator test lab with associated volt-amp tester, a generator and starter motor armature tester, and a voltage-regulator tester, all with auditory or tactile outputs. This equipment is now being used by a blind entrepreneur who is setting up his own automotive electrical system repair shop.

We have developed a tactile version

of our successful auditory light probe of which over 400 have now been produced commercially by the San Francisco Lighthouse for the Blind. A tactile sound-level meter has also been developed, for use in open microphone situations where tactile instead of auditory indication is desired.

Efforts are being made to introduce into commercial production some of the other vocational aids previously developed at our Center. As always, the documentation required to duplicate our devices is freely available.

Orientation and Mobility

Basic research continues on the roles of natural environmental sounds, and echolocation using cane tip contact cues. The studies are oriented toward establishing optimal parameters for improved long canes and electronic travel aids, as well as the devising of techniques for evaluating new mobility aids.

Major progress has been made in the development of a new orientation aid for the blind, the "Talking Lights" This system, which represents a departure from the traditional emphasis on mobility rather than orientation, uses a special receiver carried by the blind traveller to interpret "talking signs" consisting of speech-modulated infrared light sources. These can be placed in strategic locations just as written signs are placed for sighted orientation. The system is now in a form where limited production of a working model is possible, and a pilot installation covering all doors and elevators in a suitable building is being planned for initial evaluation of the concept.

Other new projects under way include the design of a sonic head-collision warning device,and a light-beam obstacle locator.

Information Storage and Retrieval

An innovative miniaturized note-taking, filing, and access system is under development in an attempt to combine voice recording and playback with random access capability.

Low Vision Research

Experiments, carried out with low vision patients to establish optimal parameters for electronic magnifying devices, are now complete and await analysis. The results will be used in the specification of a portable solid-state magnifier for low vision readers.

Deaf-Blind Research

Under contract to our Center and Helen Keller National Center for Deaf-Blind Youths and Adults, a deaf-blind telecommunication system is being developed at Telesensory Systems Inc. Most of the hardware of this system has been completed, and after further software refinement the device will be ready for evaluation in 1980.

Our Center has also been responsible for monitoring the progress and evaluation of the NASA/SRI Wristcom System for the Deaf-Blind. A prototype of this system has just reached the stage where evaluation can begin.

Information Dissemination

Our staff has continued to disseminate information on a nationwide basis concerning sensory aids for blind and visually impaired persons. Apart from being involved in numerous formal seminars, presentations, and exhibits, we are currently studying the feasibility of producing a multi-faceted technical magazine for the blind.

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William A. Spencer, M.D., Project Director, Thomas A. Krouskop, P.E., Ph.D., Acting Program Director, and Jesse H. Dickson, M.D., Co-Principal Investigator.

During this report period, the Texas Rehabilitation Engineering Center has continued its effort to increase the knowledge base that is available to develop improved methods of managing the effects of pressure on tissue. The primary focus continues to be to expand the scope of personal activities, vocational opportunities, and mobility for the severely disabled person, especially the high level spinal-cord-injured. The center's activities now address problems encountered during the entire rehabilitation process—from early post-injury stabilization to independent living as productive citizens in the community.

The following highlights reflect the center's program of fundamental and applied studies of the effects of pressure on tissue, and activities that transfer technology into solutions that ameliorate problems which occur during the daily experience of the severely disabled who are served by the center:

1. The Tissue Pressure Clinic program now includes other hospitals in the Texas Medical Center and the Houston VA Hospital; an average of 15 people per week is served by this activity.

2. Data that have been collected as part of the patient activity monitoring project are now being used routinely as a clinical aid during patient rounds to evaluate each individual's progress and guide the patient's plan for the following week (Fig. 1). Use of the information on time spent sitting and time out of the bed has enabled the clinical teams to decrease the number

