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NATIONAL INSTITUTE OF HANDICAPPED RESEARCH (NIHR)[a] REHABILITATION ENGINEERING CENTER PROGRAMS

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Introduction

The management of the REC is a collaborative effort on the part of the project director, the associate directors, and the executive officer. The overview function of the project director concerns itself with the thrust of the program, its scientific expertise, its academic and educational concerns, and its potential applicability in the area of rehabilitation.

The associate director for engineering research (Professor Robert W. Mann) joins in the above areas of concern and is particularly concerned with basic and applied research involving the engineers working in collaboration with clinicians. He contributes to the same objectives as are listed for the project director, particularly as they relate to the engineers working at various levels in our research program. The associate director for medical research (Dr. Melvin Glimcher) is primarily responsible for the basic medical and clinical research carried out in the Gait Laboratory and the Children's Hospital EMG Facility, the development of orthoses and prostheses, and basic medical research in the core area of neuromotor control systems. The associate director for clinical engineering services (Dr. John Hall) is primarily responsible for the program of clinical engineering services and the direct applicability into the clinical field for the multiple areas listed above.

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[a] These projects were initially organized by, and for the period reported herein were funded by, the Rehabilitation Services Administration, DHEW. Effective July 1, 1979, they were transferred to the newly established National Institute of Handicapped Research (NIHR), as described in Mr. Leclair's editorial in this issue.

Mr. Joseph E. Traub was Director, Division of Rehabilitation Engineering, in RSA and at present is Program Director for Rehabilitation Engineering in NIHR.

Description of Core Area

Although the major core area has been specified as neuromuscular control using sensory feedback systems, the sub-core area of communications is included. The expertise, interest, and capabilities of the staff in this area have been amply demonstrated, and the work is not only independent but collaborative with the large number of other investigators in this area.

Neuromuscular Control Using Sensory Feedback Systems

This is a joint engineering and clinical research project located at Children's Hospital Medical Center, M.I.T. School of Engineering and Peter Bent Brigham Hospital. The Director is William Berenberg, M.D., (C.H.M.C.) and the Associate Directors are John E. Hall, M.D. (C.H.M.C.), Melvin J. Glimcher, M.D. (C.H.M.C.), and Robert W. Mann, Sc. D., (M.I.T.).

1. Monitoring, Modifying and Testing Anterior Spinal Instrumentation

Project Responsibility: John E. Hall, M.D. (C.H.M.C.)

Co-Investigators: Derek Rowell, Ph. D., (M.I.T.) and Sheldon R. Simon, M.D. (C.H.M.C.)

Research is proceeding in an effort to improve the results of surgical procedures for scoliosis correction. An accepted technique for handicapped children with certain types of spinal deformities is anterior spinal fusion stabilized by implantation of a Dwyer Cable. It is important to reduce or eliminate postsurgical complications consisting of breakdown of the cable system and failure of fusion, which result in a loss of the correction. This might be accomplished if adequate biomechanical data were available with regard to the forces acting on the cable and the fusing spine. To obtain such data, a passive telemetry system has been developed for implantation at the time of the spinal fusion procedure. The unit will monitor and report the tension at a selected point on the Dwyer Cable for an indefinite period, beginning at the time of the operation. It should permit the orthopedist to design an individual postoperative management regimen for the duration of a patients's convalescent period which will increase the likelihood of a successful outcome.

2. Developing and Monitoring an Effective Pressure System for Use in the Boston Scoliosis Orthosis

Project Responsibility: Morton Finston, Ph. D. (M.I.T.)

Co-Investigators: John E. Hall, M.D. (C.H.M.C.), and Sheldon R. Simon, M.D. (C.H.M.C)

Depending on their location and severity, spinal curvatures may be amenable to correction by the use of bracing. The Boston Brace system, developed in conjunction with the National Orthotics and Prosthetics Corp., is proving to be a valuable improvement upon the well-known Milwaukee Brace for use in such cases. It features a pelvic module which is prefabricated from thermoplastics for improved serviceability, durability, and patient hygiene (Fig. 1). The need for individual patient castings has been largely eliminated by arriving at a range of 20 sizes which will accommodate 95 percent of those for whom the brace is indicated. The current design combines built-in pressure pads for curve and rotation correction, with strategic areas of "relief" to permit spine migration.

Development efforts are presently focused on incorporating inflatable pads in the Boston Brace, as a means of controlling and varying the pressure applied at various locations during the course of treatment.

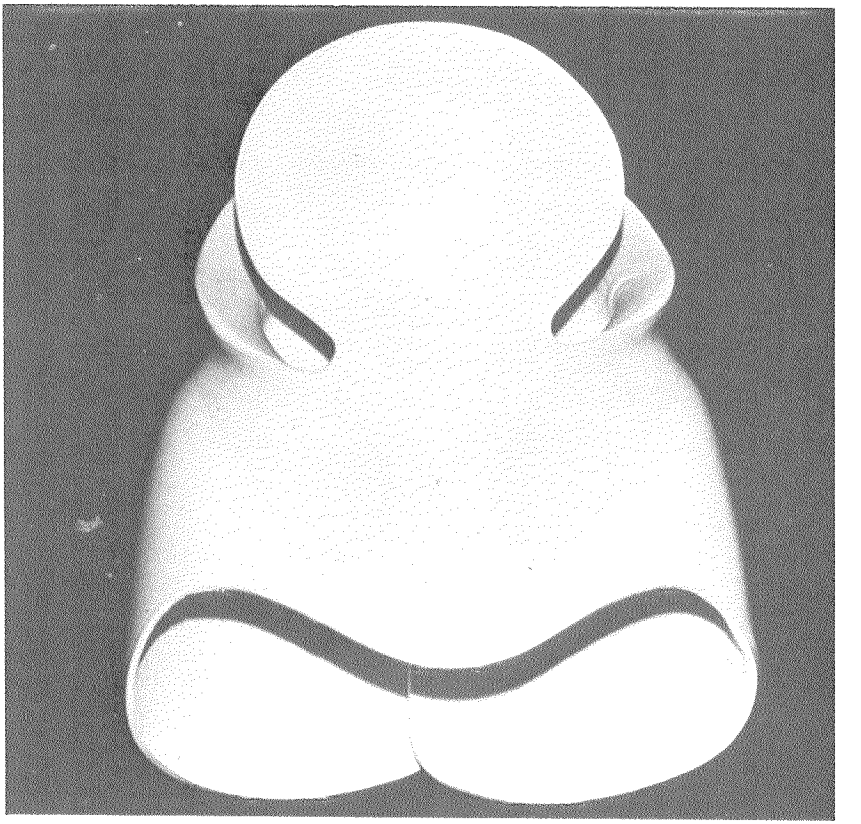
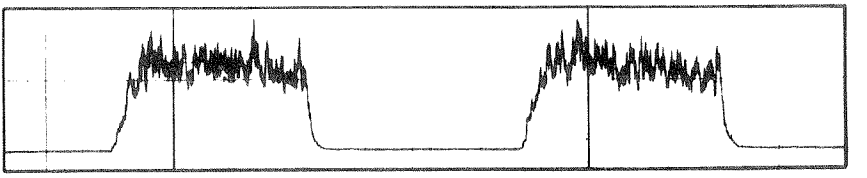


FIGURE 1. — Boston Scoliosis Brace.

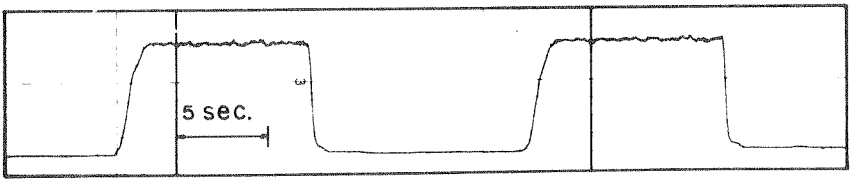
3. Neurophysiological Feedback from Extremities

Project Responsibility: Neville Hogan, Ph. D. (M.I.T.)
Co-Investigators: Robert W. Mann, Sc. D. (M.I.T.), and Michael J. Rosen, Ph. D. (M.I.T.)

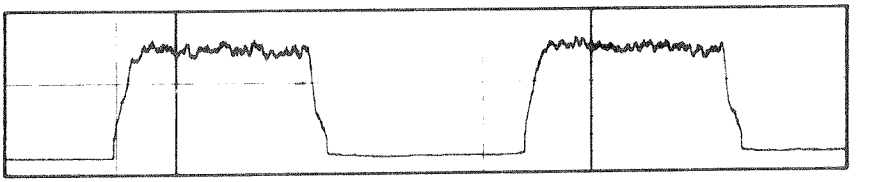
Contemporary movement control research is being applied to myoelectrically controlled, externally powered, assistive devices, to determine to what extent a high-fidelity forward path will reduce dependence on the presumed need for external sensory feedback. A recently improved "myoprocessor" design, which gives a high-fidelity representation of muscle activity (Fig. 2), will be used with a control system designed to give the prosthesis compliances similar to those of the natural limb — with the compliance determined by the amputee co-contracting his relevant residual muscles. A prosthesis with com-



Output of Common Myoelectric Signal Processor



Corresponding Isometric Muscle Force



Output of Improved Myoelectric Signal Processor

FIGURE 2. — Improvement in fidelity of the muscle force estimate provided by the improved myoelectric signal processor (bottom trace) compared with that of the common myoelectric signal processor (top trace). Both processors have the same response time to a step change in muscle force.

pliance similar to the natural limb will reliably replicate the response of the natural limb.

It is hoped that, with experience, the amputee will be able to perform the ballistic portions of movement without need for external position feedback.

4. Clinical Evaluation of a Computer-Interactive Above-Knee Prosthesis

Project Responsibility: Woodie Flowers, Ph. D. (M.I.T.)

Co-Investigators: Robert W. Mann, Sc. D. (M.I.T.), Sheldon R. Simon, M.D. (C.H.M.C.), and Derek Rowell, Ph. D. (M.I.T.)

For the last 10 years, with NSF support, a growing effort at M.I.T. has been directed toward developing radically improved prostheses for above-knee amputees. The philosophy has been to equip the prototype prosthesis with an electrically controllable damper or actuator and govern its behavior during use, instant-by-instant, via interaction with a computer. An endless variety of prosthesis characteristics can be tested experimentally with no changes in equipment, simply by altering the program running in the computer. Leg-computer interaction schemes have been developed with this laboratory-restricted system which allow amputee subjects to walk with a dramatically improved gait in straight-and-level, stair-climbing, and ramp-climbing conditions.

During the last 3 years, a Harvard-M.I.T. Rehabilitation Engineering Center project has been devoted to developing a portable, clinical version of the computer-interactive AK prosthesis (Fig. 3). The small size, economy, and low power requirements of the microprocessor have allowed the knee's "intelligence" to be reduced to a purse-sized case. This wearable computer controls an electric brake which damps prosthesis movements with a resistance which is adjustable, by the amputee, and/or the therapist, through readily accessible controls. This feature allows the prosthesis to accommodate the changing needs of the immediate post-operative patient, making the transition from locked pylon to articulated prosthesis a gradual process. Through the cooperation of Massachusetts General Hospital, several clinical subjects, including two geriatric new amputees, have participated in the system's evaluation (Fig. 4).

5. Evaluation of Gait in Selected Groups of Children with Cerebral Palsy and Scoliosis

Project Responsibility: Sheldon R. Simon, M.D. (C.H.M.C.)

Co-Investigators: Melvin J. Glimcher, M.D. (C.H.M.C.), Robert W. Mann, Sc. D. (M.I.T.), and Robert Rosenthal, M.D. (C.H.M.C.)

FIGURE 3. — MIT graduate student Michael Shepley adjusts damping controls on microcomputer-interactive knee prosthesis. The magnetic particle brake is in the distal cylindrical element above the foot unit.

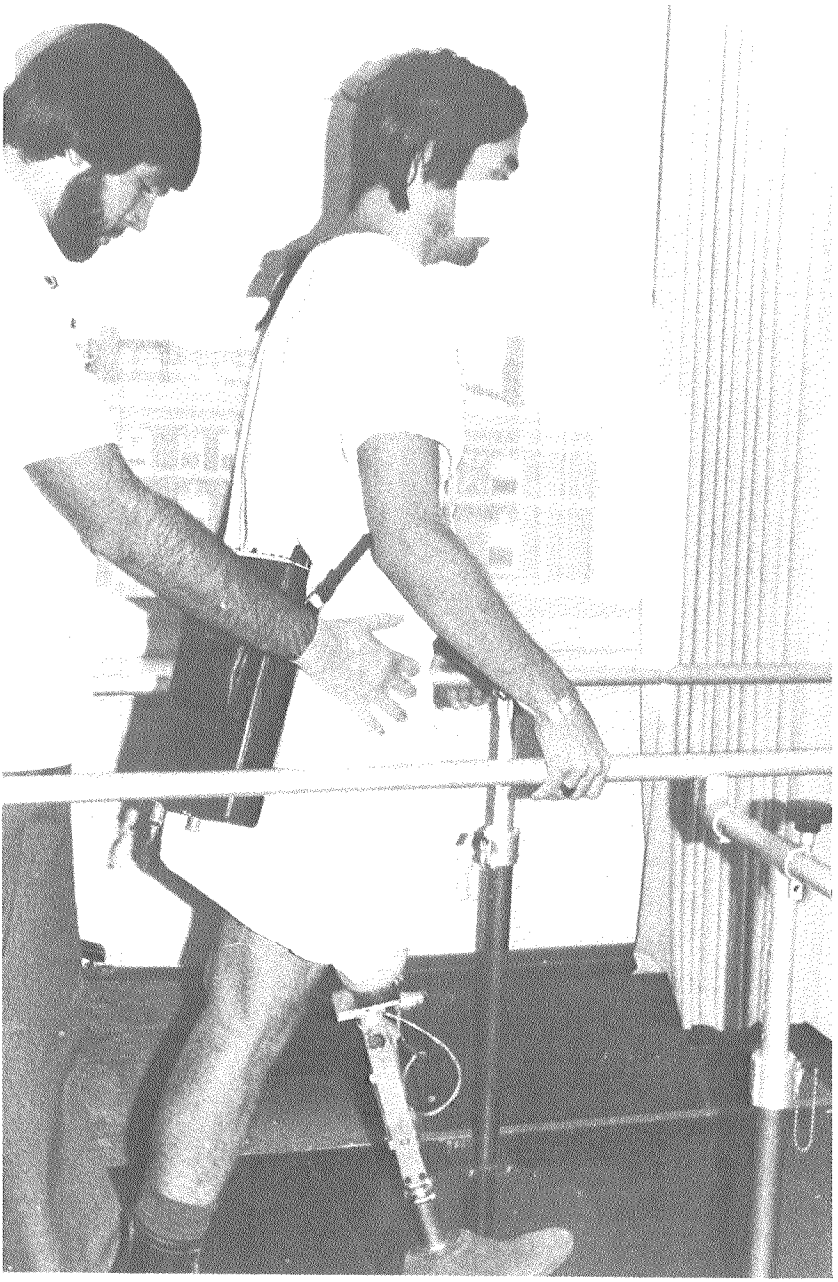


FIGURE 4. — David Porell, R.P.T., helps amputee develop his walking skill with an immediate postoperative fitting prosthesis. Damping controls are readily accessible for adjustment by clinician and/or amputee.

One of the major goals of rehabilitation is the improvement of ambulation. A computerized gait evaluation system incorporating motion analysis, EMG recordings, and foot-floor reaction forces is being used to evaluate the gait of children with various disorders. The system permits detailed analysis of gait abnormalities and of the effectiveness of different treatments (surgical or non-surgical) in correcting them. Severe gait problems whose rapid and complex movements may elude the unaided clinical eye are clarified by this facility. Treatment of simpler gait abnormalities may also benefit from the capability of the system to distinguish among the many possible causes of these problems.

At present, the system is being used in the development and evaluation of an ankle-foot orthosis which provides dynamic correction of a genu-recurvatum gait without limiting normal knee motion (Fig. 5). Intended for use in cases which are not amenable to surgery, or those which may result as a complication of prior surgical procedures, this lightweight, washable, polypropylene orthosis is low in cost, fits into regular shoes, and can be worn under normal clothing without causing excessive wear. The orthosis overcomes excessive knee extension during the stance phase of gait by bringing the tibia forward when the foot is flat on the floor. In addition, the orthosis provides correction of heel and mid-foot deformities, and improves push-off. All of these factors contribute to a smoother and more normal-appearing gait.

6. Objective Measurement of Stretch Reflex in the Evaluation of Spastic Dysfunction

Project Responsibility: Sheldon R. Simon, M.D. (C.H.M.C.)
Co-Investigators: William Berenberg, M.D. (C.H.M.C.), Mark Hallett, M.D. (P.B.B.H.), and Laurence R. Young, Ph. D. (M.I.T.)

A substantial number of people with neuromuscular disorders endure reduced function due to exaggerated reflexes or involuntary rhythmic movements. Central-nervous-system injury, stroke, multiple sclerosis, amyotrophic lateral sclerosis, and cerebral palsy can all lead to one or both of these problems. Present methods for measuring and controlling them are inadequate: the aim of this project is to develop improved techniques.

Spasticity is an ill-defined but often used term which describes an increase in reflexive muscle stiffness, observed either continuously or when a limb is moved passively. An instrument which flexes the ankle and measures the force necessary to do so has been designed and built. At present, it is being evaluated on patient subjects in a clinical setting. The apparatus is accurate enough to distinguish between reflex activity produced by nerve pathways of different lengths, a po-

FIGURE 5. — Subject tries out lightweight ankle-foot orthoses (AFO's) intended to correct a genu-recurvatum gait.

tentially useful capability for both diagnostic and theoretical purposes (Fig. 6).

7. Suppression of Abnormal Involuntary Movements by Application of Mechanical Loads and Biofeedback

Project Responsibility: Michael J. Rosen, Ph. D. (M.I.T.)

Co-Investigators: Carlo J. De Luca, Ph. D., (C.H.M.C.), and Sheldon R. Simon, M.D., (C.H.M.C.)

The goal of this project is to develop novel means of suppressing disabling tremors. Its long-range clinical motivation is the return of

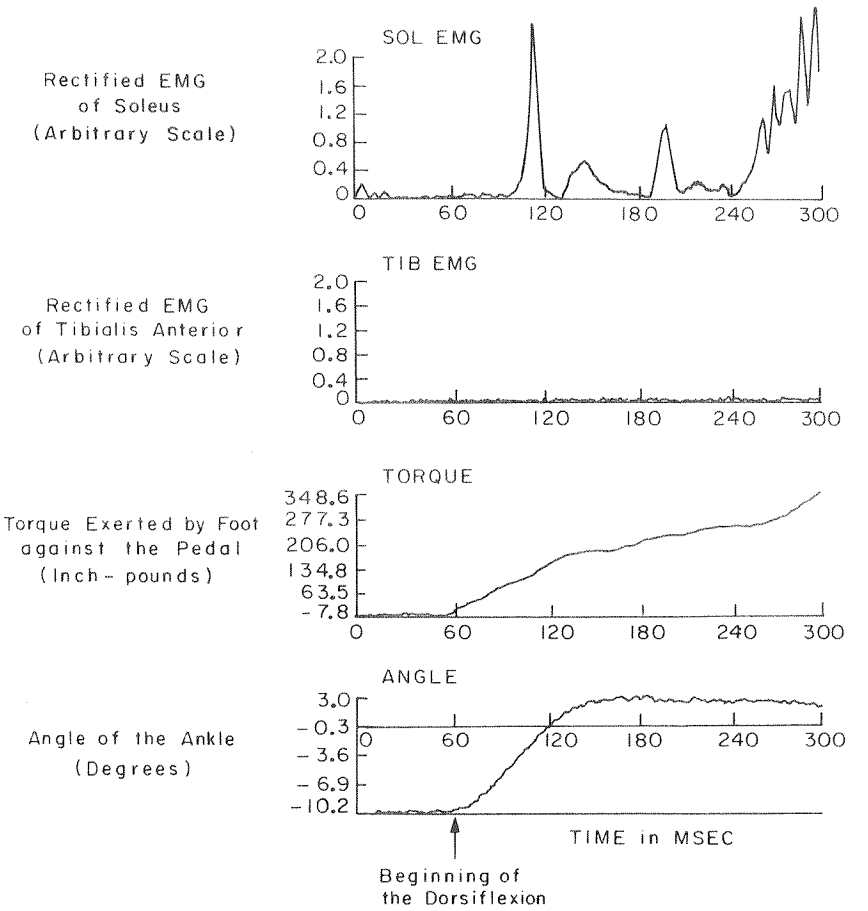


FIGURE 6. — Electromyographic events following rapid dorsiflexion of the ankle. This normal subject shows successive soleus EMG responses to the perturbation. One of the major goals of this project is to observe the changes in these different responses in patients with spasticity.

limb function to neurologically impaired individuals who have useful levels of strength and voluntary control which are masked by high-amplitude involuntary movement. The hypothesis being tested is that selective attenuation of abnormal tremor may be accomplished by application of appropriate energy-absorbing loads across joints whose muscle systems are producing tremor.

