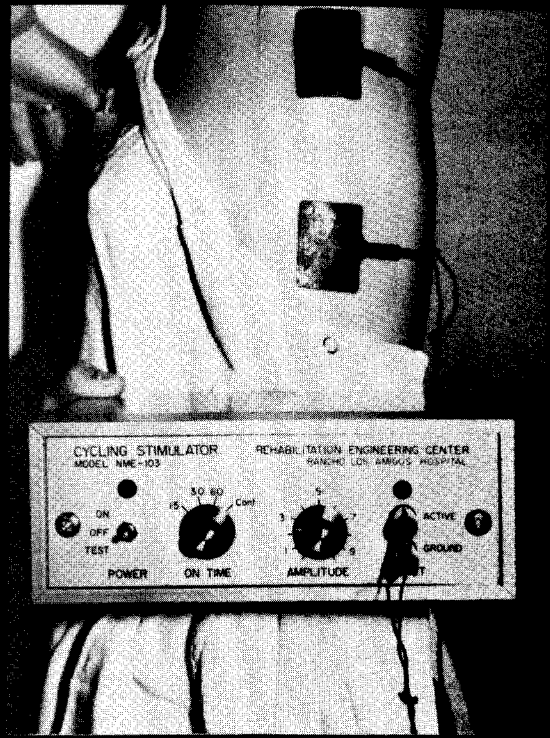
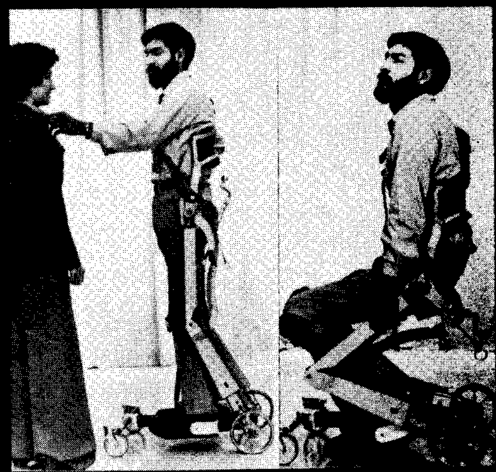
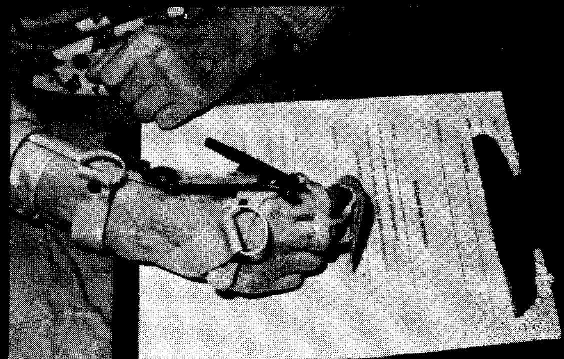

CYCLING STIMULATOR
MODEL NME-103
REHABILITATION ENGINEERING CENTER
RANCHO LOS AMIGOS HOSPITAL
ON
OFF
TEST
POWER
ON TIME
AMPLITUDE
ACTIVE
GROUND


PALMAR
DORSAL
NORMAL





FOREWARD

General public concern for the quality of life of the disabled has in the past peaked after each war to provide better rehabilitation services for our returning veterans. This resulted in periodic renewal of efforts to offer improvements to benefit all who became disabled, but special emphasis was placed on those disabled through their involvement in the military services. Concern for those others in our society who became handicapped from birth defects, disease or accident, developed only haltingly despite the increasing vigorous political efforts of the civilian disabled themselves. Ultimately, the Rehabilitation Act of 1973 was passed by the Congress and signed into law. It was in this law that Rehabilitation Engineering and its role in providing technology to aid the handicapped was enunciated clearly.