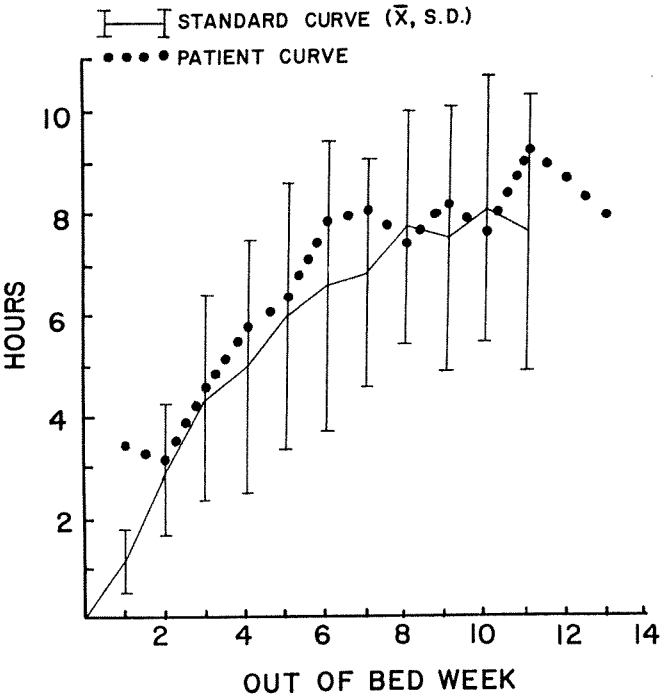


FIGURE 1
Comparison of time-out-of-bed curve for a 30-year-old C-8 quadriplegic with the standard curve (mean and standard deviation, daily time-out-of-bed for 15 SCI patients without complications).

of patients who suffer setbacks during their rehabilitation program due to tissue pressure problems.

3. Information about the motions performed by disabled workers is being collected and used to define those motions that produce pressure relief during vocational activity (Fig. 2).These data are currently being analyzed to produce guidelines for use in workstation design and job layouts that do not require extraneous weight shift exercises.

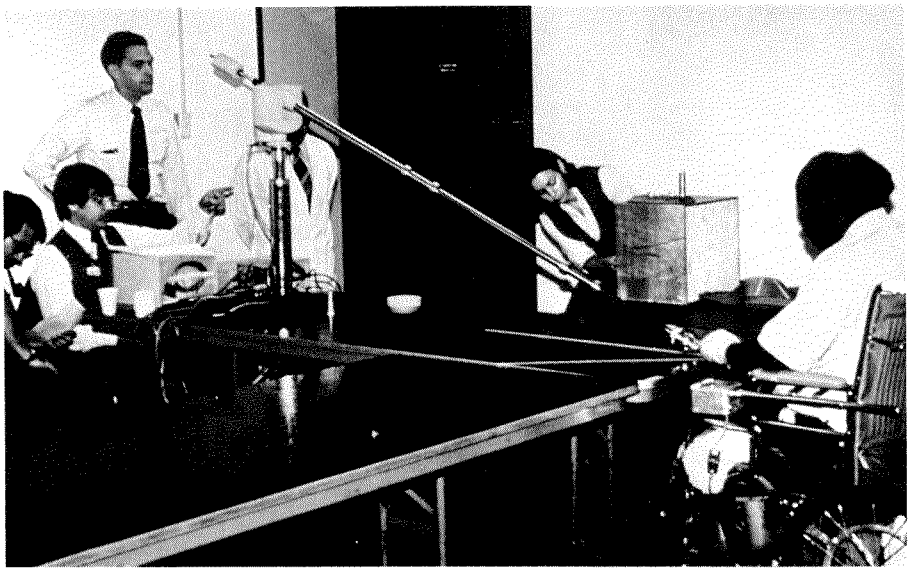
4. Porous glassy carbon and vapor-deposited-carbon coated titanium implant systems are being evaluated for use in orthopedic applications and as a means of providing long-term stable transcutaneous passage of power leads and/or stimulation leads (Fig.3).

5. A study has been conducted to evaluate the effectiveness of various commercially available bed-support systems in redistributing pressure away from the bony prominences.

6. The Rehabilitation Engineering Center has become actively involved with the Texas Rehabilitation Commission IMPART program (a rehabilitation technology referral service) as advisors and as a source for custom devices. The Rehabilitation Engineering Center is now considered a satellite referral center for IMPART.

7. Plans for a master's level degree program in rehabilitation engineering technology have been formulated in conjunction with the Texas Women's University. This program is aimed at attracting therapists, nurses, and new physicians in order to make them more effective in transferring and using technological innovation.

FIGURE 2
Work Station set-up used to collect data on motions that produce pressure relief.