In current experiments, to test the hypothesis at a single joint during tracking tasks which simulate activities of daily living, subjects are required to perform sinusoidal wrist extension/flexion movements in pursuit of a target trace on a CRT screen, while their movements are opposed by a rotational viscous load (Fig. 7). Dramatic reduction in RMS tremor has been measured in a small number of tremor-disabled subjects, at damping constants which produce no significant reduction in the average intended movement (Fig. 8). Refinement of target movement and data-processing techniques, as well as testing of larger, clinically homogeneous subject groups are planned.

8. Automated Muscle Fatigue Indicator
Project Responsibility: Carlo J. De Luca, Ph. D., (C.H.M.C.)

In rehabilitation programs involving muscle re-education, better means are required to evaluate the effectiveness of treatment. Con-

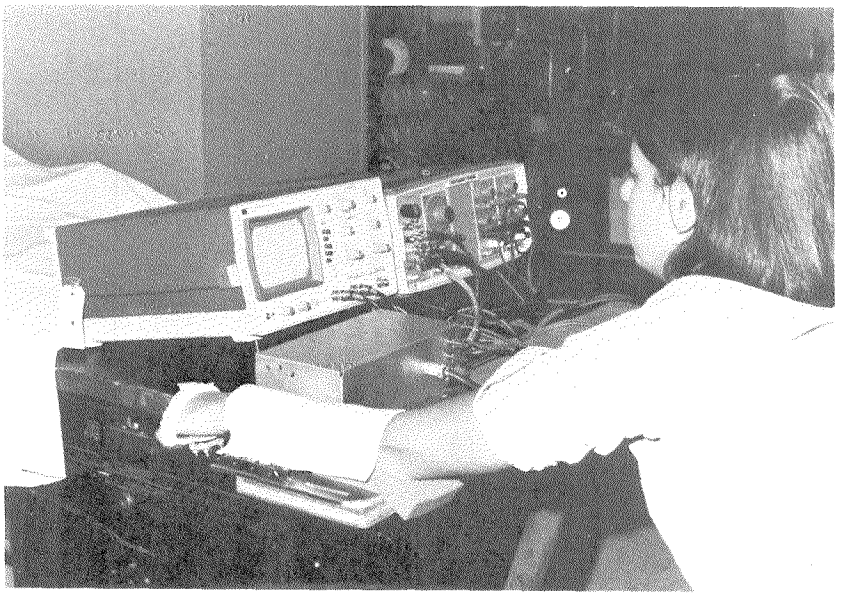


FIGURE 7.—MIT graduate student Loretta Deming being tested with the tremor-suppression apparatus.

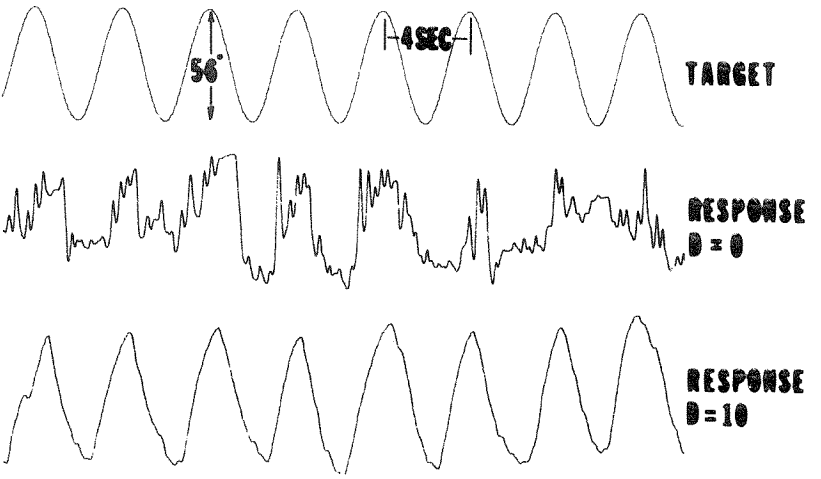


FIGURE 8. — Effects of damping on involuntary movement.

ventional testing procedures are often manual and subjective, so that results may vary with the skill, experience, and bias of the clinician. More accurate procedures may now be feasible, based on analysis of the electromyographic (EMG) signal which can be recorded from a muscle as it is used.

Recently, it has been observed through electronic spectral analysis that the proportions of slowly varying and more rapid activity in the EMG signal change systematically during a maintained muscle contraction (Fig. 9). It appears, then, that this spectral shift may be a convenient objective measure of muscle fatigue (exhaustion) which will allow clinicians to determine the effect of therapy on a patient's response to exercise during physical therapy. It should also find application in measurements of muscle metabolism and in studies of fatigue in assembly line workers. The Muscle Fatigue Monitor, which performs automated, on-line, real-time EMG analysis and displays muscle fatigue indices, has been built and tested with human subjects (Fig. 10).

9. Communication Systems for the Non-Vocal Severely Motor Handicapped

Project Responsibility: Robert W. Mann, Sc. D. (M.I.T.)

Co-Investigators: Derek Rowell, Ph. D. (M.I.T.), Michael J. Rosen, Ph. D. (M.I.T.), and G. F. Dalrymple, Ph. D. (M.I.T.)

Non-vocal communication is a necessity for people who have lost—

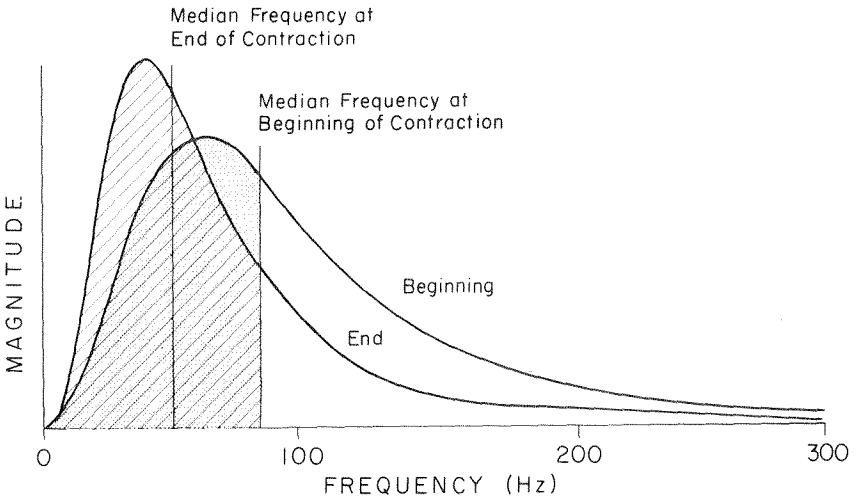


FIGURE 9. — Idealized frequency spectra illustrate shift toward lower frequencies during muscle contraction.

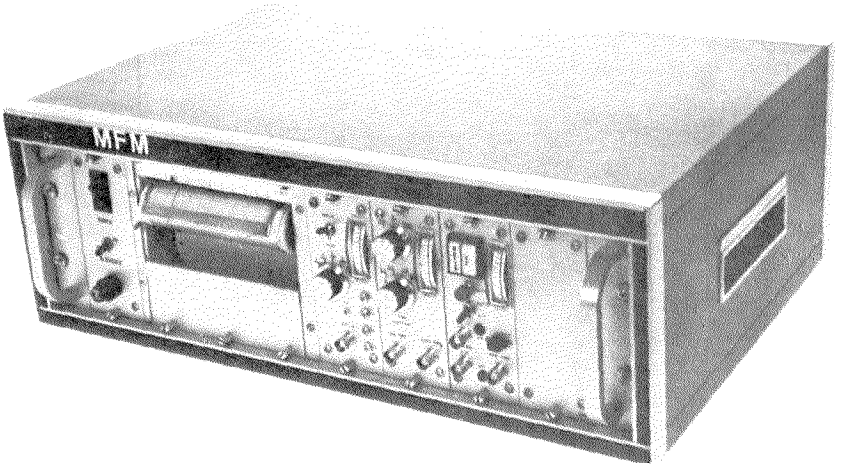


FIGURE 10. — Prototype muscle fatigue monitor.

or have never had — the power of spoken speech. If, in addition, control over movement of the limbs has been lost or impaired—due, for example, to cerebral palsy, stroke or injury—the problem is compounded. While a number of practical technologically based systems are in use which provide alternative means of talking, the center has developed two systems which address previously unmet needs in this field. The systems are:

a. The UNICOM system, developed with additional support from

the United Cerebral Palsy Education and Research Foundation. It exploits the inherent flexibility of the microcomputer to provide several communication strategies, depending on the capabilities and requirements of the user. In addition to the microcomputer, which automatically accepts a variety of input devices (mouthswitch, keyboard, joystick, etc.), the system includes a video display—for editing as well as display of characters and/or vocabulary—and a printer for generating hard copy of final text (Fig. 11).

b. EYECOM, a device requiring only sequential eye movements for selecting words or characters from a coded array of up to 64 items. It may be used by itself or in conjunction with UNICOM, and requires that the user wear a specialized eyeglass frame which presents him with a miniature rectangle of eight targets (Fig. 12). By consecutively directing his gaze at any two of these targets, the user selects a word or character, which is then displayed. Such an encoded communication scheme may prove considerably faster than present alternatives, especially for severely paralyzed users, at a relatively modest cost for hardware and electronic components.

FIGURE 11. — REC staff member Dr. George Dalrymple and Kennedy Memorial Hospital therapist Nancy Kamil, O.T.R., watch as a young student uses a UNICOM in direct-selection mode.

FIGURE 12. — Prototype EYECOM spectacle frame with the infrared source on the nasal side and image detector on the temporal side mounted on the frame.

10. Evaluation of an Audio-Electromyographic Threshold Device
Project Responsibility: Carlo J. De Luca, Ph. D. (C.H.M.C.) Co-Investigators: Michael J. Rosen, Ph.D., (M.I.T.), Sheldon R. Simon, M.D., (C.H.M.C.)

Partial loss of strength and control in limb muscles of people with neurological disorders or injury may be accompanied by impaired or insufficient awareness of the residual activity of these muscles. Muscle re-education therapy can enhance the amount and quality of returned function by providing patients with a signal to indicate the presence and strength of muscle contractions. Commercially available instruments provide biofeedback of muscle electrical activity (EMG), but they are large and excessively complex (and therefore expensive) for clinical use by therapists. The REC has developed an economical, wearable device, optimized for simplicity of use by practitioners and patients (Fig. 13). Seven copies of the prototype are now being evaluated in clinical settings. A total of nearly 400 training sessions has been conducted by clinicians on over 100 patients whose therapeutic needs cover a broad range.

The latest version of the device is packaged in a standard transistor-radio-sized case and incorporates only three controls. The volume of the signal tone, and the threshold level of EMG activity

which evokes the tone, are both knob-adjustable. In addition, a switch position determines whether the tone is heard when the EMG rises above or falls below the set level. This control allows the device to be used to encourage either muscle contraction or muscle relaxation. The portability of the system allows its use during ambulatory activities in the clinic or at home. Particularly convenient to position and secure is the dry electrode system which avoids skin preparation and materials required by other devices (Fig. 14). The simplicity and technical novelty of the unit serve to motivate patients, while providing specific information about their functional gains.

11. Refreshable Braille Data Display System
Project Responsibility: Derek Rowell, Ph. D. (M.I.T.)

In a joint vocational rehabilitation engineering project with Arkansas Enterprises for the Blind and Southwestern Bell Telephone Company, an interface has been designed and field-tested which permits blind and visually handicapped persons to function as telephone operators (Fig. 15). The heart of the interface is a microcomputer connected to a standard operators' console. Signals generated in the

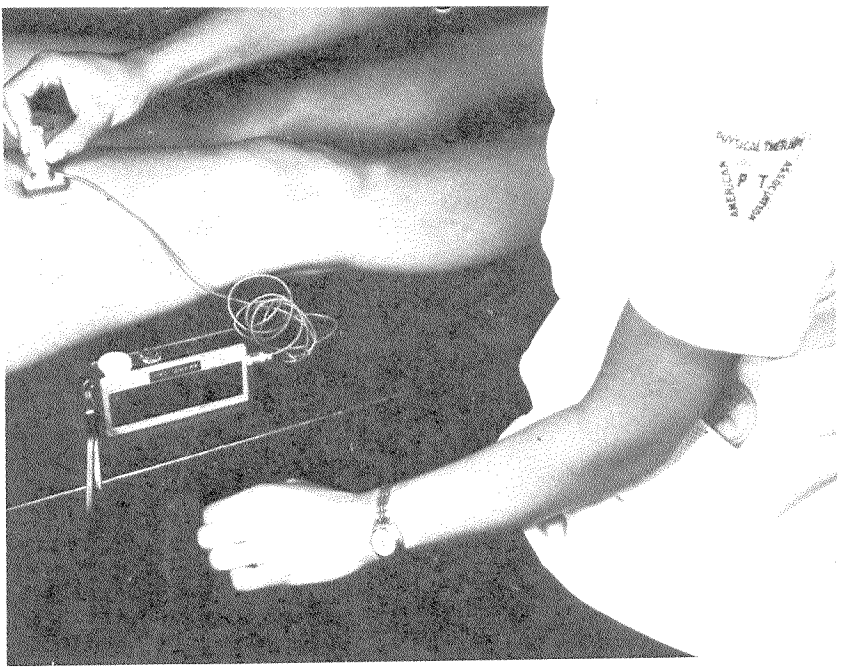


FIGURE 13.—Physical Therapist evaluating audio myoelectric threshold device. It is applied to patient's leg during muscle retraining session.

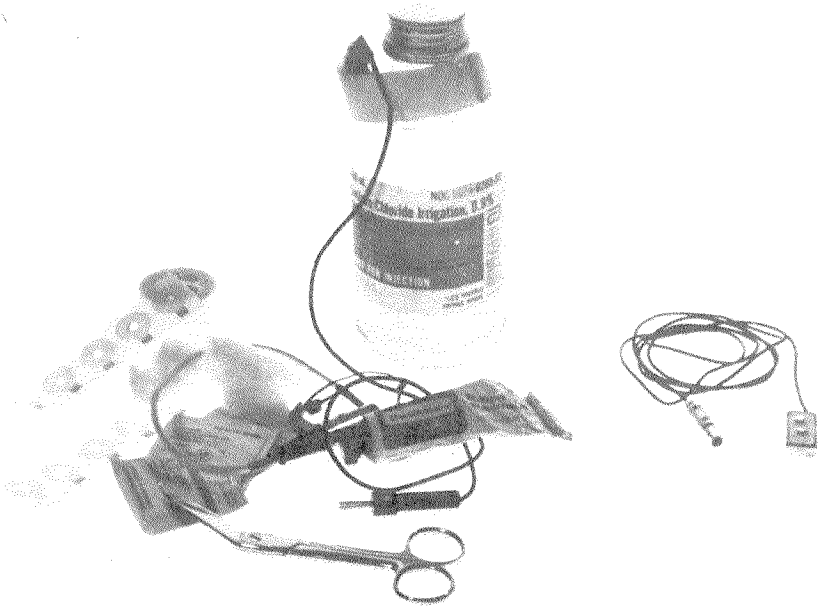


FIGURE 14.—Comparison of the assortment of materials needed for application of the conventional electrode (on the left) with the simple pasteless electrode designed for the myoelectric feedback device (on the right).

console during the handling of an operator-assisted call are used to activate a refreshable 12-character braille display. The display provides the blind operator with coded messages representing visual information (signal lights, numerical data, etc.) presented by the console to the sighted operator. A six-button keyboard enables the blind operator to review the status of various parts of the console during the processing of a telephone call (Fig. 16).

Two blind operators have been trained and have demonstrated an ability to work competitively with their sighted peers (Fig. 17). As a result of this demonstration, a commercial company is undertaking the development of a system for evaluation and deployment on a national scale.

12. Evaluation of Systems and Devices for the Disabled in the Acute Care Setting

Project Responsibility: Philip A. Drinker, Ph. D., (P.B.B.H.)

A. Typing Systems for Quadriplegics

Two typing systems, both configured to allow remote operation by high-level quadriplegics, have been extensively tested and are cur-

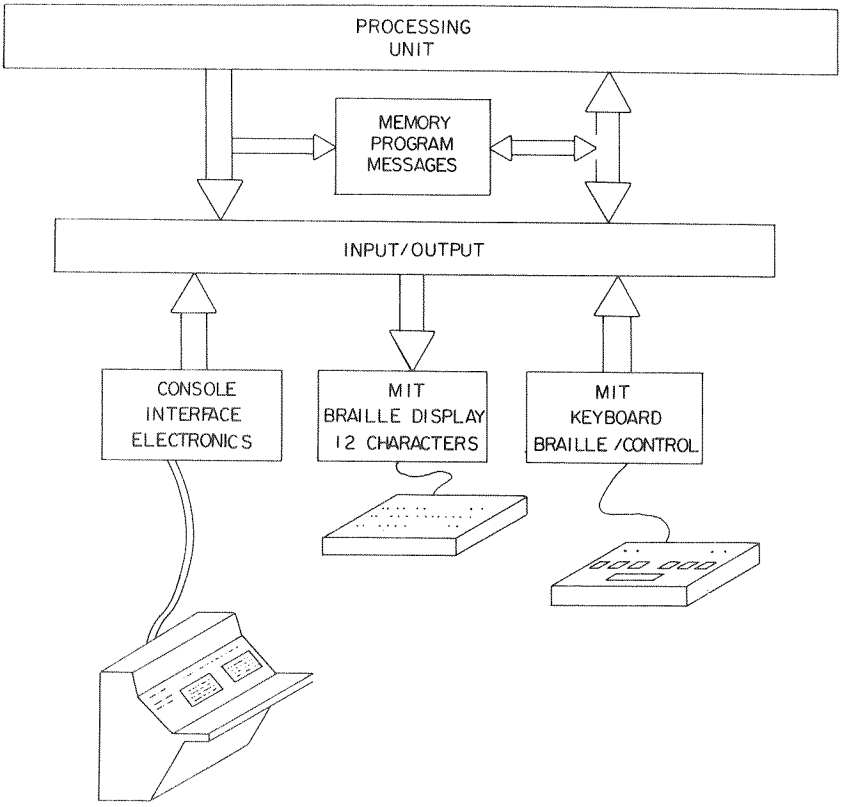


FIGURE 15. — Structure of MIT interface for blind telephone operators.

rently in use. The first is the OCCUR, a light-spot operated system developed by the Canadian National Research Council, which is being used with a model 33 TTY and slave video monitor. The OCCUR is being used by a 23-year-old woman, quadriplegic since age 11 as the result of a cervical astrocytoma, who is currently in a chronic care facility. The second typing system, the UNICOM (described elsewhere in the REC Project Summary) is being used by an 18-year-old woman injured in a swimming pool diving accident (cord transection, C-1, C-2) in the summer of 1977 who is now in her first year of college (Fig. 18).