Throughout the years following the Second World War until the passage of the Rehabilitation Act of 1973, coordination of the various Federal programs in the field of prosthetics and orthotics was provided by the Committee on Prosthetics Research and Development of the National Academy of Sciences. The first workshop on Rehabilitation Engineering conducted by the NAS at the request of the Veterans Administration and the Rehabilitation Services Administration (RSA) produced a report entitled, "Rehabilitation Engineering—A Plan for Continued Progress" in 1971. This plan has guided the development of the Rehabilitation Engineering efforts in this country, even before the enactment of the Rehabilitation Act of 1973. Unfortunately, the National Academy of Sciences has been unable to continue to provide these services in recent years. As a result, the Rehabilitation Services Administration and the Veterans Administration joined together in an informal coordination to support a series of 12 state of the art workshops in specific subject matter areas to develop near and long term plans for further program development in research, development, education, and service delivery in the field of Rehabilitation Engineering. Although representatives of other Federal agencies participated in the individual workshops as appropriate, the RSA with it primary mission to provide rehabilitation services to the civilian disabled population and the VA with similar responsibility for the militarily disabled took the lead in this effort.

Each of the 12 state of the art workshops has been completed and the reports printed and distributed widely. This document is a summary report of the deliberations and recommendations of each of those workshops. It, also, presents recommendations for a more formal and comprehensive interagency program management structure to guide everyone with interest in Rehabilitation Engineering so that the program can continue in an orderly coordinated fashion to grow to the point where all the population in need can receive Rehabilitation Engineering Services in the most effective and efficient way.

This document and the proceeding workshop reports are intended to provide the basis for the wise use of government resources to avoid unnecessary duplication and to support the various Federal, State and private agencies to accomplish the real goal of improving life's quality for the disabled, through the enlightened application of technology—Rehabilitation Engineering in practice.

Max Cleland
Administrator
Veterans Administration

Robert R. Humphreys
Commissioner of
Rehabilitation Services

REHABILITATION ENGINEERING

A PLAN FOR CONTINUED PROGRESS
II

produced jointly by

the Rehabilitation Services Administration

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and

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at the University of Virginia

CONTENTS

PREFACE

Seven years ago the first publication on Rehabilitation Engineering was prepared by the Committee on Prosthetics Research and Development of the National Academy of Sciences, with a major recommendation to establish several Rehabilitation Engineering Centers. Since then the Rehabilitation Services Administration of the Department of Health, Education, and Welfare has funded twelve such centers, and the Veterans Administration has funded their first. These centers form the cornerstones of Rehabilitation Engineering in this country. Through these centers and other projects funded by the Rehabilitation Services Administration and the Veterans Administration tremendous strides have been made as is indicated by the depth and scope of work reported in this document and the twelve workshops that contributed to it.

There is still much to be done. Although there are many examples where patients are receiving outstanding care and technical assistance as a direct result of the program, the full value will not be realized until more effective means are found for evaluating new developments, educating professionals and recipients alike, and improving the means for service delivery. These and other topics are addressed in this report which concludes with recommendations for an organization on a national scale to better meet the needs of the nation's disabled population through the application of science and technology.

Some 400 persons contributed to this document in the hope that it will serve as a resource and planning aid to those responsible for legislation, administration, research, education, and service for the physically disabled.

INTRODUCTION

There have been sporadic instances throughout history where the medical and engineering professions have worked together as a team to provide solutions to health problems, but it was not until after World War II that any sustained effort of team work involving the two professions came about.

One of the major factors in the marriage of the two professions, especially in the field of physical rehabilitation, resulted when the Surgeon General of the Army, an orthopedic surgeon, requested the National Academy of Sciences (NAS) to advise his service concerning the standardization of artificial limbs for returning war veterans who needed them. The matter was referred to the Panel on Orthopedic Surgery of the Division of Medical Sciences of the National Research Council. After a conference early in 1945 consisting of scientists, engineers, surgeons, and prosthetists in which it was brought out that very little scientific effort had been devoted to amputation surgery and artificial limbs, it was recommended that a research and development program be initiated at once.