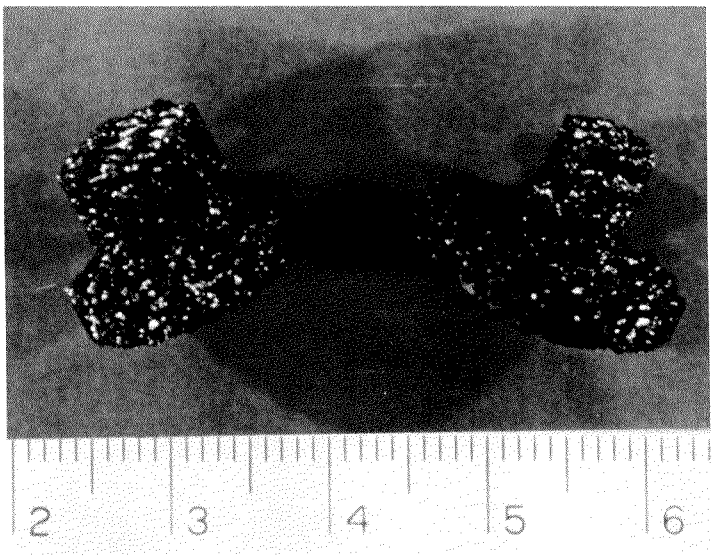


FIGURE 3
Implant system which is being studied for transcutaneous passages.

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Warren G. Stamp, M.D., D. Sc., and Colin A. McLaurin, D. Sc., P.E.

The core area for this center's research is spinal cord injury with emphasis on wheelchair mobility. With the maturation of the center, this is becoming more definitive and almost all of the research effort is now directed towards wheelchair mobility and spinal engineering.

The wheelchair mobility effort has application for all types of patients and covers both powered and user-propelled wheelchairs. Powered wheelchair tasks include performance-testing of commercially available wheelchairs, the design of electric motors and drive systems, the testing of batteries, and the design of motor controllers. The objective is to develop basic engineering data that contribute to the efficiency of electrically powered systems. These data can then serve as design criteria for the next generation of powered wheelchairs. Associated with this is the investigation of a wheelchair-mounted manipulator. A common control system utilizing a microcomputer is used for both the chair and the manipulator.

The wheelchair propulsion studies have continued and data concerning seat position have been generated. The instrumented handrim is now part of the system, so instantaneous torque can be recorded. Wind tunnel data from NASA are now included. Wheelchair design concepts have also been investigated, and one model seems to offer significant functional improvement over existing wheelchairs. A model for use on the beach has also been built.

Some work on interfacing for persons with high spinal cord lesions has been carried out, but the staff members responsible for that task have resigned from the REC and the activity has been discontinued.

Many of the tasks described in our last report have been completed, allowing a more concentrated effort on the two core areas. One significant task that continues is the orthosis to control elbow and wrist contractures. This has undergone further development and 90 units are now being fabricated for evaluation.

The Spinal Engineering tasks are progressing well. The spinal monitoring of evoked potentials has yielded consistent results with cats, and plans are now being formed for its use in the operating room as a clinical evaluation tool in scoliosis surgery and spinal cord injury. In addition, the data from the operating room will be analyzed in an attempt to understand the nature of these signals. The spinal stability studies are now well established. Apparatus has been constructed and the strengths of different spinal repair techniques are being measured. The interaction between surgeons and engineers will lead to a better understanding of the biomechanics of repair techniques, and eventually to improve methods and devices.

Evaluation Activities

The evaluation activities are many and diverse. The VA Rehabilitation Engineering Demonstration Unit (REDU) continually monitors all devices that are loaned out to patients for trial purposes. Some items developed at UVa REC are undergoing local evaluation. Items developed outside the REC fall into two categories, those with a formal evaluation protocol and those in the initial stages of investigations. The evaluation of the Memphis seating system is essentially complete. The Staircat evaluations have barely started. The nickel-zinc battery testing still awaits the batteries, although some gel-cell testing has been done.

Dissemination of Information

The main means for dissemination of information is the REDU. Requests for information and visits to the Center are increasing. This service includes recommendations to consumers, demonstrations of equipment, videotape, catalogue service, and an equipment loan service for home trial. Some 8,000 items are listed, and the number of personal visits exceeds 125 this year. In addition, all spinal-cord-injured patients in the UVa Rehabilitation program receive an orientation briefing regarding technical aids at the Unit. It is hoped that additional personnel will be funded to expand this service in the coming year. Information is also disseminated through reports, publications, conferences, and seminars. In October this year, the Virginia chapter of the Occupational Therapy Association will be meeting at UVa and this will include a briefing and tour of REDU. Community information has been further enhanced by the needs assessment study which has used the local media to reach consumers.