Both of these women were first given the typing system while they were in the acute care setting. The opportunity to work with these two young women, both of whom have worked as paid consultants to the study, has proven of great value. Their insight and motivation, and their willingness to perform quantitative, often repetitive, testing

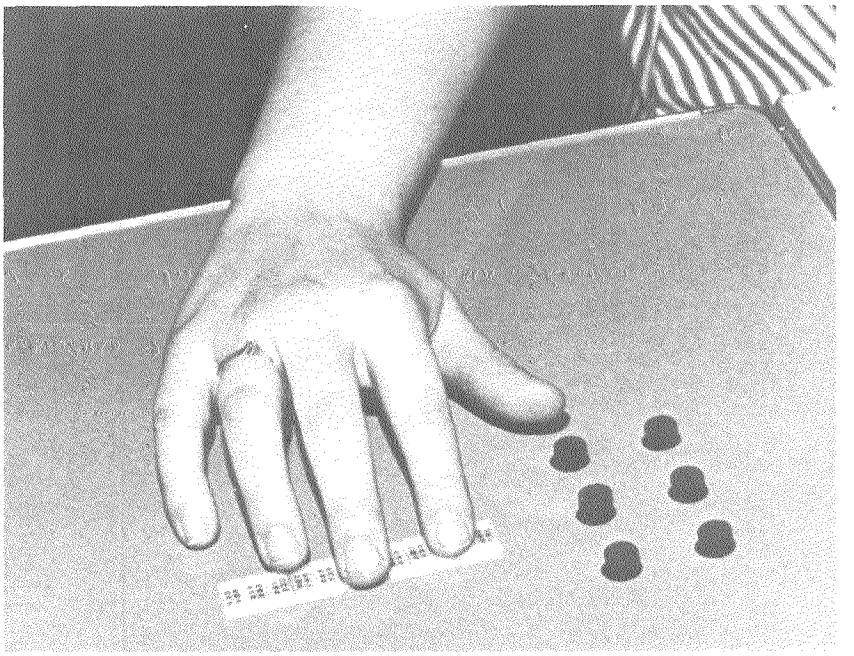


FIGURE 16.—Close-up of 12-character Braille display used in MIT interface. Buttons next to display allow operator control of information being displayed.

have helped greatly in refining the designs of these two systems. The concept of hiring a newly disabled patient to collaborate in meaningful research also appears to offer a very real rehabilitation benefit.

B. *A Simple Message Board Using Encoding by Eye Movements*

A message board based on the concept of encoding by eye movements was developed and is in use by patients with neurologic disorders that have left them cognitively unimpaired but unable to either speak or write. The basic communication scheme is easily learned, and the message boards are made up of low-cost materials by the patients' families. As a direct offshoot of our experience with the message board, the development of EYECOM (described elsewhere in this REC project summary) was undertaken. EYECOM is an optoelectronic eye movement communication system based on the same 2-digit octal code. A prototype unit is currently undergoing field evaluation by a stroke patient at a nearby rehabilitation hospital (Fig. 19).

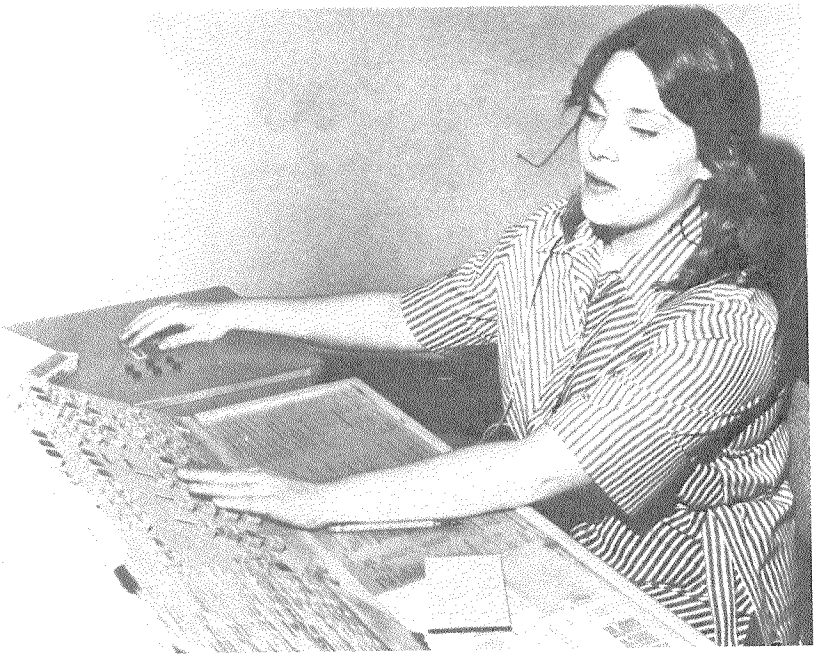


FIGURE 17. — Therapist evaluating the MIT interface on the job at a working operator's station at Southwestern Bell Telephone Company.

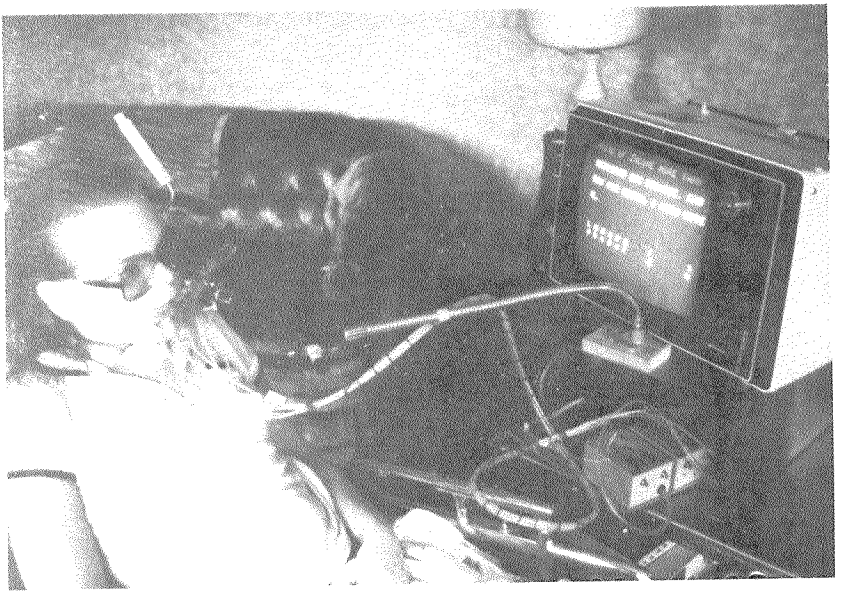


FIGURE 18. — Disabled user/consultant Cynthia Folsom evaluating UNICOM.

FIGURE 19. — MIT graduate student William Durfee demonstrating eyeboard.

Richard A. Brand, M.D., Reginald R. Cooper, M.D., and Kwan Rim, Ph. D., Co-Directors

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Rehabilitation — Low-Back Pain

Low-back pain is one of the most common ailments of Western society. Eighty percent of all adults have significant back pain during their lifetime; 50 to 60 percent of all adults of working age have significant back pain which limits their activities at some time; about 8,000,000 Americans have chronic back impairment and of these 1,000,000 have significant permanent work and activity restrictions; the onset of low-back pain in males occurs with on-the-job activities in 60 percent of cases; 50 of every 1,000 industrial workers have pain in any given year, and these workers lose about 1,400 workdays during

that year. These cases are subject to Workmen's Compensation and/or disability, and 20 percent of all compensation is reported to be paid out for back-related injuries.

Specialists treating musculoskeletal problems generally acknowledge that chronic low-back pain is one of the most difficult of all problems to diagnose, evaluate, and rehabilitate. The large number of individuals suffering with chronic low-back pain, and particularly the large number receiving compensation/disability payments, attest to this fact. No specific diagnosis can be made in 50 to 80 percent of all patients with chronic disabling low-back pain. There are few, if any, objective methods to assess the severity of the problem or the degree of impairment. Rehabilitation regimens are generally nonspecific and the results frequently disappointing.

The Rehabilitation Engineering Center at the University of Iowa is in its second year. The primary goal is to improve the rehabilitation of patients with low-back pain. Several general hypotheses have been made, which, if correct (and there is already substantial evidence that they are), suggest that engineering technology can significantly aid us in that primary goal. These hypotheses are:

1. Mechanical phenomena (e.g., segmental instability or excessive motion between vertebrae) play a significant role in the etiology of low-back pain.
2. Mechanical phenomena occurring in the spine can be analyzed utilizing engineering technology. That analysis will substantially improve our understanding of low back pain and the identification or diagnosis of specific causes of low-back pain.
3. An improved understanding of low-back pain will lead to more specific and improved rehabilitation techniques.
4. Low-back pain is clinically associated with a number of mechanical and physiological phenomena (e.g., decreased trunk strength, increased paraspinous muscle firmness (tone), limitation of trunk motion, decreased endurance), which may reflect the severity of the problem. These phenomena can be objectively measured utilizing engineering technology, thus improving our ability to evaluate (determine severity of) patients' low-back pain and to evaluate objectively the effects of rehabilitation regimens.
5. Low-back pain caused by mechanical phenomena can be prevented by eliminating activities shown by mechanical analysis to raise stresses and strains in tissues above critical levels.
6. Patients with low-back pain caused by or aggravated by mechanical phenomena can be rehabilitated using mechanical methods (e.g., exercises, bracing, surgical fusion) aimed at reducing stresses and strains in those tissues associated with and comprising the spine.

The University of Iowa Rehabilitation Engineering Center has a number of projects directed toward proving or disproving these hypotheses and improving the identification, evaluation, and rehabilitation of patients with disabling chronic low-back pain. The center is focusing on chronic low-back pain secondary to mechanical causes, primarily "segmental instability" of the lumbar spine. This is a rather poorly defined, but well accepted entity present in 10 to 50 percent of patients with chronic low-back pain. Better identification of segmental instability should allow more specific therapy and improved rehabilitation.

The center has a number of projects and subprojects aimed at improving the identification, evaluation, and rehabilitation of chronic low-back pain. The major projects and principal investigators are:

Measurement of 3-D Motion Between Adjacent Vertebrae In-Vivo; Roy D. Crowninshield, Ph. D.

Mechanical Properties of Whole Lumbar Spine; Roy D. Crowninshield, Ph. D.

Mechanical Properties and Failure Characteristics of Functional Spinal Units; Y. King Liu, Ph. D.

Gross Trunk Motion; R. A. Brand, M.D.

Methods to Measure Muscle Tone (Myotonometer, Intracompartmental Muscular Pressure, Electromyography); R. A. Brand, M.D., and G. L. Soderberg, Ph. D.

Measurement of Trunk Strength and Endurance; G. L. Smidt, Ph. D., and L. Amundsen, Ph. D.

Functional Aerobic Capacity in Assessment of Low Back Pain; L. Amundsen, Ph. D.

Natural History of Segmental Instability; T. R. Lehmann, M.D.

Effects of Rehabilitation Regimens on Segmental Instability; T. R. Lehmann, M.D.

Development of Low Back School; R. A. Brand, M.D.

Prevalence Rates and Risk Factors of Low Back Pain in Agricultural Population; L. W. Knapp, Ph. D.

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The Rehabilitation Engineering Center (REC) at Northwestern University has two major goals:

1. Improved artificial joint replacements (endoprostheses); and
2. Improved technical support systems for severely disabled persons.

The center is directed jointly by a physician and an engineer. It is administered through the Department of Orthopaedic Surgery and is closely allied with the Rehabilitation Institute of Chicago (RIC), the Technological Institute and the Biomedical Engineering Center. The center shares space and equipment with the VA-funded Prosthetics Research Laboratory.

Physically, the center has 8,600 sq. ft of space on the 14th floor of the Rehabilitation Institute of Chicago, a major rehabilitation center (170 beds and active outpatient service). The center is adjacent to the Northwestern University Medical School, Northwestern Memorial Hospital (Passavant and Wesley Pavilions), Veterans Administration Lakeside Hospital, and Prentice Women's Hospital. Consequently, the center is embedded within one of the major medical centers of the Midwest.

The Rehabilitation Engineering Center works closely with the Midwest Regional Spinal Cord Injury Care System (MRSCICS) which is located in Wesley Pavilion and the RIC. It is involved with the training functions of Research and Training Center No. 20 located on the 16th floor of RIC and also with the Prosthetic-Orthotic Education program of Northwestern University, located on the 17th floor. Along with the clinical load of the RIC, these programs provide significant places for application of rehabilitation engineering concepts and for dissemination of the ideas generated by this clinical involvement.

Northwestern Memorial and other hospitals of the McGaw Medical Center provide a wide range of orthopedic joint problems. Coupled with a large orthopedic residency program, the center is strategically located for investigations of orthopedic implants.

The center works closely with personnel of the Illinois Division of Vocational Rehabilitation (DVR). A DVR counselor handles their difficult cases and works closely with the center, frequently referring clients to the Rehabilitation Engineering Clinic. The center also assists DVR with recommendations concerning the desirability of new equipment which comes on the market.

Margaret Pfrommer, a disabled volunteer on the center's staff, works as a research associate and consumer advocate in the center. She serves as a vital link between the center and the community. This is a unique interaction providing valuable input to the center and valuable links to the community through the Center for Program Development and the Handicapped (City Colleges of Chicago), the

Advisory Committee to the Director of the Mayor's Office of Senior Citizens and the Handicapped (City of Chicago), the Illinois Council of the Congress of Organizations of the Physically Handicapped (COPH), and the Illinois Delegation to the National White House Conference on Handicapped Individuals.

Major Recent Accomplishments

A major achievement during the grant year was adoption of design ideas of a tibial knee component by a major manufacturer, and development of an implanted femoral component concept for possible adoption. These components represent an optimal configuration design based on finite-element analysis of fixation, and experimental and theoretical analysis of knee ligaments. They also incorporate observations made from collection and examination of 24 removed prostheses in the joint retrieval program.

A method for evaluating a knee prosthesis for ligamentous compatibility has been completed. This represents a significant step towards the goal of objective methods for comparing knee prosthesis designs.

Another significant achievement was completion of an interactive graphics system for doing two-dimensional finite-element stress analysis of prosthetic structures (NUFIG). A manual has been written and used at Cornell University. Other users are being sought.

Biomaterials. — Perhaps the most important accomplishment of the biomaterials group is the national and international acceptance of bone cement standards which, to an important degree, were promulgated by this group.

Assistive Devices. — Over 350 models of the E&J 12-V "quad chair" systems developed by the center have been distributed through commercial facilities to severely disabled persons. While yet small in number, this is a significant start in the rehabilitation of severely disabled persons. A new "quad" chair (24-V design) has also been completed.

Anticipated Future Results

1. The "Removed Prosthesis Study" should further expand understanding of why some internal prostheses fail. This knowledge should lead to improved designs and to improved surgical techniques.
2. It is believed the finite-element stress analysis programs will continue to be of fundamental importance in the design of internal joint prostheses.

3. Scientific investigations of the polymers used in orthotic and prosthetic devices should improve the quality of these devices.

4. Careful studies of the rheological properties of bone cement should improve the effectiveness of this material in joint surgery.

5. During the next year, completion of a "distributed" (distributed all around the home or office rather than in one place) environmental control system is anticipated. This should improve performance and reduce the cost of these controllers.

6. Field evaluation of a microcomputer-based communication and control system is underway.

7. A new (24-V) powered wheelchair, superior to the E&J Type 33 chair, will become commercially available with breath-control and other optional control schemes for severely disabled persons.

Evaluation Activities

1. The Gulbransen device for assisting quadriplegics with eating was evaluated. Suggestions for improvement were made and the new design was also evaluated. A videotape concerning the use of this device was produced and is available.

2. The Orthomot, myoelectrically controlled drive mechanism for a powered prehension orthosis, was evaluated.

3. A powered prehension orthosis of Orthotic Systems (Houston) is presently under evaluation.

4. Evaluation of electro-spinal instrumentation equipment (Medtronic) (implanted electrodes) has continued. Three subjects have been given this electrical stimulation equipment for control of their scoliosis.

5. A 24-V powered wheelchair with the special controller developed in this laboratory is being evaluated by four disabled persons prior to possible production of the system.

6. General evaluation of internal prosthetic joints and materials continues as a fundamental part of the joint replacement program.

Dissemination of Information (Total Joint Replacement)

1. A "Removed Prosthesis Report" is mailed twice yearly to surgeons and engineers in centers where major work of this type is going on. It is also mailed to manufacturers of internal joint prostheses. This report summarizes the findings concerning failed prostheses collected in the Chicago area.

2. An exhibit entitled "Effect of Knee Ligaments on Joint Implants" was presented at the annual meeting of the American Academy of Orthopaedic Surgeons during February 1979.

3. Additional three-dimensional finite-element analysis of a hip

prosthesis was completed for the University of Southern California as part of their study on design of a total hip prosthesis. A combined USC-NU paper on this topic was presented at the Orthopaedic Research Society during February 1979.

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Restoration of Function in Patients with Mobility Disorders

The Rehabilitation Engineering Center at Case Western Reserve University was established to investigate restoration of function in patients with mobility disorders. Center activities are administered through the Department of Orthopedics at C.W.R.U., and research and clinical work takes place in the major teaching hospitals associated with C.W.R.U.: Cleveland Metropolitan General/Highland View Hospital; the Cleveland Veterans Administration Medical Center; and Rainbow Babies and Childrens Hospital. These institutions provide us with a high degree of clinical interaction and contact with the physically disabled.

The core area of research in the center is functional electrical stimulation in the upper limb. Progress has resulted in the development of small stimulators for control of hand function in high-level spinal-cord-injury patients. The two systems which have been developed are intended to provide prehension and release in the C-5 quadriplegic hand, and lateral pinch and release in the C-6 quadriplegic hand.

Systems are presently being tested on three subjects. Four additional subjects also in the program are scheduled to receive stimulators in the near future. These studies are being performed in conjunction with the VA Rehabilitative Engineering R & D program, and the current status is detailed elsewhere in the Bulletin (see "Development of Upper-Limb Orthoses Employing Electrical Stimulation" under RER&D Service Programs).

Tendon Transfer — Properties of the Transferred Muscle

Restoration of upper-limb function through tendon transfer is also an ongoing area of study closely related to the core research. The

purpose of this work is to determine the properties of the transferred muscle which affect its viability as a functional entity. Studies involving tendon transfer have yielded important information about a number of physiological properties of upper-limb musculature, including excursion and length/tension properties, and have provided the surgeon with an important means to assess, intraoperatively, the function of the transferred muscle. At present, one of the REC staff members routinely participates in each upper-limb tendon transfer on spinal-cord-injured patients at both of the associated institutions. The techniques being developed promise to have wider application to most tendon transfer procedures. Ultimately a comprehensive program involving either FES or tendon transfer, or both, will be instituted to provide for the optimal rehabilitation of upper-limb function in the severely disabled.

Effects on Gait of FES in Children with CP

Studies are also being performed to evaluate the effects of functional electrical stimulation on neuromuscular control in children with cerebral palsy. Changes in gait during stimulation and possible therapeutic effects that persist beyond the period of stimulation are being examined. Three patients are presently in this program. Preliminary analysis of data demonstrates significant changes in the patients' gait with stimulation, but no readily detectable evidence of carry-over effects.

Development of Refined Control Techniques

Studies involving the development of control techniques to provide command information to external aids have resulted in the refinement of three controllers. Two of these utilize position information for derivation of command information; a shoulder-position transducer provides two-degrees-of-freedom commands, and a head-position transducer produces a single degree-of-freedom command. Additionally, myoelectric control has been investigated for particular applications which require only slowly graded responses. Each of these techniques is presently being evaluated.

Shoulder-Position Wheelchair Controller

Studies dealing with control of mobility have resulted in the completion of a wheelchair controller which interfaces the shoulder-position transducer with the electronics of standard powered wheelchairs. This system has been tested extensively by normals and is in the initial phases of clinical evaluation.

Center Moves into Cleveland Metropolitan General/Highland View Hospital

Many of the REC projects have gone through the phases of design and development and are presently being evaluated clinically. In the next year, in conjunction with our move into the Cleveland Metropolitan General/Highland View Hospital complex, an even greater emphasis on evaluation and refinement of the present system is anticipated. With an expanded commitment to a service function, a broadened base of involvement with a much wider variety of physical disabilities in future years is foreseen.

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Introduction

In a workshop dealing with the question of Impaired Mobility for Spinal-Cord-Impaired People that was sponsored by the National Academy of Sciences in 1974, attention was drawn to the need for assistive devices and systems to enable persons with severe disabilities to drive their own vehicles. In an effort to point out the need for proper technological control of existing systems of this kind, and the need for design and development of further devices to enable a larger sector of the population to benefit from such devices, an Interagency Committee, with representatives from the Veterans Administration, the Rehabilitation Services Administration of the Office of Human Development of the Department of Health, Education and Welfare, and the Department of Transportation, sponsored a state-of-the-art workshop in Washington in 1976.