This was done through the NAS, first with funds from the Office of Scientific Research and Development (OSRD), later with funds from the Office of the Surgeon General after the disbanding of OSRD following the cessation of hostilities, and still later by the Veterans Administration (VA) which had inherited responsibility for care of the patients.

It seems to have been the general feeling that most of the problems of the amputee could be solved by providing the engineers with criteria developed by the surgeons for artificial limbs. It was soon realized that sufficient data for development of criteria did not exist, and laboratories at the University of California at Berkeley (UCB), and at the University of California at Los Angeles (UCLA), were engaged to conduct fundamental research studies concerning the functions of lower and upper limbs, respectively. In these projects, especially the locomotion study at UCB, a strong relationship developed between the medical and engineering faculties. Concurrently with the fundamental studies, the NAS program, through the University of California, initiated a project to evaluate the so-called suction socket for above-knee amputations. These two experiences clearly demonstrated that teams of medical and engineering personnel could produce results that could not be otherwise obtained.

Continued support of the research program in artificial limbs by the Veterans Administration was based on effective medical-engineering teams and, after about ten years of work nearly every aspect of amputee management was improved through the nationwide program coordinated by the NAS for the VA. The results of research were made available on a nationwide basis through formal education programs given by the medical schools at UCLA, New York University, and Northwestern University, all of which continue to operate today.

The Vocational Rehabilitation Act of 1954 gave the Office of Vocational Rehabilitation (OVR) of the Department of Health, Education, and Welfare (DHEW) authority to support research that would lead to improvement of the vocational potential of physically disabled individuals, and in 1955 the OVR requested the NAS to assist in developing a program in research to be supported by grants from OVR which would be complementary to existing work.

From the beginning of the artificial limb program it was recognized that many of the findings would be applicable to orthopedic appliances, or orthotics, and thus much of the OVR-supported effort was, in due course, directed toward orthotics, and other appliances for the physically handicapped, including the blind. (The Veterans Administration has maintained since 1945 a small research program in aids for the blind.)

Through the years 1955-75, the Veterans Administration and the DHEW through, consecutively, the office of Vocational Rehabilitation Administration (VRA), the Social and Rehabilitation Services (SRS), and now the Rehabilitation Services Administration (RSA) provided funds for the National Academy of Sciences, for correlation of all aspects of the rehabilitation program involving engineering through its Committee on Prosthetics Research and Development. From 1968, the Committee was responsible for clinical evaluation of devices and techniques emanating from the program.

In 1970, the CPRD organized and conducted a conference that resulted in a plan for the conduct of research, development, evaluation, and education in "Rehabilitation Engineering" a term proposed by DHEW personnel to encompass the application of engineering "to improve the quality of life of the physically handicapped through a total approach to rehabilitation, combining medicine, engineering, and related science."

The report, in addition to pointing out needs in research and education, recommended the formation by SRS (now RSA) of Rehabilitation Engineering Centers to carry forth part of this work, complementing the work supported by the VA and others.

Since 1971 twelve centers have been established. At the same time the VA program has been expanded with one Rehabilitative Engineering Center funded and others planned. Other government agencies, such as the Department of Transportation, the National Science Foundation, and the National Institutes of Health, have either entered the field of Rehabilitation Engineering or have expanded existing programs, and the National Aeronautics and Space Administration (NASA) has been applying some of the results of their research to medical problems.

In 1975 the National Academy of Sciences suspended the services provided by the Committee on Prosthetics Research and Development while it evaluates its role in this area. Because more than six years have elapsed since the publication of "Rehabilitation Engineering, A Plan for Continued Progress," both the RSA and the VA felt an urgent need for a revised plan. Accordingly, Joseph Traub (RSA) and Anthony Staros (VA) arranged through existing contracts and grants for a series of workshops and conferences that would eventually produce the information needed for developing a timely plan for continued progress in Rehabilitation Engineering.

Twelve workshops were held (see Table I) and on May 12-13, 1977, the chairmen of the workshops and other leaders in the field met in Washington, D.C., to help develop the overall report. This document is that report.