Cooperation with Industry

There has been no major breakthrough in this area. The REC continues to work with Tumble Forms in the development of the foam block seating. Batteries have been supplied by manufacturers for testing. Many other items have been provided for display and evaluation in the REDU. Perhaps the most significant new item is the UVa wheelchair: this model was demonstrated at the Atlanta conference and received enthusiastic support from a leading manufacturer who encouraged a patent application. It is hoped that this and other designs can be accepted for manufacture.

Another recent example of industrial cooperation is with TARC, which is a committee of representatives from aircraft manufacturers to develop means for making commercial aircraft accessible for the

disabled. The UVa REC is now working with TARC in the design and evaluation of an on-board wheelchair for transportation in the aisles and in washrooms of aircraft.

Major Accomplishments and Future Indications

The major accomplishments at the end of the third year are bringing the two core areas of research to an effective working level, and preparing for a community engineering service. The center is already established as a leader in studies of the user-propelled wheelchair. Much of the equipment and some of the energy studies are unique, and new information is being generated constantly. This scientific approach allows the development of new concepts and an objective evaluation. The new UVa wheelchair is a recent example. Similarly the work on powered chairs, the assessment of performance efficiencies, motors, control systems, drive trains, wheels, and energy storage are producing valuable data for future designs and for the evaluation of existing wheelchair models. In brief, the REC has acquired a "critical mass" of competent people to deal with the problems of wheelchair mobility.

In spinal engineering, two points are noteworthy:

1. The monitoring of evoked spinal potentials is now ready for use in the operating room, and the UVa Hospital is committed to the procurement and use of this method in departments of orthopedics, neurosurgery, and cardiology.
2. In spinal stability, several orthopedic surgeons and residents are involved with engineering professors and their graduate students. This team effort is assuring progress in spinal repair techniques. The recent addition of a bio-chemist to the Department of Orthopedics will allow a three pronged approach—electrical, mechanical, and chemical—to problems of the spine and cord thus providing a unique opportunity for research in this field.

The community engineering program is finally taking shape on several fronts. The REC can now make a practical effort towards helping individuals in the UVa Rehabilitation Program. The needs-assessment study has opened up the awareness in the community and CETA personnel have been and will be available to build a service. The students in the new graduate training program through their practicum can contribute to this service. The REDU has an unexcelled source of information and demonstration devices. The Woodrow Wilson Rehabilitation Center has a two man service team who cooperate with the UVa program. All together these activities form the foundation of a comprehensive service which hopefully can be brought together in the next year or two. ■

Non-REC Projects
National Institute of Handicapped Research
Division of Rehabilitation Engineering

The following progress reports represent the activities of projects which are not part of any Rehabilitative Engineering Center (REC) and are directly funded by NIHR, or in some cases are jointly supported by NIHR in association with the Veterans Administration.

Design of Bathrooms, Bathroom Fixtures
and Controls for the Able Bodied and Disabled
RSA Grant No. 23-P-57959/3-03
Richmond VA Medical Center
Richmond, Virginia 23249

Pascal M. Malassigne, M.I.D., and
James A. Bostrum, B. Arch.

Research Objective

The purpose of this project is to design, develop, and evaluate new and retrofitted bathroom fixtures that meet the needs of the disabled, the elderly, and the able-bodied. The basic product philosphy of the research is that bathroom fixtures can be designed to serve the varying physical needs of the disabled, elderly, and the able-bodied user without being excessively overdesigned. These fixtures should be adaptable to meet various needs—either by altering the means of usage or by directly changing the physical characteristics of the unit.

General Research Methodology

The design and usage criteria for development of new bathroom products is derived mainly from considerable contact with disabled people of all ages, and from close association with medical professionals. The research team has devoted a large amount of time to conducting task analysis of disabled people, using mockup bathroom facilities and executing transfer sequences (with a wheelchair). The development of new bathroom fixture prototypes is intended to alleviate or eliminate problems illustrated during these analyses.