In response to the needs established through these conferences and brought to our attention by the agencies involved, a group of faculty and research personnel from four different departments of the University of Michigan prepared a proposal for the establishment of the University of Michigan Rehabilitation Engineering Center (UM REC) with the research and development focus on assistive driving devices and systems for persons who are disabled.

The Department of Physical Medicine and Rehabilitation (PM&R) at the University of Michigan Medical School provides both modern

diagnostic and prescription facilities, and physical and occupational therapy, to meet the medical needs and to provide for the management of adults and children with acute and chronic physical disabilities. PM&R has an established driver evaluation and training program for the purpose of preparing adults with severe disabilities for driving vehicles which have been modified for their particular needs. This program and the clinical staff have many years of experience in dealing with the driving problems resulting from physical disabilities, and provide an important body of expertise in the efforts of the UM REC.

The Department of Industrial Operations Engineering (IOE) includes an Engineering Human Performance and Safety Laboratory that provides research, education and service with respect to the design of machines, vehicles, tools, procedures and the environment; this research is based on man's needs, capabilities, health and safety. It deals with the anthropometric measurement tasks, with the driver-seat design problem, and with the design of vocational sites to extend the quality and effectiveness of life of persons served by the UM REC.

The capabilities of the Mechanical Engineering Department include the design of assistive device components, systems, and vehicle modification design. The machining, assembly and testing facilities, and the human resources of their Automotive Engineering Laboratory, assist in dealing with the physical systems aspects of the UM REC.

The Highway Safety Research Institute (HSRI) at the University of Michigan conducts research programs in the general area of transportation. Crash test facilities make it possible to evaluate the capability of wheelchairs, chair restraints, seat belts, and other devices developed to withstand crash impacts.

The Rehabilitation Institute, Inc. (RI) of Detroit is an integral part of the UM REC. It has extensive clinical facilities and laboratories and long experience with the application of hand controls, the design and modification of vans for use by persons who are paraplegic or quadriplegic, and the training of persons with severe disabilities to drive. It has also collaborated with Creative Controls, Inc. (CCI) of Troy, Michigan, a subdivision of the McGraw Edison Corp. of Detroit, in the design and development of throttle and braking systems. The capability of RI to provide clinical services, as well as its expertise in dealing with the particular needs of persons who are severely disabled and wish to drive, represent an important clinical and technical resource for the UM REC.

The proximity of the University of Michigan to Detroit, the center of the automotive industry in the United States, makes possible col-

laboration with the automotive industries in the fabrication, and the nation-wide (indeed, world-wide) distribution, installation, maintenance, and sale of devices and systems that are essential for those individuals throughout the country with severe disabilities who wish to drive. The Chrysler Corporation, for example, provided essential information and a Dodge Omni for the design of a wheel-chair-compatible vehicle and with information for the assessment of the effect of wheelchair-accommodating modifications on their vans.

The UM REC maintains a subcontract with CCI. That group has the capability to design, develop, fabricate, install and evaluate physical devices and systems for the purposes of the UM REC. The expertise of CCI forms a link with the design function of the UM REC that minimizes the time from concept to delivery of vehicles for the population served by the UM REC.

The organization of the above resources to deal effectively with a spectrum of problems, ranging from the assessment of the ability of a person with a severe disability to drive a vehicle, through modification and installation of special equipment, to the driver education process in which the client learns to use adaptive equipment properly, may be seen in the organization chart of the UM REC (Fig. 1).

Representatives of the UM REC have also collaborated with members of the Ad Hoc Committee for the Safety and Quality of Special Automotive Driving Aids of the Society of Automotive Engineers, Inc. This committee has dealt with the establishment of a standard attachment point for the installation of currently available hand controls, the establishment of standards for the modification of vehicles to accommodate wheelchairs, and other technical details created by the effort to make essentially standard vehicles accessible for persons who are disabled. The UM REC has dealt with the latter problem at the request of that committee.

Goals

The focus of research, development and delivery for the UM REC is on ways and means to enable persons with disabilities to drive their own personal licensed vehicles. This includes concern for the abilities of the driver, and requires determination of health limitations, perceptual capabilities, and the assessment of abilities in terms of range of motion, strength, coordination, and control. Training (either to overcome functional deficiencies or to adapt to modified driving systems) will be within the domain of concern for the individual driver on the part of the UM REC. The field of focus also includes research, design, development, fabrication, maintenance, a concern for the reliability and safety of the physical devices and systems that are or will

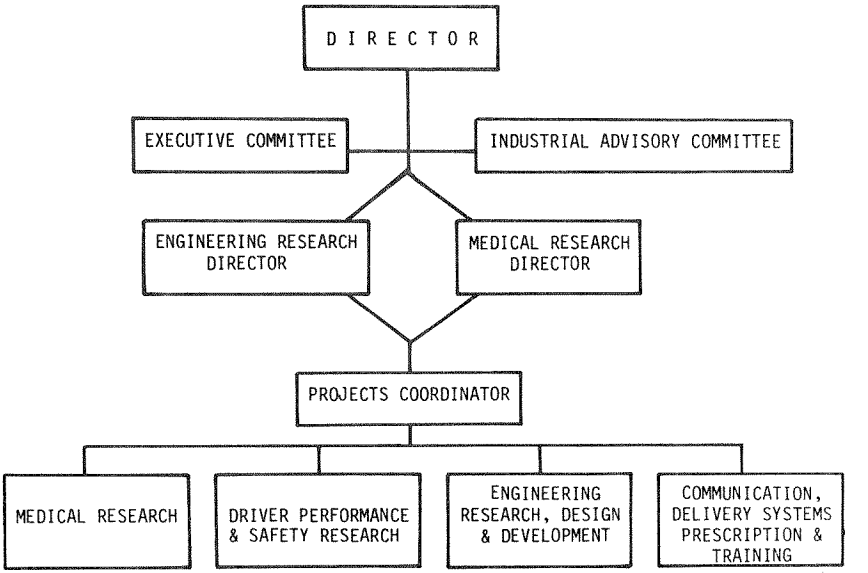

FIGURE 1. — Organization chart of the University of Michigan Rehabilitation Engineering Center.

be used to modify vehicles to facilitate safe driving by persons with disabilities.

The specified objectives of the UM REC, outlined below, are to—

1. Develop quantitative measurement techniques to assess the performance capabilities of persons with disabilities.
2. Provide performance and safety design guidelines to designers of vehicle systems for drivers who are disabled.
3. Establish liaisons with major automobile adaptive device research and government organizations.
4. Explore innovative and cooperative approaches to the design and development of vehicle adaptive devices and systems.
5. Propose a standardized evaluative methodology for specific vehicle adaptive devices and systems.
6. Establish a testing center for vehicle devices and systems.
7. Develop a working clinical model for extended service delivery to drivers with disabilities.
8. Provide educational and research opportunities for university

students who can make professional contribution in the area of rehabilitation engineering.

9. Extend performance assessment and workspace design guideline from objectives 1 and 2 (above) to applications in the occupational environment.

Projects and Principal Investigators:

Assessment of Performance Capabilities of Persons with Physical Disabilities
Thomas J. Armstrong, Ph. D.

Driver-Vehicle System Performance and Safety Guidelines
James M. Miller, Ph. D.

Application of Performance Assessment and Workspace Design Guidelines to Occupational Environment
Thomas J. Armstrong, Ph. D., and James M. Miller, Ph. D.

Innovative Approaches to the Design and Development of Vehicle Adaptive Devices and Systems
J. Raymond Pearson, M.Sc., M.E., Robert C. Juvinall, David H. Harden

Investigations of Physiological and Psychological Factors Affecting Driver Performance
Paul L. Olson, Ph. D., Theodore M. Cole, M.D., Donald G. Kewman, Ph. D., Donald L. Henson

Develop a Working Clinical Model for Extended Service Delivery
James L. Cockrell, Ph. D., Donald L. Henson

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The Rancho Los Amigos Rehabilitation Engineering Center was the first of what are now 15 federally funded National Centers concerned with the application of science and technology in combination with medicine to improving the quality of life of persons with disabilities. This center has two major core areas; namely, Functional Electrical Stimulation and Pathokinesiology. A third group delivers Rehabilitation Engineering Services to referred clients.

The center is co-directed by James B. Reswick, Sc.D., an engineer, and Augusto Sarmiento, M.D., an orthopaedic surgeon. Dr. Sarmiento is Lowman Professor of Orthopaedic Surgery and Head of the Department of Orthopaedic Surgery of the University of Southern California. Dr. Reswick, in addition to his responsibilities as Director of the Rancho Rehabilitation Engineering Center, serves as Director of Research of the Department of Orthopaedics. This arrangement has brought the Rancho REC into the total research activities of the USC/five-hospital consortium (Rancho Los Amigos Hospital, Orthopaedic Hospital, Los Angeles County Medical Center, Good Samaritan Hospital and Childrens Hospital).

Recognizing the expanded duties of Drs. Reswick and Sarmiento, Robert Waters, M.D. (Chief of Surgical Services, Rancho) and Donald McNeal, Ph. D., were appointed to the Rancho REC as Chief of Medicine and Chief of Engineering, respectively.

Core Areas

A. *Functional Electrical Stimulation*

Functional Electrical Stimulation is the primary core area of the REC at Rancho Los Amigos Hospital. The work is carried on primarily by the Neuromuscular Engineering Group directed by Donald R. McNeal, Ph. D., and Bruce Bowman, M.S.

The goal of this group is simply stated: to use electrical stimulation to alleviate problems of patients with chronic disabilities, and to encourage the commercialization of equipment that has been found to be efficacious in carefully controlled clinical studies. At the present time, the primary clinical involvement is with the Stroke Service and the Spine Service of Rancho Los Amigos Hospital. Three projects are being carried out in collaboration with stroke service personnel: upper extremity control, cyclical stimulation therapy, and gait assist. Spine service projects are scoliosis correction and spinal cord monitoring. Work has also continued (at a very low level) during the past year in the use of direct current to accelerate healing in long term nonunions.

In addition to the clinical program, approximately 15 percent of the effort is directed toward research projects that directly support one or more of the clinical projects, or test feasibility of new concepts. Three projects have been active during the past year: electrical conduction block, effectiveness of surface stimulation, and analysis of peripheral nerve stimualtion.

The stroke program is under the technical supervision of Bruce Bowman, who works closely with Robert Waters, M.D., Chief of the

Stroke Service. For the past 4 years, emphasis has been placed on defining the therapeutic benefits of electrical stimulation, especially in the upper limb. This work has resulted in a variety of devices which are now in common use in Rancho Los Amigos Hospital. One of these devices, a cyclical stimulator used primarily for preventing contractures and strengthening atrophied muscle, will be evaluated at six centers throughout the United States. It is expected that these centers will also assist in the evaluation of other devices at a later time.

Jens Axelgaard, M.S., has the technical responsibility for the spine program, and works closely with John Brown, M.D., Chief of the Spine Service. Electrical stimulation through surface electrodes shows promise as an alternative to bracing in the treatment of scoliosis, an affliction that strikes many thousands of adolescents, especially girls. The treatment program developed by the REC is now being tested in Sweden, and will be expanded to other centers if clinical results continue to look encouraging. MedGeneral, a Minneapolis-based company, is providing stimulation equipment for this evaluation and is assisting in program coordination.

A second project is directed toward development of a microprocessor-based instrumentation system to be used to monitor the neurological integrity of the spinal cord during surgery on the spine. A prototype system is expected within 3-to-5 yr.

B. *Pathokinesiology*

Having retired from active surgery, Dr. Jacquelin Perry during the past 9 yr has created one of the leading human-function laboratories in the world. Co-director for engineering is Daniel Antonelli, M.S. Pathokinesiology deals with the objective measurement of human function in normals and in patients, using a wide variety of modern instrumentation techniques, and in relating these measures to pathology. This Pathokinesiology Service is unique in that the major portion of staff activity is spent on diagnosis and followup of Los Angeles County patients, a medical service as distinct from research. During 1978, more than 900 patients were seen. Thus the space and a large group of staff supported by the County of Los Angeles provide a nucleus for the research and development activity that has been conjointly developed. The result of this is that, with moderate additional funds (now coming from RSA and the VA), a very significant REC activity ranking as a "core area" now exists.

Among the measurement techniques in use in the laboratory to produce quantification of human function are:

1. Footswitch definition of stride characteristics and foot support pattern;

2. Dynamic electromyography to identify the pattern of muscle action;
3. Energy cost measurement of locomotion;
4. Dynamic goniometry to define the pattern and extent of joint motion during walking and upper-limb function;
5. Force measurement to identify support forces (force plate), ankle control demands (force brace), assistance provided by walking aids (force cane, force crutch); and
6. Foot-floor reaction vector generation.

A computer facility has been developed during the past 5 years. Emphasis is placed on data analysis, with printouts organized to provide clinicians with information directly related to the patient's disability and in a form to assist in medical decisions. The printouts become part of the patient's records.

C. *Utilization and Service Delivery — "Project Threshold"*

The Rancho Los Amigos Rehabilitation Engineering Center takes the point of view that (in all that it does) research utilization is an inherent activity of high priority. The close collaboration with industry by the Neuromuscular Engineering Group, and its evaluation projects in stroke therapy and scoliosis correction, are examples. The Pathokinesiology Service is continually evaluating its new measurement and computer analysis techniques on the hundreds of patients going through the service each year, and its new devices are part of the Veterans Administration evaluation programs throughout the country. The many publications and reports of both staffs receive wide distribution.

In 1977, it was decided that the Rancho REC should become more active in the direct delivery of rehabilitation engineering services. Accordingly, a new project called Project Threshold was initiated, under the co-direction of Donald McNeal, Ph. D., and Nancy Somerville. Project Threshold is really two separate but interrelated projects: Model Home and Client Services. The Model Home is one of three rehabilitation equipment demonstration units established as experimental models by the Rehabilitation Services Administration in May 1977, to help the disabled obtain the most appropriate rehabilitation equipment to serve their needs. It is a 1,400-square-foot building, designed to look like a home, which is being stocked with equipment that will be available for trial use by disabled individuals. Equipment brochures, distributors' catalogs, sound/slide shows and videotapes will also be available to supplement the equipment in stock.

Consultation on equipment is provided by a team of professional people through the Client Service program. Modification of equip-

ment and custom design of equipment for which there is no commercial source are also available. This program, essentially self-supporting, makes extensive use of the Model Home, both as an information source and for client evaluations.

A block-funding arrangement was negotiated with the California State Department of Rehabilitation, to enable their counsellors to refer clients (especially the severely disabled) needing special rehabilitation engineering services. As of this writing, more than 50 clients have been referred by counsellors, and an additional eight via private providers.

Ancillary Activities Briefly Mentioned

In addition to core areas of activity, the center carries on research, development, patient care, and evaluation in a wide range of projects wherein the experience and expertise of the professional persons encourage them to make unique contributions. Often the REC support is only minimal but synergistically effective, as, for example, when its staff supports a resident physician in his research project. In addition, the center undertakes evaluation of devices developed in other centers or new manufactured items.

An aggressive effort to get devices to patients is maintained. A significant number of relationships with private industry have been developed which have led to commercial availability of REC-developed assistive devices.

Center staff have presented a number of workshops on new techniques, and have been active in other center workshops as well as on local, state and national committees.

The center is also active in training at all levels. A number of students (medical, engineering, P.T., O.T., O/P) from the University of Southern California as well as other colleges are involved in REC programs.

The REC is now working closely with the California State Department of Rehabilitation and the RSA Region 9 office in a statewide program to improve the delivery of rehabilitation engineering services throughout the state.

The principal investigators of the aforementioned projects are: James B. Reswick, Sc.D., Augusto Sarmiento, M.D., Robert L. Waters, M.D., Donald McNeal, Ph. D., Jacquelin Perry, M.D., Bruce Bowman, M.S., Daniel Antonelli, M.S., Jens Axelgaard, M.S., and John Brown, M.D.

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Evaluation of Electronic Self-Help Devices for Severely Disabled Patients

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Since October, 1974, IRM has conducted a multidisciplinary clinical evaluation of various electronic assistive devices. The purpose of this investigation is to determine the usefulness of such devices within the rehabilitation of the severely disabled. While early efforts were limited to devices operable by persons with spinal cord lesions above the level of C-5, current work is related to the needs of all severely physically disabled individuals, with emphasis on persons with high level spinal cord injuries or progressive neuromuscular disorders.

A total of 45 devices (11 mobility, 11 environmental, 5 dictating/recording, 3 page-turners, 4 typewriter systems, 7 communication aids, and 3 door-openers) are in various stages of evaluation. Evaluation consists of comparative testing by each participant of as great a number of devices of a category as feasible. Devices are evaluated in the occupational therapy electronics laboratory, hospital, bedside, home, school, and on-the-job. Data are collected in the areas of device performance, user operation characteristics, and user acceptance.

Current findings indicate that 5 devices warrant general clinical application: Prentke-Romich ECU-1, ECU-2 and ADT-5B; MED "Breath"/Short-throw Wheelchair Control System, and Canon Communicator. Detailed findings on the commercially available devices evaluated during the initial 3-yr study are available in a monograph entitled: Environmental Control Systems and Vocational Aids for Persons with High Level Quadriplegia. (See "Publications of Interest" in this issue of BPR for listing.)

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

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Specifications of Instruments for the Severely Disabled

A proposed specification for pneumatic ("puff" and "sip") controls for powered wheelchairs and a proposed specification for pneumatically controlled environmental control units have been completed and distributed to other REC's for review and comment.

These specifications bear the qualification ". . . for an 'ideal' . . ." version of each device. The designation "ideal" as used in the IRM proposed specifications is intended to describe an optimal version of those instruments which are currently available. It has not been the intention to be restrictive or to rule out the utilization of newer technology. In developing these specifications the IRM/NYU Multidisciplinary Rehabilitation Engineering Center Advisory Group studied the functional electrical and mechanical capabilities of eight different available environmental control systems and three pneumatic wheelchair controls. Although the available devices have many capabilities in common, it was found that the instruments were so different in physical and electrical makeup as to preclude the possibility of developing a specification which would include them all. It was, therefore, decided to develop specifications for the "ideal" device; i.e. the device that one would most like to have, and to use the specification for that "ideal" instrument as a "yardstick" against which to evaluate and compare the available devices.

Environmental Test Laboratory

The environmental test laboratory at the IRM/REC is now complete, and specialized test equipment is available to perform the operational, safety, environmental and accelerated life tests in accordance with the proposed IRM/NYU specifications. Included are the following:

1. LAB Vibration Testing Machine, Model BRVD-24-100. This machine has a 24 in. x 24 in. table size; can accept loads up to 100 lb., and vibrate same over a frequency range of 8-60 Hz.

2. Thermotron Environmental Chamber, Model SM-8-C. The internal working space is 24 in. wide by 24 in. deep by 24 in. high. Temperature range is −73 deg C (−100 deg F) to 93 deg C (+200 deg F); humidity range is 20 percent to 98 percent in the drybulb range of +35 deg F to +190 deg F.

3. LAB Shock Testing Machine, Model No. SD-10-42-30. This machine can accept instruments up to 30 lb. in weight and subject them to shocks of up to 50 "g's."

4. Biddle AC High Potential Test Set, Model No. 230305-1. This is a high-voltage (0 – 3000 V a.c.) test equipment for detecting assembly flaws (such as stray wire strands, etc.) and defects in marginally sound insulation, which can present a hazard to the user or cause failure during normal use.

5. Biddle Dielectric Test Set, Cat. No. 220005. This is a high-voltage (0 – 5000 V d.c.) test equipment for applying d.c. voltages to the insulation system of an instrument and measuring the applied voltage, the ohmic leakage current, and the manner in which these quantities vary with time.

Independent Living Laboratory (Electronic Assistive Devices)

One of the conclusions reached by the multidisciplinary committee, as part of its evaluation of instrumentation for the disabled, is that "bench" testing does not provide realistic insight into the functional utility and aesthetic aspects of the devices. There has, therefore, been established a model habitat (Independent Living Laboratory) in which the environmental control systems to be evaluated are installed in an actual home or office environment, and can be operated and evaluated by professional staff and disabled consumers. This facility has also proved extremely valuable to the families of patients, home planners, and architects engaged in developing plans for the remodeling of

FIGURE 1. — Independent Living Laboratory with electronic assistive devices at the Institute of Rehabilitation Medicine.

existing apartments or the building of new homes for disabled persons. One view into this facility is shown in Figure 1. A layout of the facility is shown in Figure 2.