TABLE I
STATE OF THE ART WORKSHOPS IN REHABILITATION ENGINEERING

	TITLE AND LOCATION	*DATES*	*CHAIRMEN*
*1.	The Role of Engineering in Spinal Cord Injury Castle Point, NY	May 3-5 1973	Frank Clippinger
*2.	Mobility for Spinal Cord Impaired People Downey, CA	Feb. 22-24 1974	Maurice LeBlanc James Reswick
3.	Functional Electrical Stimulation-Application in Neural Prostheses Pomona, CA	May 17-19 1976	Terry Hambrecht James Reswick
4.	Personal Licensed Vehicles for the Disabled Washington, D.C.	June 14-17 1976	J. Raymond Pearson Richard M. Herman
5.	Rehabilitation Engineering Education Knoxville, TN	Nov. 3-5 1976	Robert E. Tooms Colin McLaurin
6.	Locomotion and the Clinical Analysis of Gait Philadelphia, PA	Dec. 6-8 1976	A. Bennet Wilson Uroz Stanic
7.	Delivery of Rehabilitation Engineering Services in the State of California Pomona, CA	Jan. 16-18 1977	Herbert Leibowitz Gordon Cummings James Reswick
8.	Environmental Barriers and the Physically Disabled Witchita, KS	Feb. 6-8 1977	Pamela Cluff Thomas Moses
9.	Total Joint Replacement Chicago, IL	Mar. 3-5 1977	Clinton Compere
10.	Sensory Deficits and Sensory Aids San Francisco, CA	Mar. 23-25 1977	Lawrence Scadden Carl E. Sherrick Howard Freiberger
11.	The Effects of Pressure on Human Tissue Carville, LA	Mar. 24-26 1977	Paul Brand Vert Mooney William Spencer
12.	External Prosthetics and Orthotics Miami, FL	Apr. 1-3 1977	Newton McCullough Raplh R. Snell
13.	Summary Meeting National Academy of Sciences Washington, D.C.	May 12-13 1977	Colin McLaurin

* Workshops organized and reports published by CPRD

MAGNITUDE OF THE PROBLEM

At the present time, precise estimates of the number of disabled persons are not available. There are sources, however, that provide sufficient information to estimate the magnitude of the disability problems which can be used in determining future research and other program activities. This information must not be regarded as reflecting official Rehabilitation Services Administration policy or as an exhaustive study of the incidence and prevalence of disability in the United States.

The data was obtained primarily from the following: The National Center for Health Statistics (NCHS) series on disability; a paper prepared by Dr. E.E. Harris, Dr. Gustav F. Haas, and Mr. Peter J. Nelson in March 1975 for Dr. Frank W. Clippinger, Jr., Chairman of the Committee on Prosthetics Research and Development, NAS; information from disability associations; and, especially, expert estimates from the series of state of the art workshops on Rehabilitation Engineering conducted primarily during 1975-77 as listed in Table I. International studies in the United Kingdom and Denmark were also used to verify U.S. data. The information base is mostly from 1966 through 1972, since the major portion of the original data was generated then.

The data for Table II is synthesized from the report, "Prevalence of Selected Impairments," NCHS, series 12, number 99. Information for the report came from a survey of approximately 46,000 households with roughly 134,000 occupants. The survey was conducted by the U.S. Bureau of the Census under specifications established by NCHS.

The population covered by the sample for the Health Interview Survey is the civilian, noninstitutionalized populations of the United States living in the U.S. at the time of the interview. A more detailed description is included in the appendix of NCHS, series 10, number 99.