All prototypes are fabricated either as mockups for "dry" transfer testing, or as operational units capable of typical usage. The mockups are used in the early stage of development to test the method of use for safety and appropriateness. Then, after testing, the design is altered as required to improve the potentials for safe use. If testing shows that the design is totally inappropriate or unsafe, then development does not proceed beyond the mockup. Those prototypes fabricated for actual use are later tested in real-life situations. By using the mockups for preliminary testing and the operational prototypes for wet testing, some developmental time is saved.

Research Activities 1979.

From 1976-1978 testing and

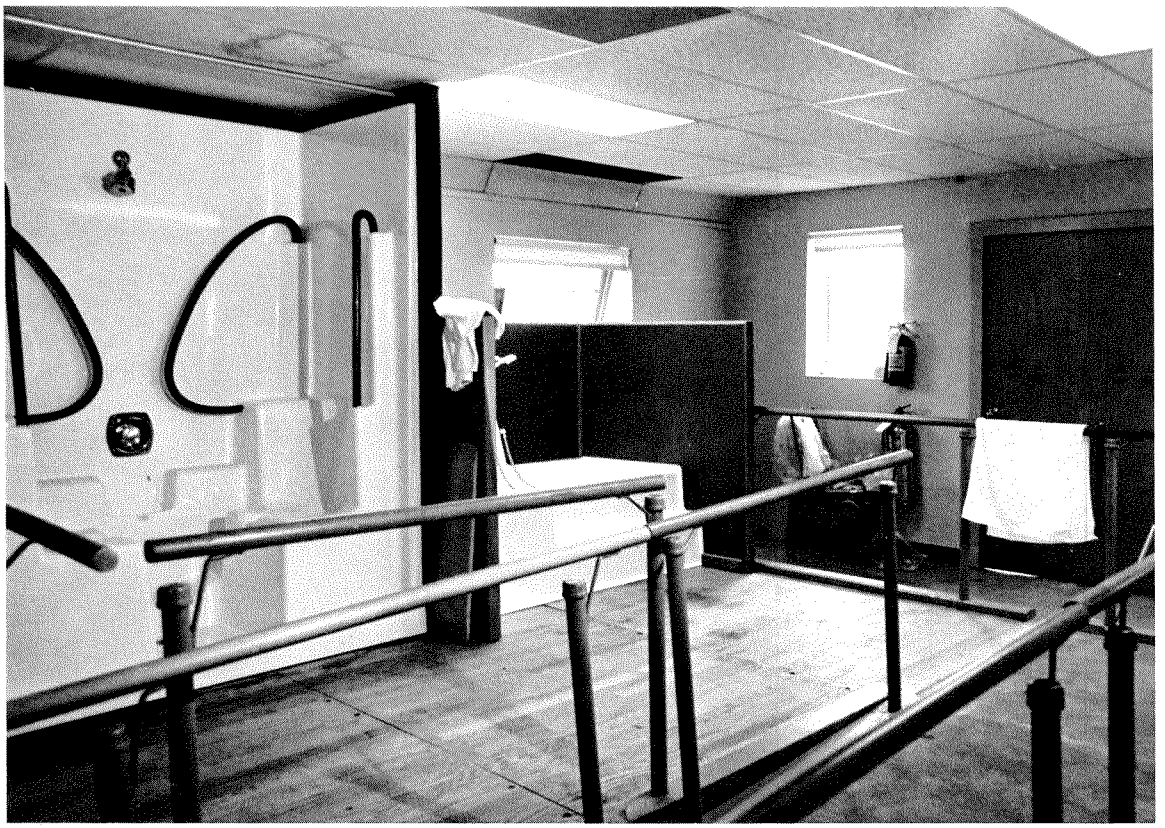

FIGURE 1.
Testing Room at the McGuire VA Medical Center, Richmond, Va. This photograph shows the hemiplegic shower, as well as the quadriplegic tub/shower.