Available environmental control systems have been especially criticized by disabled users for their factory-like appearance and because the limitation on cord length necessitates that line powered peripheral devices be clustered in close proximity of the ECS. Such clustering does not permit proper functional organization of the disabled person's room or office and certainly destroys the aesthetic appearance.

All power receptacles have been removed from the ECS unit shown. The unit functions only as a low-voltage control system. Multiple

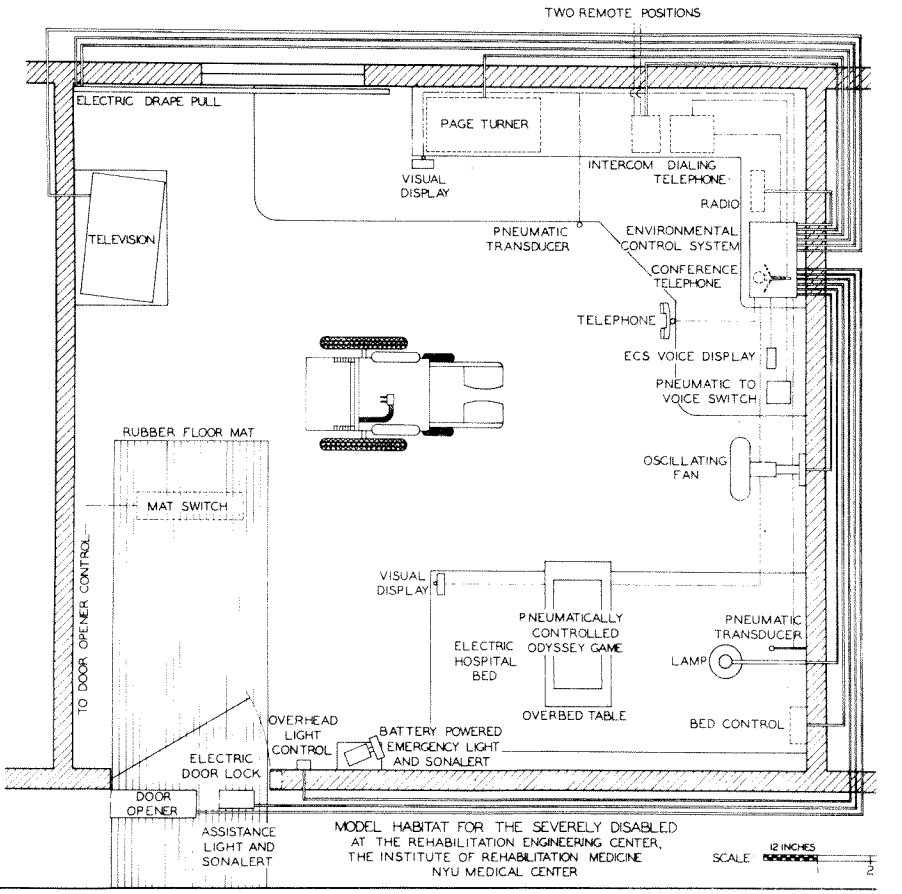

FIGURE 2.—Independent Living Laboratory "model habitat for the severely disabled", also shown in Figure 1. Double lines represent low-voltage control wiring connecting environmental control system with electrically powered devices.

transducers, operating electrically in parallel, are deployed as required. This concept is illustrated in the arrangement shown in Figure 2. One pneumatic (breath) transducer is suspended over the user's head to enable him to operate the system when he is reclining in bed; a second is on his workbench. Powered devices are energized directly from "localized" 115-V 60-Hz receptacles or from remote power receptacles. Wiring from the ECS to each appliance is accomplished with low-voltage (12-V d.c.) wiring similar to that used in the installation of telephones. This system eliminates the need for clustering and makes possible a very functional and aesthetic layout of the user's habitat or office.

This laboratory is instrumented so that all of the peripheral devices can also be controlled by voice from the IRM Voice Controlled Powered Wheelchair.

A paper titled "A New Concept in the Design and Utilization of Environmental Control Instruments" which describes this facility and the modifications of the ECS system has been accepted for presentation at the IEEE Engineering in Medicine and Biology Society, Denver, Colorado, 1979.

Voice Controls Applied to Instrumentation for the Severely Disabled

Evaluation of the IRM/NYU Voice Control system as applied to powered wheelchairs and environmental control systems continues, utilizing the new Mark II prototype. Seven cerebral palsy patients with severe dysarthria have been successful in learning to operate both the wheelchair and the system shown in the Independent Living Laboratory.

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Blind and visually impaired individuals, properly rehabilitated, can perform the majority of tasks encountered in daily life without the intervention of sighted people or the products of modern technology. However, in many identifiable situations, immediate access to additional information available in the visible environment would be beneficial to this population and thereby increase its degree of independent functioning. Sensory aids are instruments and devices which provide blind and visually impaired people with some of the useful

information existing in the visual world. For the totally blind person, a sensory aid must present information through an intact sensory modality, usually the senses of touch and hearing. For visually impaired individuals, the needed sensory aids must enhance the available residual vision by providing necessary illumination, magnification or enlarged field of view.

The San Francisco Rehabilitation Engineering Center, located at the Smith-Kettlewell Institute of Visual Sciences, was established in 1975 with the express mandate by the Rehabilitation Services Administration to conduct research and evaluation activities in the core area of sensory aids for blind and visually impaired individuals. Since that time, a scientific and support staff with varied and supplementary academic and experiential backgrounds has been established. The expertise represented on the staff includes the disciplines of experimental psychology, biophysics, neurophysiology, and electrical, electronic, mechanical, and computer engineering. Available within the medical center are ophthalmologists, optometrists, rehabilitation specialists, and various counseling professionals.

Close working relations have been established with many nearby universities, hospitals, service-delivery agencies, industries, and consumer organizations. An informal consortium of organizations working with blind and visually impaired individuals has been established locally, to cooperate in all aspects of research and evaluation programs. This consortium includes individuals from the Smith-Kettlewell Institute of Visual Sciences, Pacific Medical Center, University of California School of Optometry, University of California Medical School, University of the Pacific School of Engineering, Stanford University Department of Electrical Engineering, San Francisco State University Department of Special Education, Veterans Administration Western Blind Rehabilitation Center, California State Department of Rehabilitation, Sensory Aids Foundation, San Francisco Lighthouse for the Blind, and Telesensory Systems, Inc. These components provide a unique opportunity for optimal sensory aids research, development, evaluation, and application.

Recent research has been conducted in numerous areas including the following:

1. *Vocational Rehabilitation Engineering:*

Instruments have been designed and fabricated leading to the employment of a number of blind individuals. Both passive and active light probes designed in this center are now commercially available. These small probes permit the user, not only to detect and determine the brightness of light, but also to determine differential reflectivity

of various surfaces. This latter ability permits the user to detect pointers on visual meters through the typical glass covers.

Additional forms of meter-reading devices have been developed, for both analog and digital equipment. Such devices are currently being used by employed blind people in repair shops, machine shops, radio stations, and various industrial locations. Other devices developed under this project include tactile line indicator systems for use by deaf blind teletype operators, revolution counters for revolving instruments, and baker scales.

2. *Graphic Displays:*

Both auditory and kinesthetic oscilloscopes for blind individuals have been developed. Psychophysical experimentation has demonstrated that both kinds of oscilloscopes can be used by blind people for rapid and accurate wave form analysis and measurement.

3. *Orientation and Mobility:*

This center has been engaged in fundamental research regarding the orientation and mobility processes of blind travelers. The differential influence of ambient environmental sound and that of self-controlled acoustic patterns produced by cane tips have been studied. In addition, speech modules for elevators and audible signs consisting of modulated infrared light and specially developed receivers have been developed and installed. These latter devices have provided orientation for many blind travelers.

4. *Information Storage and Retrieval:*

A variety of computer displays have been tested in the center's laboratories. Spelled speech, full vocabulary speech, and electromechanical braille displays have been investigated.

5. *Low Vision Research:*

Optimal parameters for electronic magnifying devices are being investigated through systematic experimentation with low-vision patients. This project has been initiated for the purpose of determining the characteristics needed for a solid state electronic magnifying system for low-vision readers.

6. *Evaluation of Devices Developed in Other Laboratories:*

A permanent feature of this center's research program is the evaluation of both commercially available and prototype sensory aids developed elsewhere. In the past year, center staff members have been

engaged in the evaluation of the Digicassette, Sonicguide, Mowat Sensor, Canterbury Monaural Aid, and various other small devices.

7. *Deaf-Blind Research:*

A variety of telecommunication systems for deaf-blind individuals is currently under development and evaluation at this rehabilitation engineering center.

8. *Information Dissemination:*

The staff of the San Francisco Rehabilitation Engineering Center of the Smith-Kettlewell Institute of Visual Sciences is currently engaged in a nationwide program of information dissemination concerning the current state of the art in sensory aids for blind and visually impaired individuals. This program includes a large number of publications and the conduct of seminars and exhibits.

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The Texas Rehabilitation Engineering Center is a cooperative center comprising Texas A&M University, Baylor College of Medicine, and The Institute for Rehabilitation and Research.

The center is engaged in a balanced program of fundamental and applied studies which have produced new synergistic relationships between rehabilitation practices and the center's research and development activities. The efficacy of this approach to studying the effects of pressure on human tissue, as encountered during early post-injury institutional stabilization of the spinal-cord-injured, has been demonstrated. Now efforts are extended to include the prevention of pressure sores during independent living in the community and during gainful employment in a vocational industrial rehabilitation center.

The full range of circumstances that relate to tissue pressure management in the variety of settings experienced by the severely dis-

abled during daily living are now part of the program. The major focus continues to be on the improvement of the variety and tolerance that these people enjoy during personal activities, vocational experiences, and travel or mobilization. The high level spinal-cord-injured persons, who are increasing in numbers due to the increasing availability of emergency systems and transport, and better acute treatment, require new technology as well as transferred technology to prevent pressure-induced tissue damage, since these persons have less tolerance to pressure, greater exposure, and less physical ability to re-position their bodies periodically.

The current activities of the Texas Rehabilitation Engineering Center are consistent with the recommendations for activity that resulted from the RSA-sponsored workshop on Pressure Effects on Tissue, held in Carville, Louisiana, in March 1977. The following is a comparison of the workshop recommendations and the center's current activities.

Workshop Recommendation: "Better instrumentation is needed for clinical use to determine the distribution of forces over the residual limb." *Texas REC Activity:* 1. A single-cell pressure evaluator has been developed as an outgrowth of the PEP to measure the pressure inside a prosthetic socket. 2. A study is being formulated to utilize the technology developed in the "contourgraph" activity as input for a finite-element analysis of the residual limb to describe the effect of varying the socket shape on the stresses experienced by the limb. It is anticipated that this study will ultimately aid prosthetists with the process of deforming the cast that is used to fabricate a socket.

Workshop Recommendation: "The work of Leon Bennett of the VAPC, New York, should be extended to comprehensive trials of socket brims of various stiffness. The thermoplastics now available make such a study feasible." *Texas REC Activity:* A flexible A/K brim has been designed and fabricated and is being used on a test basis at Muilenberg Prosthetics.

Workshop Recommendation: "Instrumentation is needed to clinically measure volume changes accurately and quickly." *Texas REC Activity:* 1. A contourgraph has been developed to measure volumes and limb cross-sections, and is available to be used clinically. 2. An algorithm has been developed and is being tested at A. Muilenberg's Prosthetic Center to use a measuring tape and pocket calculator to determine residual limb volumes.

Workshop Recommendation: "Instrumentation is needed to measure tissue viability." *Texas REC Activity:* A soft-tissue tonometer has been developed and clinical testing is continuing.

Workshop Recommendation: "Studies involving so-called skeletal attachment should continue in providing support and suspension . . ." *Texas REC Activity:* The center is developing and evaluating the potential of a new generation of porous vitreous carbon for providing transcutaneous connections and as a structural replacement for the skeleton.

Workshop Recommendation: "More data on extent of limb usage are needed. To obtain this, improved counters are needed." *Texas REC Activity:* An extensive patient-activity monitoring system has been developed; the system is readily used to monitor the use of artificial limbs and orthoses (it has been used effectively for these purposes) and is currently being used in studying the useful lifetime of pressure distributing cushions and patient support surfaces. It is also being used to guide patient activity levels so that the possibility of severe complication resulting from excessive activity is minimized and the patient's rehabilitative program can proceed at its maximum rate with maximum effectiveness.

Workshop Recommendation: "The feasibility of loading tissue prior to fitting a socket, in order to 'build up' tissues, should be determined." *Texas REC Activity:* The Tissue Pressure Management program is using the results from the basic studies conducted in the Rehabilitation Engineering Center, and clinical experience gained at The Institute for Rehabilitation and Research and other centers, to develop guidelines for activities that strengthen rather than weaken a tissue's ability to withstand loading.

This program has now been extended to include a study to expand the vocational opportunities available to the severely disabled, through workstation design that incorporates pressure-relief motions into the task performance. Also, this project is focusing on the development of methods for predicting the useful life of such pressure distribution systems as wheelchair cushions and bed surfaces.

Workshop Recommendation: "Very little significant progress can be expected without the basic research needed to determine the results of the application of pressure on human tissues. Such research will involve the mechanics of various types of tissue, and techniques of

assessment of tissue at any given time. A method for accurate prediction of tissue failure should follow." *Texas REC Activity:* The program has been involved since its inception with basic studies of the physiology of tissue metabolism and breakdown mechanisms. The activities have included "Studies on Soft Tissue Metabolism", "Lymphatic Mechanics," and "Internal Mechanisms of Tissue Breakdown." A new study is being proposed as part of this report to investigate the correlation between hydroxyproleneuria and the ability of soft tissue to withstand pressure. If the hypothesis of the study is valid, it may be practical to develop a urine analysis test for home use that will permit a person to evaluate his susceptibility to pressure-related soft tissue damage before there are clinically observable symptoms.

Thus, the broad spectrum of activities that constitute this Rehabilitation Engineering Center program are strongly and logically related to the core interest area. These activities have been carefully nurtured so that this center can continue to perform effective research on the effects of pressure on human tissue.

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The University of Virginia Rehabilitation Engineering Center was started on July 1, 1977. Dr. Warren G. Stamp, Chairman of the Department of Orthopedics and Rehabilitation, is the Project Director, and Colin A. McLaurin is the Engineering Director. The Rehabilitation Engineering Center (REC) has the cooperation of the School of Engineering and Applied Science in fulfilling the center's projects.

The REC has an active affiliation with the UVa Hospital, including the hospital's Towers Rehabilitation Center and its Children's Rehabilitation Center; with the Woodrow Wilson Rehabilitation Center and its Virginia Model Regional Center for Spinal-Cord-Injury Rehabilitation; and with the UVa Department of Mechanical and Aero-space Engineering's Graduate Program in Rehabilitation Engineering. The other institutions and businesses with which the REC affiliates are the Department of Occupational Therapy at the Medical College of Virginia (Virginia Commonwealth University), Woodrow Wilson's Research Utilization Project, the Virginia Polytechnical Institute, the National Aeronautics and Space Administration, and with Yardney Batteries, Artic Cat, Tumble Forms, and Staircat.

Description of Core Area

The core area of the REC is concerned with research, development, and evaluation of technical aids and systems for spinal-cord-injury persons, with special emphasis on their wheelchair mobility. Other tasks concern spinal monitoring and stability, seating systems, control systems, and functional ability.

Wheelchair Mobility Research

The wheelchair propulsion laboratory serves as the center of the REC's wheelchair mobility research. The laboratory has been pursuing wheelchair propulsion energy studies, particularly with regard to wheelchair athletes. The athletes have proved to be an excellent starting point because of their cooperative nature and their upper limit of performance from which other performances can be judged. The athletes have provided insight into ways of improving performance through wheelchair design. The laboratory will be expanded this year to include motion analysis, electromyography, and instrumented handrims.

In addition to the studies of manual wheelchair propulsion, the REC is conducting work on power wheelchairs; this includes the design of motor and drive systems, control systems, battery testing, and auxiliary power systems.

A rugged variable-speed wheelchair controller has been built with electronic damping for use by brain-injured people. A related study of the interfacing of systems to disabled people has begun to determine the control requirements for efficient function of various technical devices, particularly where simultaneous control of two or more degrees of freedom is advantageous.

The interface study has application particularly in the use of manipulators. The REC has designed a microcomputer-controlled manipulator that can be operated by severely disabled individuals as a substitute for their impaired upper limbs. The manipulator, manufactured by Spar Aerospace of Canada, has been mounted next to the right armrest of an Everest and Jennings 3P 24-V wheelchair. The manipulator is being prepared to be evaluated by a number of individuals with differing disabilities, with the aim of discovering which movement functions offer the best opportunities for the microcomputer to aid a disabled individual's performance in the activities of daily living.

A propane powered generator has been built and added to a 24-V electric wheelchair, as an auxiliary source of power. While the concept of the propane auxiliary power system has been demonstrated satisfactorily, the REC believes that the new nickel/zinc NASA batteries,

and the center's new motor-wheel design, (developed in cooperation with University of Southern California) will yield a range and performance that will obviate the use of auxiliary power systems.

Spinal Monitoring and Stability

The related core work in the area of spinal monitoring and stability has progressed quite well since its initiation. The study of the evoked potential in the spinal cord of cats is being completed. This research has led to the development of an instrument to be used in the operating room to warn the surgeon of existing or impending damage to the spinal cord during surgery. The UVa research in spinal monitoring has verified the Rancho REC's efforts, which are in a more advanced stage—both REC's will continue their collaborative work in evaluation of spinal monitoring in the operating room with human subjects.

The first stage of the spinal stability work has been focused on the effectiveness of various surgical procedures in repairing the cervical spine following trauma. It is expected that this will lead to improved means for fixation and stabilization of the cervical spine.

Movable blocks of covered foam are being studied as a means of postural support. These blocks are attached by Velcro strips to an insert attached to the wheelchair. Tumble Forms, using a firm foam, has manufactured a dozen sets of blocks and inserts of varying sizes with integral vinyl skin. It is hoped that this support system will provide an easy and rapid means of trunk support and seating for the cerebral palsied, the muscular dystrophied, and the spinal-cord-injured.

Modular Work Station

Considerable effort has led to the design and fabrication of a modular workstation for severely disabled wheelchair-bound people who are pursuing desk vocations or higher education. Related to this project is the establishment of a demonstration unit (REDU), which provides disabled consumers, or their health professionals, to examine or try a variety of commercially available technical aids such as work stations as a part of their equipment selection and procurement process. Also, the unit has been evaluating equipment to help the consumer acquire the most appropriate and reliable technical aids possible.

A recently added activity of the REC is the assessment of those needs of the disabled that can be met with rehabilitation engineering services, and the formation of a plan to meet these needs. When fully funded, this activity will provide unique information on needs through a community-based outreach program.

Orthotic System

Finally, a simply designed, easily applied and adjusted orthotic system has been manufactured to make the correction and prevention of upper-limb deformity due to contractures easier to attain. This orthotic system is expected to especially benefit the C-5 and C-6 quadriplegic population.

Evaluation Activities

Evaluation is becoming a significant part of the program. Three UVa R&D items are now entering the initial evaluation stage: the modular desk; the foam-block seating; and the upper-limb contracture orthoses. Four units of the desk are being constructed at Woodrow Wilson, and that institution will be cooperating with the REC in their evaluation. Twelve sets of the foam-block seating system have been ordered and a protocol has been drafted for evaluation at the Children's Rehabilitation Center. Several sets of the orthoses for the prevention of wrist and elbow contractures are being fabricated at the REC, in three sizes, for evaluation at UVa, Woodrow Wilson, and elsewhere.