Participants in the Health Interview Survey were questioned to determine the nature and extent (if any) of a limitation. The National Center for Health Statistics classified the severity of limitation as follows:

Chronic Activity Limitation

Persons were classified into four categories according to the extent to which their activities were limited at the time as a result of chronic conditions. Since the usual activities of preschool children, school-age children, housewives, workers, and other persons differ, a different set of criteria was used for each group. There were general similarities among them, however, as will be seen in the following descriptions of the four categories:

1. Persons unable to carry on major activity for their group (major activity refers to ability to work, keep house, or engage in school or pre-school activities). Preschool children: Inability to take part in ordinary play with other children. School-age children: Inability to go to school. Housewives: Inability to do any housework. Workers and all other persons: Inability to work at a job or business.
2. Persons limited in amount or kind of major activity performed (major activity refers to ability to work, keep house, or engage in school or preschool activities). Preschool children: Limited in amount or kind of play with other children, e.g., need special rest periods, cannot play strenuous games, or cannot play for long periods at a time. School-age children: Limited to certain types of schools or in school attendance, e.g., need special schools, special teaching, cannot go to school full time or for long periods at a time. Housewives: Limited in amount or kind of housework, e.g., cannot lift children, wash or iron, or do housework for long periods at a time. Workers and all other persons: Limited in amount or kind of work, e.g., need special working aids or special rest periods, or cannot do strenuous work.
3. Persons not limited in major activity but otherwise limited (major activity refers to ability to work, keep house, or engage in school or preschool activities). Preschool children: Not classified in this category. School-age children: Not limited in going to school but limited in participation in athletics or other extra-curricular activities. Housewives: Not limited in housework but limited in other activities such as church, clubs, hobbies, civic projects, or shopping. Workers and all other persons: Not limited in regular work activities but limited in other activities such as church, clubs, hobbies, civic projects, sports, or games.
4. Persons not limited in activities (includes persons whose activities are not limited in any of the ways described above).

A more complete description of the definitions can also be obtained from appendix 2 of NCHS series 10, number 99.

To simplify presentation, Table II shows the total population estimates (all 4 categories of limitation) and the estimates of population limited in activity due to that condition (total of categories 1-3). As shown in Table II, most people are judged by the survey to have a disability without an accompanying activity limitation.

It is interesting to note that the United Kingdom statistics on patients with locomotion difficulties, reported by Dr. E. E. Harris in 1975, compare quite favorable, when adjusted, to the population base of disabled reported in National Center for Health Statistics reports.

In addition to data shown in Table II, several sources have estimates of disability groups and rehabilitation device users that are not divided by age or severity of handicap. A listing of this data by source follows:

Disability Groups and Rehabilitation Device Users

Muscular Dystrophy—Reports are not very definitive in this area because of the difficulties of diagnosis, but the National Institute of Neurological and Communicative Disorders and Stroke (N.I.N.C.D.S.) estimates are 200,000 (N.I.N.C.D.S. publication no. 77-944 page 1, 1976).

Amputations—The workshop on the Effects of Pressure on Human Tissue reports an incidence of 0.5 per 1,000 with a total estimated population of 500,000.

Spina Bifida—The workshop on the Effects of Pressure on Human Tissue reports 30,000 spina bidifa cases in the U.S.

Multiple Sclerosis—The National Multiple Sclerosis Society estimates are 500,000.

Peripheral Neuropathy—The workshop on the Effects of Pressure on Human Tissue reports 2,500 leprosy cases in the U.S. NCHS report no. 80 Series 10, 1969-70 estimates the total diabetic population to be 5,000,000. Of this group 1,000,000 have diabetes leading to insensitivity of tissue.

Neurological Epilepsy—The NINCDS reports an incidence between 1 and 2%. The total population is estimated to be 2,500,000 which includes 157,300 children under 14.

Braille Use—At the workshop on Sensory Deficits and Sensory Aids, Louis Goldish reported the following: 60,000 persons have been instructed in its use; 40,000 persons can read braille; and 13,000 persons find it almost a necessity (9,000 students and 4,000 employed).

George Magers, Acting Director, Office of the Blind and Visually Handicapped, RSA, stated that several sources, such as the Association of Blind Secretaries and the Rehabilitation Teachers Association, estimate that 100,000 persons use braille to some extent, from keeping track of poker scores or telephone numbers to extensive use in their work.