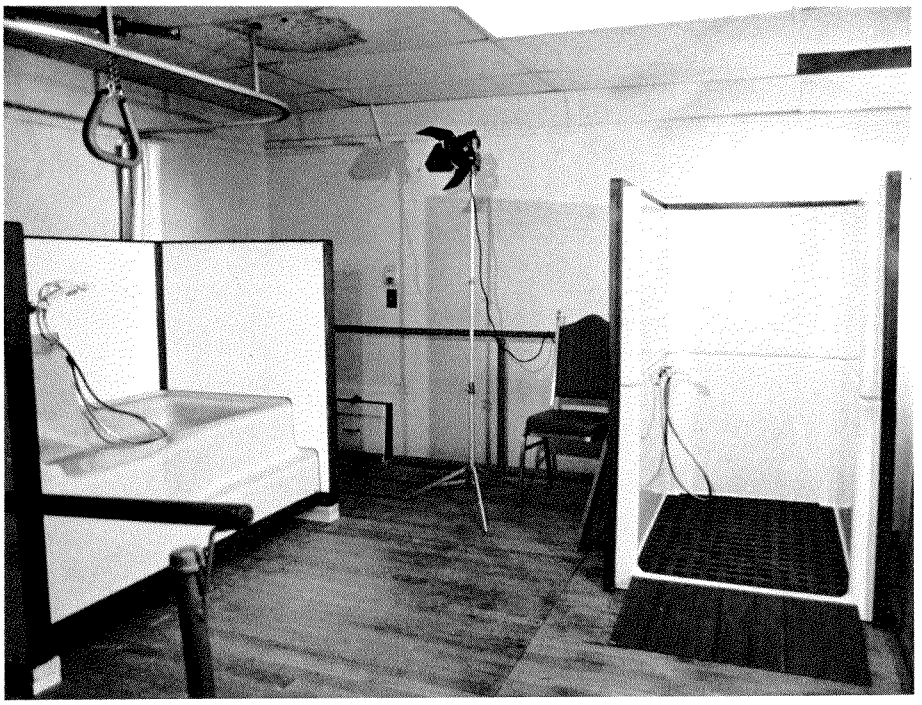

FIGURE 2.
Quadriplegic tub/shower to the left; roll-in shower to the right (McGuire VAMC, Richmond, Va.).

evaluation occured primarily at the Woodrow Wilson Rehabilitation Center, Fishersville, Virginia. In early 1979, testing activities shifted to the McGuire Veterans Administration Hospital in Richmond, Virginia. Here, the research team was exposed to a wider range of disability types of various ages. A testing room (Fig. 1-6) within the Occupational Therapy department was provided for the evaluation of the prototypes. Patients, medical staff and volunteers were able to inspect and discuss the prototypes, an activity that produced valuable feedback.

After a brief period of training to familiarize the disabled volunteer with the prototype, two types of testing occurred; a "dry" test for purposes of evaluating transfer safety and potential, and a "wet" test to study both the suitability of the cleansing method and the degree of trunk stability and balance. Documentation of the test sequences is done by a combination of videotape and still photography. This allows the research team to analyze closely the movements that may affect safe usage. Film documentation also

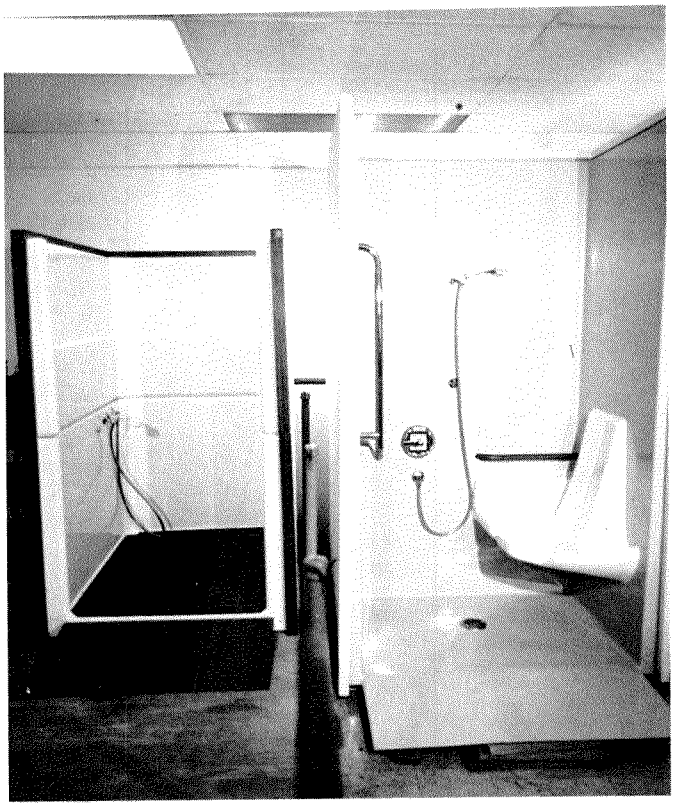

FIGURE 3.
Prototype of shower stall with seat. This particular stall is for the paraplegic who can roll-in to the edge of the seat and transfer on to it. (McGuire VA Medical Center, Richmond, Va.)

allows general comparisons to be made between disability types and their use of the different prototypes. This comparison has helped to isolate the key physical features of each fixture prototype that are essential for safe use by each specific disability type. These features are then the ones that must be present, in some form, in any "universal" fixture intended for widespread use by the disabled, the elderly, and the able-bodied.