Several items developed elsewhere are also either being evaluated or will be in the coming year. One is the Memphis seating system for cerebral palsy patients, which is nearly complete and awaiting the followup review. The first phase of testing for the Memphis wheelchair propulsion system has been completed and further testing is anticipated. Arrangements are being made to obtain NASA-designed nickel/zinc batteries for testing, and in this connection, typical wheelchair power requirements are being investigated. Also the UVa REC has been selected to evaluate the Staircat, a stair-climbing wheelchair.

In addition to the specific activities already described, the REDU task includes followup evaluation of all devices provided to patients within a 50-mile radius of Charlottesville, Va. This will be a cooperative effort with the similar demonstration units at Rancho Los Amigos and Memphis, and with the Veterans Administration which is providing most of the devices.

Dissemination of Information

The main means for dissemination is through the REDU. Consumers and health professionals at UVa and the affiliating institutions receive first-hand information on devices and how to obtain them, as well as an opportunity for actual trial use. Information is also disseminated locally through day-to-day clinical contacts with patients and hospital staff, and through periodic lectures. Dissemination be-

yond Virginia is largely through published reports and papers, presentations at conferences, and increasingly through letters and by phone and special visits.

Cooperation with the wheelchair industry is a very important factor in the eventual effectiveness of the research program. The main purpose behind the wheelchair propulsion studies is to develop information that will be useful in designing more efficient wheelchairs. The utilization of these designs depends upon manufacturers putting them into production. The propulsion laboratory can also be useful to manufacturers by testing new designs before they go into production.

To date, very little information has been generated—the process of cooperation has not occurred except in a few instances. However, with the help of conferences such as Wheelchair I and II, it is expected that a working relationship with industry will develop. At present, new firms and designers, or those interested in entering the market have expressed greater interest than the older established firms. Several inventors have been referred to the REC for comments on proposed designs, and in several instances it was possible to point out problem areas based on propulsion data—such as the amount of power that can be expected from a paraplegic to drive a wheelchair with a given propulsion system.

In testing the nickel/zinc NASA batteries, typical battery requirements are being determined with existing wheelchairs. This is leading to performance studies on powered wheelchairs, which could provide information on how to improve performance, range, and charging methods, which the manufacturer can adopt.

In the foam-block seating system, the REC is working directly with a manufacturer who is prepared to make and distribute the product if the evaluation proves to be successful. A similar situation exists with the Spar manipulator.

The quadriplegic desk is following a different route. Woodrow Wilson Rehabilitation Center is fabricating four models from our drawings, for evaluation. There is the possibility that the center may eventually become involved with production of this and similar items. They are, however, prepared to turn over the fabrication to a commercial furniture firm if and when that seems advisable.

Major Accomplishments and Future Plans

Since the center is a relatively new program, there are no major accomplishments to date, except perhaps that interest has been focused on rehabilitation engineering in this part of the country and also the focusing of interest on the scientific aspects of wheelchair propulsion, something that seems to have been all but overlooked in

this country. The projected work in this area could lead to major results in the future. It has been estimated that the efficiency of wheelchair propulsion can be increased by a factor of three by better use of available muscle power through suitable drive systems. Thus, it can be expected that a whole new generation of wheelchairs can dramatically improve the mobility of hundreds of thousands of users.

Powered wheelchairs are rapidly proliferating in quantity and variety. Although this is good, it does raise questions regarding which is best for what purpose. The work at UVa REC in use-analysis, battery testing, motor drive systems, and wheelchair performance testing should do much towards answering these questions. Both in powered and manual wheelchair evaluation, the role as resource center is indicated for UVa.

Another area where there is opportunity for significant results is in the rehabilitation and vocational capability of quadriplegics through specialized devices. The special desk is one example and the computer controlled manipulator is another. The Demonstration Unit with its followup studies will lead to a documentation of which items are most applicable, and will also lead to a number of innovations to assist in daily life and in preparation for work.

The work in spinal cord monitoring and spinal stability is too new to suggest major results, but the potential does exist for a more rational approach and systemized devices and techniques to insure rapid and secure stability of the spine during the acute and recovery phases of rehabilitation.

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The activity of the REC-Ljubljana is concentrated on the development of new rehabilitation systems and methods based on functional electrical stimulation (FES).

In the past year the following investigations have been conducted:

1. **Multichannel FES of Lower Limbs for Gait Rehabilitation (Principal Investigator: U. Stanič, D.Sc., Co-investigators: R.Ačimović-Janežič, M.D., A.Trnkoczy, Dipl. Eng., and M. Kljajić, D. Sc.)**

The main direction of this investigation in the past year was further

development of a multichannel system for FES to improve a paretic gait. A control study of possible therapeutic effect and its duration (long-term effects) has been started, and so far data on six patients have been gathered (three stimulated; three controls). It is too early to make any statistically significant conclusions, as the sample is still too small.

It is planned that in 1½ years a sample of 20 patients will be complete and the basic question answered before starting further development in the direction of therapeutic and orthotic multichannel stimulation methodology.

To support this research, further improvement in stimulation technology has been made concerning surface electrodes and 6-channel stimulators. Following the research made at REC Rancho Los Amigos Hospital, felt pads have been used as an electrode interface with good success. Good results were also obtained using cellular tissue. Improved artificial sponge type electrodes have also been designed and tested.

After preliminary testing, the second version of the 6-channel digital stimulator was redesigned (Fig. 1). One of the most important features is the control principle enabling the triggering of the stimulator in the early phase of rehabilitation of a severely impaired gait when this is uncertain and unrepeatable. The ability to test for the appropriate polarities of electrodes is achieved by additional built-in switches. Experimentally, some new electrode sites have been found, especially important being the site for stimulation of hip flexion. This system is also used to strengthen muscles, primarily for the hip and knee muscle groups.

To follow and objectify the effects of multichannel stimulation and other rehabilitation methods, further development in measurements and evaluation procedures has been made from a theoretical as well as the technological point of view. The fundamentals for comparative study between kinesiological and computerized gait evaluation were made as it is very important that the clinical evaluation procedure, which has been developed for several years, yielding a very meaningful information to medical people, can be quantified by measurements. The main problems still exist with respect to the standardization of measurements, reference position determination, and the need to lower the encumbrance level of goniometric systems. Since the recent version of the electrogoniometric system has not performed as desired yet, a new version is in the course of construction.

In the last year, two powerful measurement systems were introduced into the clinical environment—the force crutch and the force shoe measurement systems. The former enables the measurement of

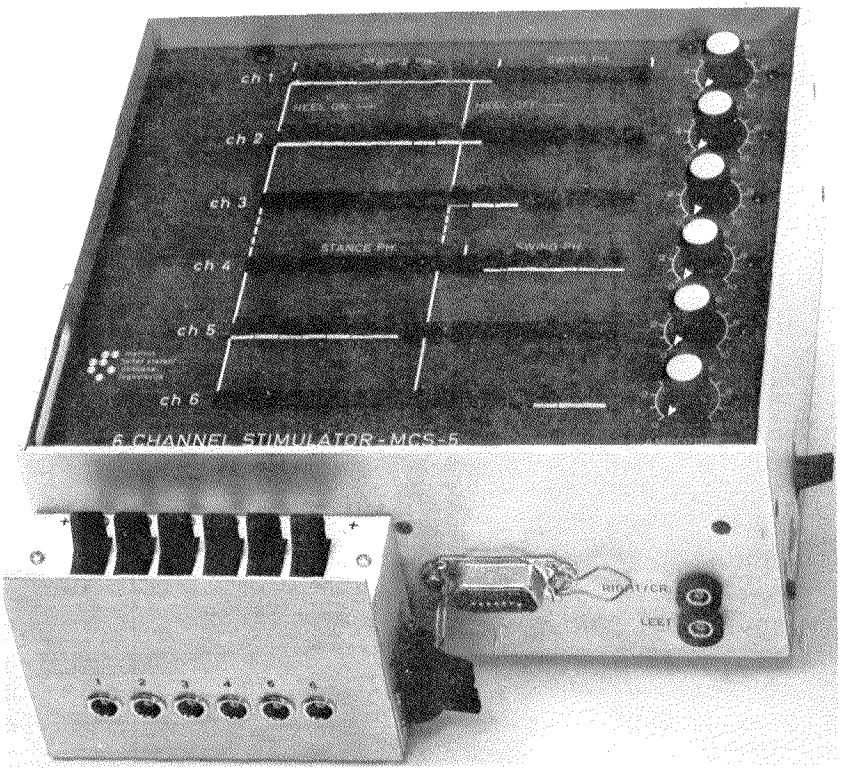

FIGURE 1. — Newly designed six-channel digital stimulator

axial force which patients exert during walking, and it is quite easy to follow the integral improvement of walking when this force lessens. The second features audio feedback with adjustable theshold value of force, used in an everyday training program.

In preliminary testing, the force-shoe system has given us a completely new insight in the process of walking from the kinetic point of view. In spite of the fact that for the time being the measured data offer qualitative rather than quantitative information, all this is of great importance for gait analysis and gait synthesis. The system is very sensitive to perturbations introduced by FES and other methods. It enlightens and documents the obtained responses. It is planned that several sizes of shoes will be made to cover the majority of our patient population.

The variability of FES responses has been studied, to quantify the FES-stimulated structures as a "motor". This is especially important for fine movement with desired long duration. The results obtained show high nonstationary properties of FES motors, since 20 percent

of 9-s long-time courses of isometric movement are nonstationary. This does not affect the FES systems where phasic activity is used (like walking) but exerts a strong influence on the FES systems with long stimulation sequences. The results are valid for constant-voltage electrical stimulation only.

2. FES of Spinal-Cord-Injured Patients—Fundamental Locomotion Patterns

(A. Kralj, D. Sc., R. Turk, M.D., S. Grobelnik, M.D., D. Sc., T. Bajd, D. Sc.)

The aim of this project is to create new knowledge in the field of FES and locomotion rehabilitation of paraparetic and paraplegic patients. The following tasks have been studied:

a. Retraining of paraplegic patient's muscles by FES; and

b. Research into fatigue phenomena in electrically stimulated upper-neuron impaired muscles.

To rationalize the costs and the personnel as well as equipment, and not to start with a large population of patients, the emphasis was put on the development of methodology, hardware, and proper selection of technology. All these activities should be carried on in the year to follow when some improvements will be put forward; then, the number of the examined and studied patients will be increased.

With patients who have received successfully the strengthening program for the muscles of pelvis and the lower limbs, the preliminary FES-induced standing experiments have been performed. The following subjects have been examined during these experiments:

a. Determination of whether the FES-obtained muscle forces are able to maintain the patient's erect standing;

b. The biomechanical principles related to erect standing: body weight distribution, transfer of the weight between the legs, and the influence of fatigue—and evaluation of FES technology used (electrodes, fixations etc.);

c. The consideration of hardware needed for better functionality, faster and easier application;

d. The collection of patients' reactions, feelings, and suggestions;

e. The proposal of additional tasks required for future research involving FES-induced standing.

The beginning activities of gait analysis, related to the study of paraparetic patients, have been planned to provide a survey of the patient population in Slovenia, Yugoslavia. So far we have collected and recorded gait parameters of 13 patients. These paraparetic pa-

tients were earlier treated by FES or were using bilateral one-channel FES peroneal stimulators.

We adhere to the philosophy that afferent FES could be very important for these patients, and that new possibilities of rehabilitation could be opened if FES were combined with external ultralight orthotic devices. Skilled physical therapists have joined in these investigations, which results in better working possibilities as well as better communication between the engineers and their patients.

It is believed that, for chronic FES of paraparetic and paraplegic patients, implanted electrodes are of great interest. The technological problems and problems related to the multichannel and multisite implanted electrical stimulators are being studied. At this stage significant data are being collected regarding electronic circuits, different encapsulations, procedures, and materials. The aim of this research is to prepare such stimulators to suit the needs of the present project as well as other FES projects in Ljubljana.

Let us summarize the major achievements of the first-year activities:

a. Muscle strengthening procedures are being fully investigated;

b. The research on muscle fatigue problems has begun;

c. A T-5 paraplegic patient has achieved the erect standing posture by means of FES; he is able to stand for more than one hour without collapsing, and a T-10 patient already stands for 20 minutes, at the beginning of the program;

d. New hardware is constructued or is near completion (walking frame and hip-joint torque-measuring orthosis);

e. An overview of the walking abilities of paraparetic patients of the Ljubljana region has been completed;

f. Procedures for neurological and biomechanical investigations of all patients admitted to the program have been established;

g. New researchers (two physical therapists and two graduate students) have been introduced to the research team.

Before ending this report on the first year's activities, it should be noted that preliminary walking experiments of paraplegic patients by means of FES have also been conducted. A T-5 paraplegic patient is able to walk in parallel bars with stimulation of only three muscle groups for each leg (Fig. 2). During the double-stance phase, both quadriceps muscles were stimulated, while during single-stance phase the dorsiflexors and hip flexors of the swinging leg were excited. Stimulation of the dorsiflexors and hip flexors also caused the reflex flexor activity of the knee flexors. Stimulation was triggered by two manual switches which, during these first experiments, were under the control of a physical therapist.

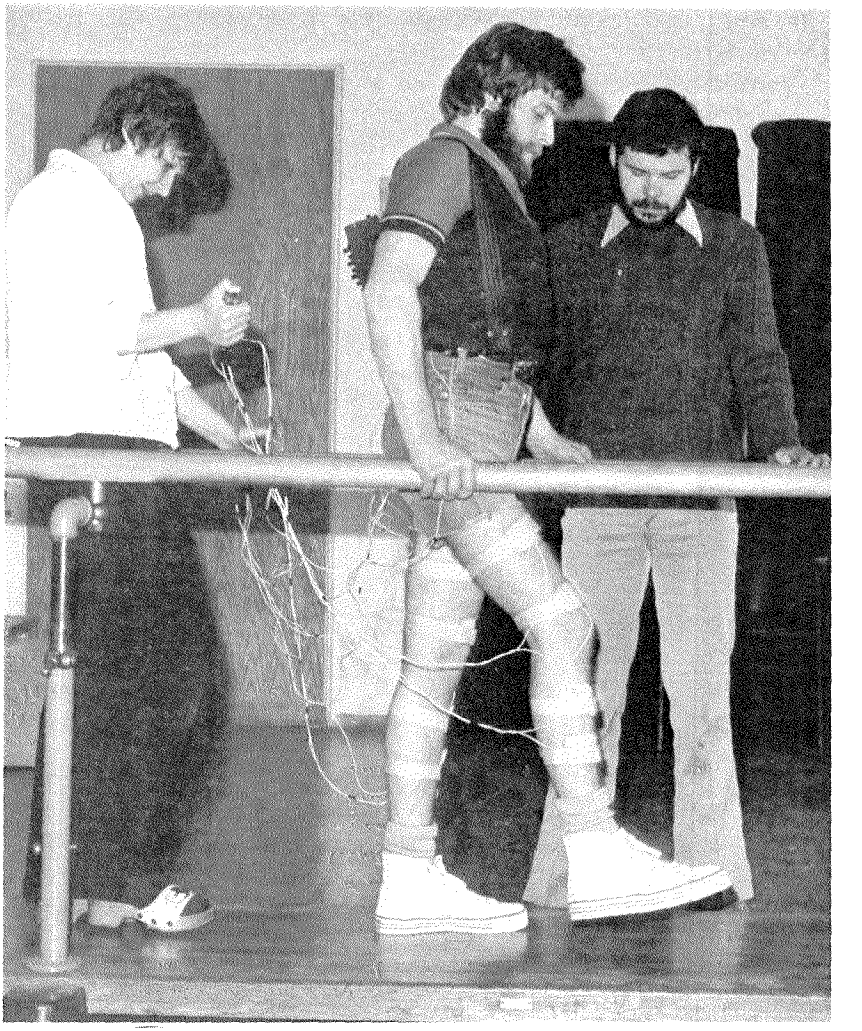

FIGURE 2. — Paraplegic patient walking by means of FES.

3. Multichannel FES of Upper Limbs — L. Vodovnik, D. Sc., A. Kralj, D. Sc., R. Ačimović-Janežič, M.D., S. Reberšek, Dipl. Eng.

In the past year, the research on FES of upper extremities was mostly concentrated on the following areas:

a. FES for quadriplegic patients:

b. Research on control signals for upper-limb orthotics; and

c. Influence of psychological conditions on responses to electrical stimulation.

Several years ago a computer-controlled multichannel stimulator for upper limbs was developed, with the hope that it could be applied usefully to hemiplegic patients for arm stimulation. It was discovered that, mostly because of electrode problems and variabilities in muscle response, the clinical application was still remote. It was therefore decided to focus on the simpler problem of forearm stimulation, for patients who need it the most—quadriplegics. A systematic evaluation of all quadriplegic patients in Slovenia regarding applicability of FES has begun and is well under way. For some of the selected patients special stimulators have been developed, and one (a rather successful hand stimulator) is shown in Figure 3. Of course, the multichannel FES for the elbow and shoulder has not been abandoned, but it is felt that some basic problems must be solved first.

One of these problems is that of control signals. Not many quantitative data are available about the capabilities of various types of patients to generate control signals. It was, therefore, decided to start an investigation which should show how many degrees of freedom a patient can control before reaching his "gadget tolerance"; what are the learning times which might be considered still reasonable; and where useful signals could be picked up for meaningful control of FES orthoses. A completely computerized experimental procedure was developed, and reference data were collected from 10 normal subjects. An arm model with up to four degrees of freedom is displayed on a CRT screen. The subject is asked to match (or "cover") the reference model with the model he is controlling with two two-dimensional joysticks. The computer measures the time until matching is obtained within a given tolerance level. Simultaneously the time responses for each degree of freedom are recorded separately. This enables a study of learning strategies of different subjects; e.g. serial (one degree of freedom after another) versus parallel (all degrees of freedom simultaneously) matching.

For some years the influence of hypnotic suggestion on muscle responses to electrical stimulation has been studied. Since responses in hemiparetic patients were found to change quite substantially due to suggestion, it was decided to start a careful study of M-responses—first on normal subjects and later on patients with various deficiencies in their central nervous system. Within this investigation a cybernetic model was also proposed, which may provide a conceptual frame for further experiments on the application of hypnosis in rehabilitation engineering.

FIGURE 3. — Hand stimulator for quadriplegic patient.

4. Neurophysiological Investigations of Pathological Motor Activity and Improvements Due to FES and other Rehabilitation Methods — F. Gračanin, M.D., D. Sc., M. Vrabič, Dipl. Eng.

The data collected in the past few years indicate that in some cases of motor disorders, FES as well as some other rehabilitation methods (e.g. biofeedback) show a substantial therapeutic effect. Unfortunately, however, the neurophysiological research of these effects has been neglected, therefore, it is presently not possible to give an adequate explanation of the therapeutic mechanisms, to improve the existing methods or make any prognostic statements for a specific patient.

The study was performed on cerebral palsy children in order to evaluate optimal sequences of electrical stimulation of peroneal nerves and its effects on the improvement of gait and posture in correlation with the distribution of motor functioning impairment and spasticity, as well as to examine the possibilities of controlling flexion synergy in swing phase, and extension synergy in the supporting phase of gait.

The research of the latter part will be carried on in the next year. For this purpose, a two-channel FES system was developed (Fig. 4). It has the possibilities of ipsilateral, contralateral, and collateral modes of control.

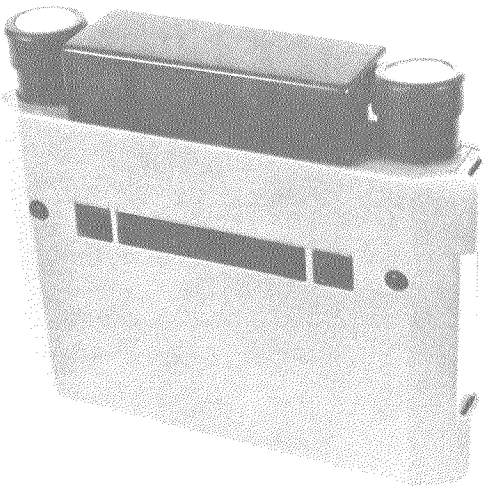

FIGURE 4. — Two-channel stimulator for CP children.

The influence of spinal reflex mechanisms during gait upon the constancy of the motor response to FES (M-wave) both in healthy adults and in hemiplegics has been investigated.

Electrophysiological analyses of the distribution of motor activity and the behaviour of the M-wave, kinesiological analyses of gait of CP children in various modes of electrical stimulation and rehabilitation engineering methods, including the development of FES system, have been used.

The objective of this investigation is to accelerate the development of insufficiently developed motor functions of locomotion and postural mechanisms, and to restore or substitute impaired motor function of the locomotion system with the optimal therapeutic approach.

5. FES of Urogenital Mechanisms (FESUM) — Design of Orthotic Aids and Special Measuring Systems

P. Sŭhel, D. Sc., S. Grobelnik, M.D., D. Sc.

Previous successful results in the treatment of urinary incontinence in man by applying acute maximal electrical stimulation (AMFES) have led the research to the studies of neurophysiological mechanisms in the urogenital tract and spinal micturition center. The unexplained effect of AMFES has demanded construction of a special electrical stimulator permitting basic research of the long-term effect of AMFES, and a neurophysiological explanation of the electrical inhibition of hyper-reflexia of the detrusor muscle. The results of the research will provide the parameters for the construction of the electrical stimulator AMFES which will be applicable also at other gynecological and urological clinics outside Ljubljana.

The development of the automatic anal stimulator Recticon X is being carried out. Ten samples of a new design of the stimulator have been constructed. Recticon X is an integrated, non-implantable, electrical stimulator contained in the anal plug, used for the treatment of urinary incontinence in man. Its action is automatic; i.e. it is automatically switched on and off when inserted in the anal aperture. The plug's form is shown in Figure 5. The front part contains a source battery and the back an electronic circuit, conditioning automatic action.

The back side of the plug is elliptically rounded, modeled into a form preventing any unpleasant pressures. The electrodes are formed in such a way as to fit into the anal aperture.

With the aim to study the feasibility of electrically provoked ejaculation in paraplegic patients, several forms of electrical stimulation have been tested, i.e., sinusoidal form, triangle form, and square form of

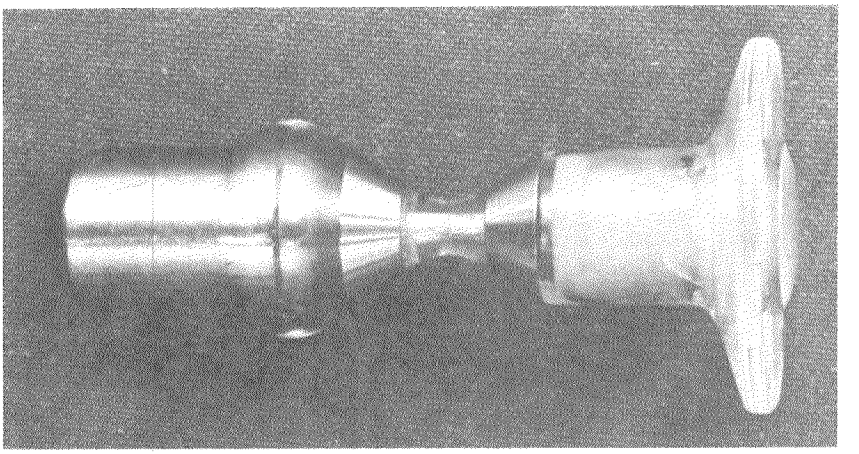

FIGURE 5.—Recticon X, an anal stimulator for the treatment of urinary incontinence.

electrical stimuli. A laboratory type of electrical stimulator generating monophasic square pulses has been designed, since this form of stimulation seems to be the most effective. Several types of stimulating electrodes for intrarectal application (i.e., circular current probe and longitudinal current probes) have been designed and tested. Stainless steel electrodes are incorporated into a plastic housing made in the form of a thimble. A longitudinal current has proved to be the most effective.

6. FES of Urogenital Mechanisms (FESUM) — Studies of Urodynamics and Evaluation of Orthotic Aids

L. Ravnik, M.D., D. Sc., S. Plevnik, M. Sc.

Two main topics were investigated: effects of externally applied electrical stimulation on the function of the bladder and the urethra in patients with urinary incontinence, and the feasibility of electrically provoked ejaculation in paraplegic patients.

External Electrical Stimulation: Studies of the Acute Effects and Clinical Results.

Within this topic the effect of the electrical stimulation on the function of the urinary bladder was urodynamically examined. Studies of cystometrograms made before and during electrical stimulation which was externally applied to the pelvic floor muscles (the studies being performed in a group of stress-incontinent patients) proved that the electrically provoked inhibition of the detrusor muscle enlarged the capacity of the bladder due to electrical stimulation. This

finding represents the basis for further research into more efficient methods of external stimulation for the rehabilitation of patients in whom the lack of bladder inhibition (i.e. the hyperactive bladder) represents the main cause of incontinence.

The clinical evaluation of anal automatic electrical stimulators was impossible because of the problems of electrode corrosion. A new method of electrical stimulation for incontinence was developed and evaluated instead, i.e., the maximal electrical stimulation (MES).

It was shown that in patients with urge incontinence and a reflex bladder, the electrically provoked inhibition of the bladder is most pronounced when using electrical stimulation of high intensity. Therefore, the strong electrical stimulation (i.e. maximal electrical stimulation) was externally applied to the pelvic floor muscles via anal and/or vaginal needle electrodes for the short period of time of 15-to-20 minutes. The bladder inhibition with urethral sphincter contraction was urodynamically observed during MES in most of the patients. Fifth percent of the patients were permanently or temporarily released from their symptoms.

The neurophysiological evaluation of the post-MES effects was performed in patients with the symptoms of urge incontinence. The EMG studies of the pelvic floor muscles were carried out before the application of MES. An attempt was made to correlate the neurophysiological findings to the effect of MES.

It was noted that the urethral sphincter tended to be the most abnormal muscle in the observed group; this, however, did not preclude the success of MES if the other pelvic floor muscles were only moderately involved. EEG studies did not seem to be related to the continence problem.

In a group of patients with urge incontinence and mixed urge and stress incontinence, the EMG studies of the anal and urethral sphincters were performed before and a few days after the application of MES. The most consistent change was an increase in tonic activity.

Some patients showed a specific defect — being unable to activate the sphincter voluntarily: in these patients at least some voluntary activity was regained after MES.

Maximal electrical stimulation, which has so far been evaluated on 300 patients with different types of urinary incontinence, will continue to be done in the future. Studies will be preceded by careful selection of patients with urinary incontinence, in order to achieve more homogeneous groups of patients in terms of the etiology of the disease.

Electrical Stimulation for Ejaculation

Within this topic the feasibility of electrically provoked ejaculation

in paraplegic patients was studied. In a group of spinal-cord-injured patients, different external stimulation methods (i.e. different types of electrodes and different forms of electrical stimuli) were intrarectally applied with the aim of provoking ejaculation. The results of electrostimulation trials were rather poor. However, it is of interest to note that in some patients therapeutic effects were observed, i.e. the ability to ejaculate was improved after the stimulation although no effect was observed during the stimulation.

Although the preliminary results in this subarea are not very encouraging, they suggest some ideas which should be tested in the future. The experimental conditions should be changed with the aim of minimizing possible supraspinal inhibitory effects. Hypnotic suggestion could be used for this purpose. Therapeutic effects, which seem to exist, should be further evaluated.

A. Bennett Wilson, Jr., Director, Gordon Moskowitz, Ph. D., Associate Director, Nathaniel Mayer, M.D., Medical Director, and Dolores Scott, Administrative Assistant
Rehabilitation Engineering Center
Moss Rehabilitation Hospital, Temple University, Drexel University
Philadelphia, Pennsylvania 19141

Introduction

This center was established in 1972, in a manner similar to other centers, around a series of individual projects supported at that time, primarily by the Social and Rehabilitation Services of the Department of Health, Education, and Welfare.

The Moss Rehabilitation Hospital is the primary site for the residency program in Rehabilitation Medicine for Temple University, and, thus, was selected to supply the medical expertise. The Department of Rehabilitation Medicine had had a long history of collaboration with the Engineering School of Drexel University in biomedical engineering education, and therefore Temple turned to Drexel for the assistance needed in forming a Rehabilitation Engineering Center for a series of research projects.

From the beginning it was anticipated that a center (in contrast to a series of projects) would consist of a program involving research, development, evaluation, and education, as well as the operation of a model clinic for the delivery of rehabilitation engineering services to complement all of these elements.

The initial core area of research and development was designated

"Assessment and Remediation of Neurosensory Disabilities," under the directorship of Richard Herman, M.D.

In 1977, with the agreement of Joseph Traub of the Rehabilitation Services Administration (successor to SRS for the administration of research in rehabilitation), the core area of research and development was narrowed to "locomotion and mobility."

It is the objective of the center to carry out research and development in the assigned area, to conduct evaluation of the results of research from other sources when called upon, to prepare educational material, to present educational programs as appropriate, and to conduct a model rehabilitation engineering clinic as part of the nationwide program to determine the proper role of the engineer in patient and client management, and to provide feedback to research and development groups.

Recent Accomplishments

1. Development, evaluation, production, and distribution of the Limb-Load Monitor, a device that assists physical therapists and patients to determine the amount of weight that is supported by the lower limb, or limbs, during standing and walking. Twenty-eight units were sold in 1978, and 19 have been sold during the first 6 months of 1979. Rate of sales is about 4 per month.

2. Development and evaluation of the Ultralight Below-knee Prosthesis, including publication of an instruction manual.

The Veterans Administration is planning to conduct a nationwide clinical evaluation of this design. The limbfitting services in both Scotland and England have also advised that clinical studies in this technique will be undertaken in the near future.

3. Development of Lower-Limb Orthoses fashioned from sheet plastic (usually vacuum formed) and preparation and distribution of an instructional manual for prescription and fabrication of these new types of orthoses. The manual is being used in the formal education programs at New York University, the University of Washington, Shelby State College, etc.

4. Evaluation of the CARS-UBC knee orthosis for arthritic patients. Results were published in the March 1979 issue of Orthotics and Prosthetics.

5. Development of a method for visualizing the force vector during comparison including shear components. A report that will permit duplication of this device was prepared and distributed to more than 200 institutions throughout the world.

6. Development of a Publications Office for better dissemination of information concerning results of research. The list includes publica-

tions that are the result of work at this center, REC, but it would seem to be desirable for other REC's to make use of this center for some of their publications.

7. Production of an educational film on normal human locomotion that will be made available shortly to physical therapy and other educational programs.

8. Continuing study of the effectiveness of functional electrical stimulation devices for lower-limb problems.

9. Completion of project and publication of report on use of pattern recognition for control of upper-limb prostheses by electromyographic signals.

10. Completion of project on augmented sensory feedback for maintenance of head position in cerebral palsy children. A comprehensive report will be published in the near future.

11. Organization of a Rehabilitation Engineering Clinic.

12. Organization and conduct of the following workshops:
   a. Locomotion and Clinical Analysis of Gait, December 1976,
   b. Personal Licensed Vehicles for the Severely Disabled, June 1976,
   c. Workshop on Wheelchairs-I, December 1977, and;
   d. Workshop on Wheelchairs-II, December 1978.

Research Activities

Phase-Dependent Reflex Reversals in Controlling Locomotion
Responsible Investigator — R. Craik, M.S.P.T.

The purpose of this project is to evaluate the therapeutic efficacy of phase-dependent reflex reversals in improving neurologically based motor control problems in human locomotion. Non-noxious electrical stimuli are being used to facilitate hip and knee flexion during the involved limb swing phase of gait.

The computer program is now available to collect data on-line and, once pre-screened and marked, to print out means and standard deviations of several biomechanical parameters.

Modifications have been made to the stimulating equipment so that the stimulus could be delivered at any interval after any of the foot-contact events, e.g., heel strike, heel-off. In addition, circuitry has been developed so that a pre-selected footswitch event can be used to begin on-line data collection.

Ten patients, chosen from the medical records at Moss Rehabilitation Hospital, were assessed this quarter. Five had left and four had right hemiplegia secondary to a CVA; the tenth was paraparetic as a result of spinal cord compression. The protocol was followed as pro-

posed; once stimulus threshold for the sural nerve had been established and data collection equipment was applied, control runs were taken until at least 16 steady-state strides were recorded. Stimulus sets, each of at least ten strides, were then recorded.

The stimulus was applied at the time of heel-off on the involved side as had been done previously. In addition, several other stimulus delivery times were attempted. Preliminary analysis of the data suggests that with the appropriate current intensity there is primily an increase in knee excursion and average angular velocity. The other stimulus delivery times appear to be useful depending on whether increased hip or knee motion is desired.

Short-term plans include completion of data reduction and analysis, repeating the protocol on the same patients to assess reliability, and an increase in the sample size.

Studies Involving Alignment of Above-Knee Prostheses
Responsible Investigator — A. B. Wilson, Jr.

These studies are being conducted in two phases. Phase I involves a representative sample of 40 above-knee amputees from local prosthetic facilities. These patients range from those who are quite "satisfied" with their prosthetic device to those "dissatisfied." On this sample, measurements are being made of those factors which are thought to contribute to satisfactory alignment with the major emphasis being on the relationship between alignment and locomotion performance. The objective of this first phase is to identify the most significant relationships between alignment and locomotion performance.

Phase II will consist of testing the hypotheses formulated during Phase I by producing controlled "malalignments" in a smaller sample of amputees and predicting the locomotor deficits which will result.

The overall objective of the project is to produce an instructional manual for prosthetists.

Augmented Sensory Feedback Therapy for Cerebral Palsied Children[a]
Responsible Investigator — C. Leiper, R.P.T.

Current therapeutic programs for young children with cerebral palsy consist of various regimens of exercises and functional training. However, even under the best conditions involving teacher, parents,

[a] Part of this project was supported by the "Easter Seal Research Foundation"

and therapist, this interval represents a small fraction of the child's active day.

Augmented sensory feedback techniques are designed to provide reliable and consistent and immediate information regarding performance to the patient, independent of the therapist. Such techniques are appropriate to teach movement or function—and then to transfer the practice of the skill into self-monitoring situations when the therapist is not present, thus extending therapy time.

This project, designed to determine the effect on motor performance of using an audio feedback signal (and/or the activation of a television set) when the cerebral palsied child held the head in an upright position, (Fig. 1) has been completed. Findings of the study on the self-monitoring abilities of school-age children were presented in a poster session at the annual meeting of the Biofeedback Society of America in February 1979. The same results were presented in paper format at the annual meeting of the American Physical Therapy Association in June 1979.

A final report summarizing the work with preschool and school-aged children over the 4 years of the project will be available in August 1979. A scientific paper will be offered in the near future to the Journal of The American Physical Therapy Association.

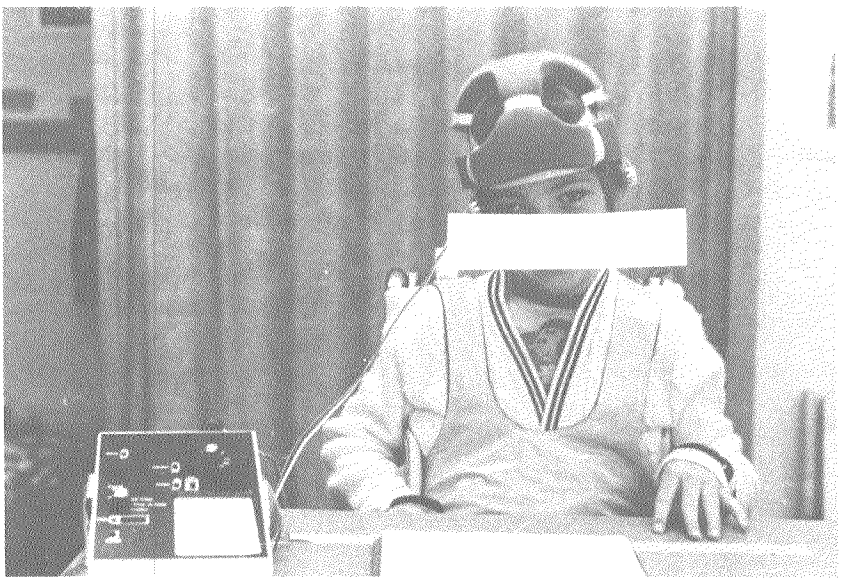

FIGURE 1.—Instrumented helmet on subject with cerebral palsy, for study of head position control.

Cervico-Ocular Reflex (COR) Effects on Eye Stability During Active and Passive Movements

Responsible Investigator — W. Freedman, Ph. D.

Objective and Description of Task

An essential element in locomotion and the control of mobility devices (e.g., wheelchairs or personally licensed vehicles) is the need for accurate information of the near environment. This information is most readily and most accurately supplied by visually processing spatial information. To achieve proper visual processing, several reflex systems act concurrently to adjust eye position to stabilize the image of interest on the retina despite head movements, body movements, or combinations of the two. These reflex systems include the optokinetic system, the vestibulo-ocular reflex (VOR) and, presumably, the cervico-ocular reflex (COR).

Although all three systems have similar responses (a slow movement of the eyes) they are served by different anatomical structures and respond to different types of stimulation.

The optokinetic system is excited by movement in the visual field. This may be a movement of the entire field or the movement of an object of interest. The resulting response is an eye positional change that allows the subject to follow or track the object of interest with his eyes as it moves about.

The VOR is stimulated by a movement of the head. The response is again an eye movement, which in this case opposes the head movement. The result is that the direction of gaze remains relatively unchanged with respect to the stationary environment. This enables the subject's eyes to remain fixated on stationary objects despite movements of his head.

The cervico-ocular system is stimulated by a rotation of the neck. Since a movement of the head in space is frequently accompanied by a rotation of the neck (although at times the head and body are rotated together) the VOR and COR are often stimulated together and supposedly function together to produce retinal image stability. The close interaction between the neck and the vestibular systems, both functionally and anatomically, is quite apparent.

The objectives of this project are:

a. To further the functional definition of the cervico-ocular reflex (COR) in humans.
b. To observe COR response during passive body movement.
c. To determine from the active and passive COR response its effectiveness in producing retinal image stability.

During this report period, experiments on normal adults have be-

gun. Some corrections were required in the computer programs needed for data analysis. The corrections have been made and the experiments are continuing.

Transportation for the Handicapped: I. Determination of the Effect of Whole-Body Vibration on the Visual Functioning of Hemiplegic Patients during a Task Involving Driving an Automobile
Responsible Investigator — W. Freedman, Ph. D.

Project planning meetings have been held to define the parameters necessary to arrive at an experimental protocol. The plans have included preliminary designs of the near-field and far-field displays to be used, the subject population, the task to be performed during vibration, etc. Still to be initiated are plans for the vibrator and the data analysis. Then an experimental protocol will be written and equipment design will begin.

Acquisition of Transient Visual Information: Implications for Mobility
Responsible Investigator — E. Kwatny, Ph. D.

Development and implementation of a testing protocol to examine visual information acquisition during postural perturbation continues. In this test procedure the purpose is to study a subject's (or patient's) ability to visually acquire and read groups of characters presented in random spatial positions for variable durations while the platform on which the subject is seated is rotated 20 deg. Rotation is either 20 deg left or 20 deg right of center; the direction of rotation is generated in a randomized fashion and is thus not predictable by the subject. The test procedure is to be executed either with the subject permitted voluntary head movement or not permitted such movement.

The posture platform has a limited frequency response, and upon initial assessment did not appear to respond linearly to a step input. As a result, a systems analysis of the posture platform control mechanism was made in order to define the control signal necessary to produce a "pseudo-step" output. It was apparent that a step in position change (for 20 deg) could not be realized and it was decided to move the platform with a constant velocity (ramp) that reached its resting position (20 deg) in one second. There is an inherent delay in the actual initiation of platform movement, and it is desirable that platform begin movement coincident with presentation of the visual stimulus.

The control program that operates all of the devices used in the test procedure and acquisition of data has been completed and tested. Testing has been carried out with two normal subjects. The data collected (i.e., eye and head position) are more complex than data collected during previous experiments in which the stimulus was acquired without platform movement. The complexity is due to the compensatory eye movements generated as a result of the platform movement (relative passive head movement—Figure 2) and eye-head acquisition of the stimulus (active-voluntary head movement—Figure 3). The initial passive body position change due to platform movement causes both the body and head to move and the eyes to counter-roll to maintain fixation of the central fixation point. Then, awareness of the actual character stimulus produces an active eye and head movement toward the stimulus. A VOR also is included in this movement.