The four shower prototypes that have been under development at McGuire have certain design features that appear to enhance safe use by the disabled: contoured seats and back supports; vinyl-skinned padded surfaces to limit slippage and reduce the tendency for skin breakdown; grab surfaces that do not require hand manipulation to use; and seat heights that allow the safest possible transfer—independent or assisted.

One of the findings of this phase of the research dealing with bathtub and shower design is that, for many disabled people, use of the bathtub is unsafe regardless of what equipment is added. The potential dangers associated with transferring in and out of the tub, as well as stepping in and out of this fixture, cannot be eliminated adequately by attaching grab bars or installing tub seats. For this reason, prototypical development has focused on showering as a safer,more independent way to cleanse the body.

Involvement of Private Industry

In order to maximize the potential for eventual manufacture of the prototypes, and to help us remain current with new manufacturing processes that might be useful,we have encouraged private industry to participate at all stages of the research. Technical and material assistance has been received from many corporations in the plumbing fixture and plastics industries. Corporations providing extensive assistance include: the Facetglas Corp. (owner of a patented padding process used in the prototypes), the Bradley Corp., the Owens-Corning Fiberglass Corp., the Crane Corp., Pittsburgh Plate Glass, and the Ferro Corp. Private industry has continuously reiterated its position of support for the research, and has indicated

FIGURE 4.
Close-up view of quadriplegic tub/shower (McGuire VA Medical Center, Richmond, Va.).

FIGURE 5.
Quadriplegic patient testing quadriplegic tub/shower (McGuire VA Medical Center, Richmond, Va.).

FIGURE 6.
Prototype of hemiplegic shower. This prototype has been designed to meet the needs of both left and right hemiplegic patients in a testing sequence (McQuire VA Medical Center, Richmond, Va.). Volunteer is shown simulating a testing sequence.

that firms feel that they lack the expertise and resources to undertake this type of research and development. However, industry is willing to consider production once the prototypes have been developed, tested and evaluated by the disabled and elderly.

Interagency Conference Exhibit

Last August, the four shower prototypes developed by this project were exhibited at the second Interagency Conference on Rehabilitation Engineering, in Atlanta, Georgia. Reaction to the prototypes was very positive, both from rehabilitation professionals and disabled individuals.

Veterans Administration Prosthetics Center, N.Y.

Additional testing and evaluation are planned by the VAPC at the VA Medical Center, Castle Point, New York. The safety of the prototypes will be further investigated. Two types of showers are now scheduled for future testing, with others to follow.

Future Research Activity

In addition to the continued progress toward both a universal fixture system and retrofit fixtures for the able-bodied and disabled, research and development will concentrate on the following:

1. Design and development of fixtures for the partial cleansing of the upper extremities (sink-lavatory type fixture).
2. Design and development of fixtures for the evacuation of body wastes (commode and urinal).
3. Design, development, and evaluation of controls suitable for use on the three types of bathroom fixtures mentioned above.
4. Study and design of new residential and commercial bathroom layouts using both the new "universal fixtures" and retrofitted fixtures.
5. The development of a compendium of design criteria for the disabled. This will consist of all the information and findings gathered during this research project.

Upon completion of these activities, a conference of members of the advisory panels to this project will be conducted, followed by a reevaluation and synthesis of the project results (i.e., the fixture prototypes and layouts). Following this activity, a final report and dissemination of the research findings will be issued.

A proposal for completion of this research has been submitted to the Veterans Administration Office of Rehabilitative Engineering Research and Development, by the Rehabilitation Medicine Service of the McGuire Veterans Administration Hospital in Richmond, Virginia.

For more information, a detailed progress report is available from the College of Architecture and Urban Studies, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24060.