This complex eye and head position data that results has required us to redefine the manner of data analysis. Current activity is to define these algorithms. Subject testing to totally debug the test protocol also continues.

Effects of Altered Sensory Input on Stair Descent [a]
Responsible Investigator — W. Freedman, Ph. D.

For the disabled and the geriatric population, the task of descending stairs is often difficult and dangerous, whether in a home environment or when using urban transportation. The principal objective of this study is to describe the effects that visual disturbances can have in achieving "functional step-down."

The necessary equipment has been developed and is undergoing testing. A cardboard room has been constructed and suspended from the ceiling by pulleys. Three wooden steps are enclosed by this room; two of the steps can be varied so that step height can be 20.3, 30.5, or 40.6 cm.

A unit that measures ground reaction forces at the time of foot contact, and a unit that measures acceleration of the head in the vertical plane, have been designed and tested. A position feedback system has been developed to move the room so that the subject's environment can either move with him or in apposition to his movement. A computer program has been developed so that the muscle activity can be integrated over any preselected time interval. The EMG activity, force, and other biomechanical parameters will provide

[a] Supported by National Institutes of Health (NIH)

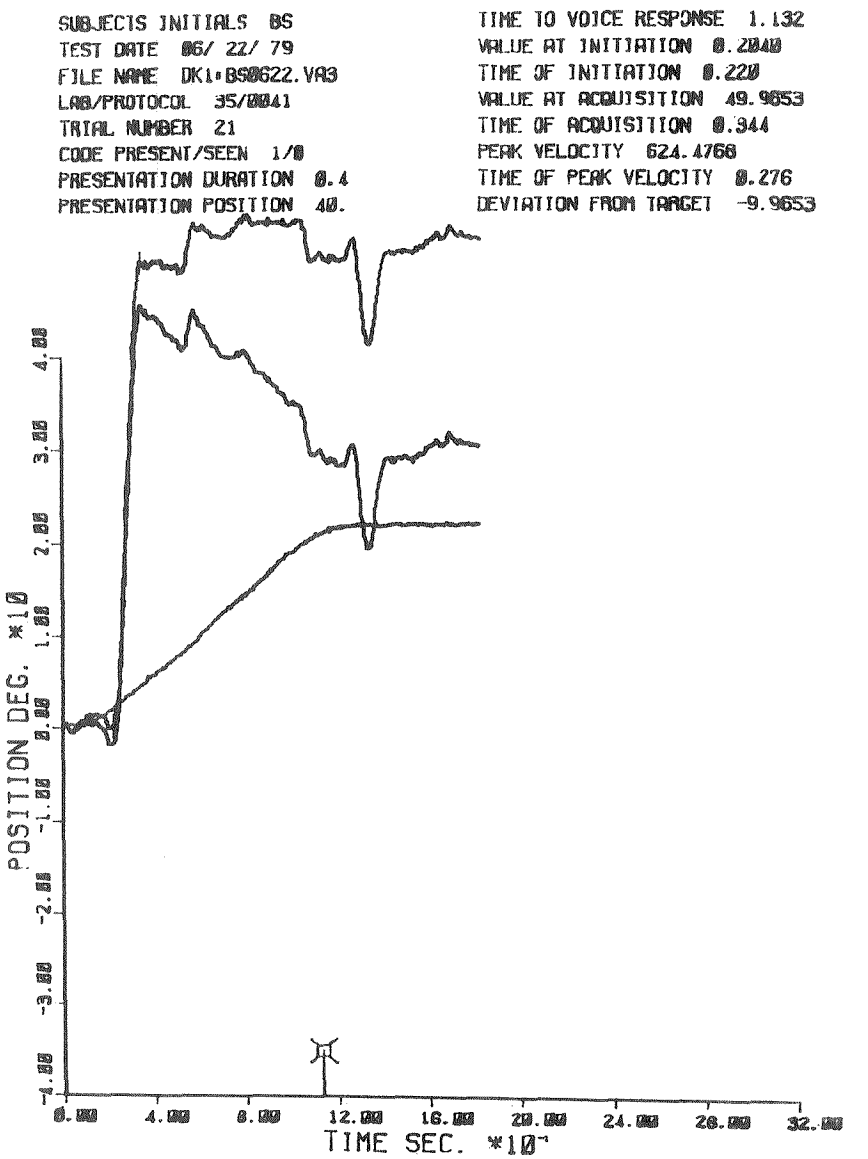

FIGURE 2.—Eye, Head, and Gaze position data for a task in which the subject did not actively move his head. The head position data follows the platform movement.

information about the "quality of a step when the afferent environment is perturbed."

SUBJECTS INITIALS BS	TIME TO VOICE RESPONSE 0.840
TEST DATE 06/ 22/ 79	VALUE AT INITIATION 3.3691
FILE NAME DK1•BSHG22.VA3	TIME OF INITIATION 0.196
LAB/PROTOCOL 35/0041	VALUE AT ACQUISITION 44.3066
TRIAL NUMBER 21	TIME OF ACQUISITION 0.348
CODE PRESENT/SEEN 1/0	PEAK VELOCITY 657.2614
PRESENTATION DURATION 0.4	TIME OF PEAK VELOCITY 0.240
PRESENTATION POSITION 40.	DEVIATION FROM TARGET -4.3066

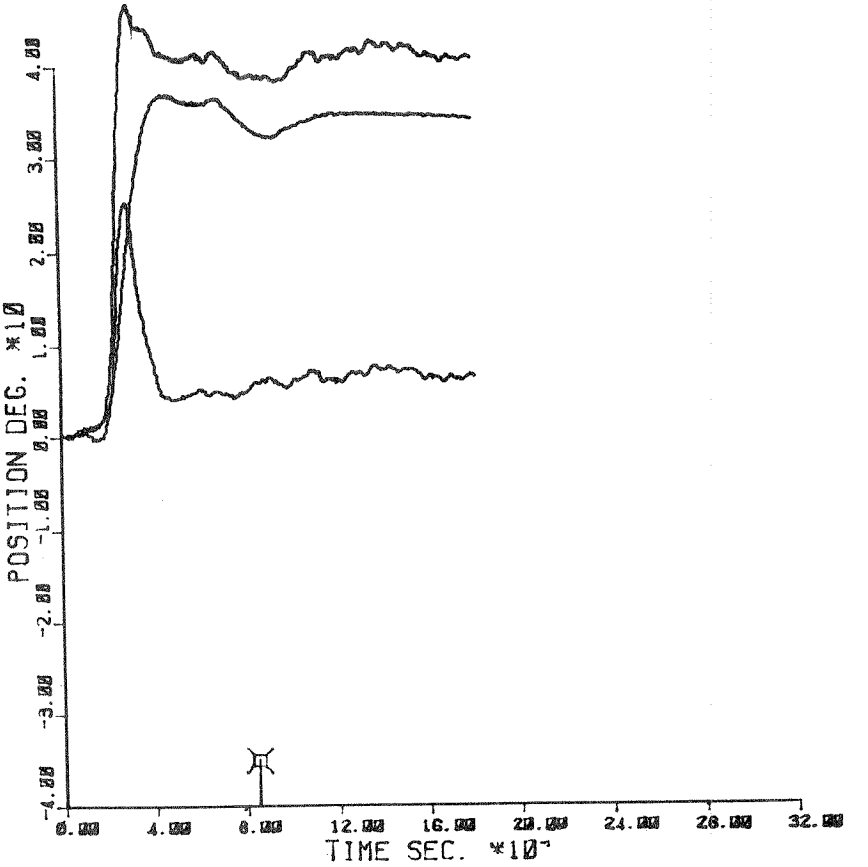

FIGURE 3.—Eye, Head, and Gaze position data for the same task as in Figure 1, but the subject *actively* rotated head and eyes to acquire the stimulus. Note the differences in eye position changes to compensate for the different types of vestibulo-ocular reflexes (VOR).

Development Activities

Myoelectric Control of the Knee for Above-Knee Amputee
Responsible Investigator — G. Moskowitz, Ph. D.

The purpose of this project is to obtain voluntary control of an artificial knee by an above-knee amputee by the use of electromyographic signals from muscles about the hip through application of pattern-recognition techniques.

The feasibility has been proven.

The actuator has been tentatively designed as a pneumatically driven double-acting ram, with a pressure reserve tank located in the shank of the prosthesis. If the actuator is to act as an energy dissipator (i.e., the torque which must be supplied by the device opposes the direction of rotation about the knee), valves will be adjusted to provide air flow resistance. When the pressure on either side of the ram exceeds the pressure of the reserve tank, that side of the ram will be connected to the reserve to conserve energy.

When it is required that the actuator supply energy (i.e., provide torque which is in the direction of motion), the reserve tank will serve as the driver. Digital computer simulation indicates that the actuator will be capable of driving the knee with torques of up to 270 in.-lb, well within the torque demands of swing phase in normal locomotion.

Each of the equations governing the behavior of the actuator was linearized using a Taylor series expansion about a nominal trajectory of the state variables of the actuator. A piece-wise linear model of the actuator will then be used in the design of a compensator. The linearized model of the actuator is currently being simulated.

Ultralight Below-Knee Prosthesis
Responsible Investigator — A. B. Wilson, Jr.

Because it is considered by many clinicians and patients that extremely light lower limbs are desirable for geriatric amputees, a design for fabrication of a crustacean-type below-knee leg, molded from sheet polypropylene, was introduced in 1976 (Fig. 4). Early results indicated that younger patients also appreciated the weight reduction.

In an effort to accelerate progress, prosthetists from other REC's, private facilities, and the major education programs were invited to Northwestern University, for a demonstration of the technique, and, in turn, to provide this center with recommendations for further work. As a result of this project, and with financial assistance from the

FIGURE 4. — Cross-section of a polypropylene ultralight below-knee prosthesis. The heel cushion and sole can be of any configuration and material desired.

VA, the fabrication method was refined and tested, and a manual was prepared and published.

Upon completion of this phase it was recommended to the VA that a nationwide clinical program be carried out. The VA responded by requesting that the REC conduct a local clinical trial involving the Philadelphia VA Regional Office Amputee Clinic. The VA provided the necessary funds.

This study, which involved 36 patients and 6 private facilities, has just been completed, the manual is being revised, and a final report is in preparation. The American Academy of Orthotists and Prosthetists is planning a nationwide clinical study of the technique which will be VA supported. The medical services in both England and Scotland are also initiating clinical evaluation programs of the ultralight prostheses developed here.

Instrument for Clinical Analysis of Gait
Responsible Investigator — D. Taylor, B.S.E.E.

The need for instruments that will permit orthopedic surgeons, physicians, therapists, prosthetists, and orthotists to make useful measures of gait in clinical settings has been stressed in many scientific meetings and, in retrospect, seems to be obvious.

The instrument under design here consists of a portable 13-ft-long walkway that uses electrical switches and electronic data processing equipment to measure step length, stride length, and velocity without the need to attach anything to the patient. It will provide the same data as the currently used cumbersome method of inking the subject's shoes and having the subject walk on brown paper, while using a stopwatch. A single pass of the subject will provide a printed record from the new instrument, giving the spatial and temporal data of these gait parameters.

A prototype is partially completed and is scheduled for trial testing by the end of August 1979.

Ambulation Energy Meter
Responsible Investigator — T. Cook

The objective of this project is the development of a rather simple device, to provide an index of energy expenditure during level walking at a cost that will make research and clinical applications in reference to energy expenditure during walking feasible. An accelerometer is used in each of three planes in an effort to collect the data needed.

During the past half-year, data have been collected in order to determine the validity and sensitivity of the instrumentation. Five hemiplegic and four amputee subjects have been used. Several more subjects will be included before a final report will be developed.

A plan to correlate metabolic energy expenditure with external mechanical work, as determined by this instrumentation, is being considered.

Evaluation Activities

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

This center has been conducting an ongoing evaluation of functional electrical stimulation of the peroneal nerve since 1972 when it was requested by the National Academy of Sciences, Committee on

Prosthetics Research and Development (CNAS–CPRD) to participate in the clinical evaluation of the Ljubljana FEPB-8 device. All known commercially available devices have been tried. The unit supplied (until recently) by Medtronic has been found to be the most acceptable, owing primarily to its electrical characteristics and the feature that permits cycling of the current.

Experience with FES units was reported by this center in 1977(1) and at the Sixth International Symposium on External Control of Human Extremities in Dubrovnik, Yugoslavia in 1978(2). FES units have been found to be useful in patients who have swing phase clearance problems, especially when they have difficulty clearing the floor during swing phase as a result of proximal as well as distal musculature weakness in the lower limb. Only patients with upper motor neuron syndromes (and with intact peroneal nerve function) are considered for this device. Patients with upper motor neuron syndromes and swing phase control problems are clinically suitable for use with FES units.

A problem with commercially available units has been their poor reliability. Because the Medtronic design is no longer available, this center has fabricated and refined a newer FES model unit. Twenty-five of the units have been built so that the FES study can continue without interruption. Special attention has been given to quality control in the fabrication of these new units and their reliability is actively being investigated.

Among features of this unit is the presence of a cycling and a walking mode combined into one housing. In addition, the unit has an anti-slap feature which allows current to continue into the initial part of stance phase, to control deceleration of the foot as it prepares to make contact with the ground after heel strike.

REFERENCES

1. Ship, G., and N. Mayer: Clinical Usage of Functional Electrical Stimulation in Upper Motor Neuron Syndromes: *In:* Functional Electrical Stimulation Applications in Neural Prostheses. Edit: F.T. Hambrecht and J.B. Reswick. Marcel Dekker, Inc. 1977.
2. Ship, G., and N. Mayer: Peroneal Nerve Functional Electrical Stimulation: For Whom? *In:* Proceedings of the Sixth International Symposium on External Control of Human Extremities, Dubrovnik, Yugoslavia 1978.

Conjoint Development and Evaluation for a Foam-in-Place (FIP) Seat Designed at the REC — University of Tennessee

Responsible Investigator — C. Leiper, R.P.T.

Activity in this evaluation has centered on determining the techniques for preparation of the foam.

One patient has been evaluated and provided with a FIP back and seat. This child was an extremely difficult seating problem. The wheelchair seat now doubles as a car seat for transportation purposes. A close follow-up will be maintained to determine how well the material holds up over time.

Evaluation of Prefabricated Modular Seating System from REC — University of Tennessee
Responsible Investigator — C. Leiper, R.P.T.

This evaluation project is virtually completed. Seven children were fitted with a molded plastic insert (MPI) seat following selection criteria and fabrication instructions provided by UT/REC. Followup evaluations were carried out 4 months following each fitting. All data have been forwarded to UT/REC for tabulation there. Recommendations made by this center included:

1. More preparation of the parts to be done by the supplier;
2. Provision for trying lumbar pads, pommels, and X-strap harnesses on the fitting chair; and
3. Narrowing the width of the interfaces so children can reach the wheels of chairs to propel themselves.

Education and Dissemination of Information

Student Affiliation Program
Clinical Coordinator — R. Craik, M.S.P.T.

An affiliation program is offered to physical therapy students to expose the student to the research process and its application in the field of physical therapy.

During a 4-8-week internship, students are assigned to a specific research project under the supervision of a staff therapist. The student gains experience in protocol design, data collection, data analysis, and report writing. In addition, students participate in clinical rounds, research conferences, and clinical workshops. To date, there are eight universities which affiliate with the center. Future plans are to include occupational therapy students.

Training Films on Locomotion
Responsible Investigator — T. Cook

The availability of the force-line visualization technique and a method for displaying EMG activities through lights mounted on electrodes placed on the surface of the skin, makes it possible to

activities) that are more effective than those currently available.

A 20-min. film of normal human locomotion is nearing completion. The faculties of the Prosthetics and Orthotics School, NYU, and the NYU School of Physical Therapy have been consulted during the design and production.

Planning has begun on production of a locomotion film on above-knee amputees. The faculty at New York University has agreed to cooperate in the production of this film. Film footage is being accumulated on a large sample of above-knee amputees in conjunction with the study on above-knee prosthesis alignment.

DELIVERY OF SERVICES

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

A rehabilitation engineering clinic was established early in 1977 in an attempt, in conjunction with other REC's, to determine the role and effectiveness of engineering and engineers in the management of patients during medical rehabilitation and the provision of services to clients seeking independence and employment. The clinic was established in consultation with the Pennsylvania Bureau of Vocational Rehabilitation and has served 65 clients. In addition, patients referred by International Rehabilitation Associates, the U.S. Army, and others have been seen.

The Rehabilitation Engineering Service has expanded its role during this period to include not only inpatients assigned especially to the Medical Director of REC and referrals from BVR, but also consultations concerning regular patients at Moss Rehabilitation Hospital and Albert Einstein Medical Center, along with engineering rounds on the various services at Moss and at Temple. BVR clinics are held twice monthly on Tuesday afternoons (non-BVR referred outpatients may also be seen at this clinic) while engineering rounds on the stroke service, spinal cord injury service, musculoskeletal service, and amputee/peripheral vascular disease service are held on a monthly rotating basis along with engineering rounds in the Department of Rehabilitation Medicine at Temple University Hospital. Thus, formal engineering service activities are held on a weekly basis every Tuesday afternoon.

In addition, a weekly engineering administration meeting is convened for the purpose of screening new referrals to the engineering service and making a determination as to whether the patient and his problem should be evaluated prior to clinic by various members of the

engineering team. Review of concurrent problems and progress and recommendations are also brought up for discussion at the weekly administration meeting. Ward rounds on the rehabilitation engineering service inpatient unit are usually conducted weekly on Tuesday mornings from 8 to 9:30 AM. The rehabilitation engineer attends the Tuesday rounds as well as Thursday morning chart rounds. This provides for a maximum interaction with all of the treating therapists for patients on the inpatient unit.

A total of 46 patients with 69 problems were seen by the engineering team between January 1 and March 31 of 1979. Of these, 29 percent came from the inpatient REC service, and 35 percent came through the engineering clinic (primarily BVR). Consultations within Moss Rehabilitation Hospital amounted to 15 percent, 13 percent were seen on rounds at Temple University Hospital, 4 percent on rounds at Moss Rehabilitation Hospital, and 4 percent at Albert Einstein Medical Center. The two major sources of referral, therefore, were the inpatient REC service and the BVR clinic.

Detailed records of experiences with each patient/client are being accumulated, with the idea that guidelines can be published for use in educational programs. It is hoped that this work can be pooled with experience of other centers, to provide future practitioners with a sound foundation for providing effective rehabilitation engineering services as needed throughout this country and the world.

Clinical Gait Analysis Service
Responsible Investigator — T. Cook

Since early in 1978 the Locomotion Laboratory has been available for use by clinicians in the management of patients. Because of the volume of work needed for completion of other projects involving the laboratory, it has not been possible to make as much progress as was anticipated.

Nevertheless, during the first quarter of 1979 —

Nine patients were referred from the Moss Hospital Orthotics and Prosthetics clinics. (Six were below-knee amputees, one was an above-knee amputee, and two were patients with orthotic devices.)

One patient was evaluated for the Rheumatology service. This preliminary evaluation was directed at finalizing a more formal protocol regarding the feasibility of prosthetic knee joint surgery. Final details of the study have been worked out and patient testing is ready to begin.

Five patients from a variety of sources were evaluated and appropriate laboratory findings were forwarded to the referring personnel.

Additionally, the force visualization system has been used for three other purposes:

1. Frontal plane force line pictures were taken of an above-knee amputee for prosthetic design purposes at the request of Charles A. Blatchford and Sons, Ltd., Great Britain;
2. Force line pictures were taken during various wheelchair activities by a paraplegic at the request of Nagle Bridwell, MED Distributors, Philadelphia, Pa., and;
3. Force line pictures and recordings were taken of a paralytic patient using canes bilaterally, at the request of Dr. Eugene Murphy.

The primary purpose of this project is to demonstrate how locomotion data can be useful to clinicians in the management of individual patients. At an appropriate time a manual on the subject will be published. It is hoped that a mechanism can be established that will permit close cooperation with other groups who have locomotion laboratories.

For Publications and Presentations by these Investigators

Further information on the publications and presentations of the responsible investigators whose names appear below the titles of the foregoing research, development, and evaluation programs, contact: Director, REC, Moss Rehabilitation Hospital, 12th Street and Tabor Road, Philadelphia, Pa. 19141.