Identification and Control of Biophysical Factors Responsible for Soft Tissue Breakdown

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Helen Hayes Hospital has established a "Soft Tissue Mechanics Research Group." This project is concerned with prevention of pressure sores (decubitus ulcers) by developing means to identify dangerous biophysical conditions when they first occur in patient tissues. Research toward this goal,

carried out in cooperation with the VA Prosthetics Center, N.Y., is proceeding on two fronts:

1. A theoretical approach, in which pigs are being employed to determine stress tolerance of tissues, and computer modeling techniques are being developed to predict stress in patient buttock tissues while sitting, and

2. An empirical approach, based on clinical monitoring of patients, with studies to improve devices for monitoring environmental conditions at the skin/cushion interface and to develop special tests to detect changes in the mechanical status of patient tissues.

The work, so far, is reflected in several abstracts and publications and others are in preparation (see below).

Cochran, George Van B.: Tissue Pressure Management for the Severely Disabled. 55th Annual Session American Congress of Rehabilitation Medicine, New Orleans, La., November 16, 1978.

Reddy, N.P., and George Van B. Cochran: Phenomenological Theory Underlying Pressure-Time Relationship in Decubitus Ulcer Formation. In Federation Proceedings, 63rd Annual Meeting of Federation of American Societies for Experimental Biology, Dallas, Texas, Vol. 38/3, March 1979.

Stewart, S.F.C., V. Palmieri, and George Van B. Cochran: Wheelchair Cushion Effect on Skin Temperature, Heat Flux, and Relative Humidity. Arch. Phys. & Rehab. Med. (in press).

Mayo-Smith, W.: Pressure Measurements: Device for Obtaining Readouts from Multiple Sites Using Pneumatic Transducers. Arch. Phys. & Rehab. Med. (in press).

Palmieri, V.R., G.T. Haelen, and George Van B. Cochran: A Comparison of Sitting Pressures on Wheelchair Cushions, as Measured by "Air Cell" Transducers and Miniature Electronic Pressure Transducers. Bulletin of Prosthetics Research BPR 10-33, Spring 1980.

A Tissue Protection Team also has been developed at this institution by the project personnel, and is actively involved in using new techniques to aid in prescription of optimal seating conditions for patients with skin problems.

VETERANS ADMINISTRATION REHABILITATIVE ENGINEERING RESEARCH and DEVELOPMENT SERVICE PROGRAMS

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The area of neuroengineering combines engineering and the neurosciences to study the pathophysiology of disorders of the nervous system. Over the past year the center's efforts in neuroengineering have been confined to development and clinical trials of new electrodiagnostic tests.

One of these tests is the somatosensory evoked response, a change in cortical electrical activity caused by an electrical or mechanical stimulus. Traditionally, the somatosensory evoked response has been elicited by low-frequency pulse train (0.5 to 2 Hz). Such stimuli produce a complex, multiphasic waveform, which is often difficult to interpret. The center's study on the somatosensory evoked response utilizes high-frequency (5 to 50 Hz) stimuli which produce a simpler, sinusoidal response. In addition to the simplicity of the response, such stimuli allow for the analysis of the system mediating the somatosensory evoked response in engineering terms.

Frequency Response Characteristics of the Somatosensory Evoked Response System

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Recently, Namerow, et al (1) introduced a method utilizing high frequency stimuli which produce a sinusoidal SER (steady-state SER or SSER) quantified by two parameters: amplitude and latency or phase. They report a relation between stimulus frequency and response amplitude (frequency-response curve or FRC) which changes with diseases such as multiple sclerosis.

We have utilized a variation of this method to study the FRC for the somatosensory system, as well as FRC changes with disease. Nine adults with no neurological deficits were tested to obtain normative data. Stimuli were current pulse trains (2 to 4 mA, 100μs) delivered transcutaneously to either the median nerve or the sensory dermatomes for L-5 or S-1 at frequencies of 5, 10, 35, or 50 Hz. Scalp potentials were recorded from approximate 10/20 positions Fz (inverting) and Pz (noninverting) using a reference at Cz, with amplification of 200,000 and a passband of 1 Hz to 1 kHz. Ensemble average responses to 50 stimuli were computed. Each average response was filtered using a narrow-band linear-phase FIR digital filter centered at the stimulus frequency. Frequency response curves were calculated from the root-mean-square value of the filtered average at each stimulus frequency. All FRCs were normalized to a maximum value of 10.

Normative data were obtained from 9 subjects with stimulation of L-5 or S-1 dermatomes, or the median nerve, on the right and left sides. Pathological data were obtained from