Cystic Fibrosis—The Cystic Fibrosis patient data registry of 1975 lists 11,000 patients. Studies in New Jersey and Delaware show that only 1/3 of the people with cystic fibrosis are on the registry, therefore the total estimated population is 30,000 with only 25% over the age of 15. Incidence is 1 per 1,500 births. Due to better medical techniques the population has increased 6 times in the last 10 years and patients now have a 50% chance of reaching the age of 18.

Cerebral Palsy—United Cerebral Palsy, Government Activities Office, Washington, D.C. reports a total population of 750,000 with 250,000 under 21 years old. Four per 1,000 population have one or more symptoms of cerebral palsy. There are 1 per 200 live births and 15,000 births yearly.

Dr. Leon Sternfeld, Medical Director of United Cerebral Palsy, New York, reports an incidence of 3 per 1,000 live births, and 2,500 cases per year acquired between the ages of 28 days and 3 years. The prevalence is 3.5 per 1,000 of which 78% is congenitally acquired for a total population of 700,000. It is estimated that 1/3 of this population are wheelchair users.

Spinal Cord Discontinuity—Paul Thomas, project manager, Medical Research Studies, RSA reports 125 to 150,000 cases with 8 to 10,000 new cases per year. The April 1973 edition of Rehabilitation Record reports 1000 cases with injury at C4 or above, with 300 new cases per year, 1/3 of whom have respiratory involvement.

Miscellaneous Categories—NCHS series 10, no. 80 reports the following: heart conditions—3,609,000; mental and nervous conditions—1,033,000; arthritis and rheumatism 3,265,000; emphysema —566,000.

Total—The total number of disabled persons in all the above categories is 8,987,500—approximately 4 percent of the total U.S. population.

Note: The information on the disabled population was prepared by Richard R. LeClair and Mark

I. Bresler of the Rehabilitation Services Administration. The bibliography may be found in Appendix D.

Target Population

The term target population refers to the identifiable disability groups who could be helped by the Rehabilitation Engineering efforts. In many of the workshops an attempt was made to indicate types of patients, numbers, and future trends. The degree of disability and the benefit that might be expected are also factors considered. The following paragraphs summarize the information contained in the workshop reports.

One of the areas where Rehabilitation Engineering can be most effective is with spinal cord injured patients. This includes 40,000 quadraplegics, over 100,000 paraplegics and 30,000 spina bifida patients. Fortunately, the use of amniocentesis can be expected to reduce the incidence of spina bifida in the future. The number of quadraplegics is rapidly growing, but the benefits possible through technology are many. Such benefits often mean the difference between working, or not working, having a full time attendant or part time attendant, having a rewarding life or a wretched life. For the paraplegics the benefits are less dramatic but still significant in increasing mobility and decreasing "down time" due to pressure sores.

It has been estimated that there are about 700,000 wheelchair users which include victims of stroke, arthritis, spinal cord injury, and others. Improvements in wheelchair design, both powered and hand propelled, can thus benefit nearly 3/4 million persons to some degree.

The number of personal licensed vehicles for the disabled is also on the increase—cars with hand controls, vans with lifts, etc. There are now 124,000 users of hand controls with a potential of twice that number. For these people, being able to drive is perhaps the greatest expression of freedom and often the most economical and practical way for going to work. The Rehabilitation Engineering effort in this area is directed towards safer controls and more accessible vehicles through cooperation with the automotive and allied industries.

Another form of mobility is walking with or without aids. The studies on locomotion and clinical analysis of gait are directed toward more efficient walking and better diagnostic and treatment procedures. This can affect 4 million persons with physical disabilities resulting from a large number of causes. The main thrust here is providing clinicians with measuring techniques and know-how to allow them to better understand and cope with clinical problems. The results can be shorter treatment time and/or improved mobility.

Functional Electrical Stimulation can also have a significant effect on mobility, as well as improving arm and hand function and sitting posture. The studies here can affect a large number of persons, particularly stroke victims who number in the millions. At the present time, the system is expensive and a great deal more research and development is needed before significant results can be expected. In the future it does promise profound possibilities in the restoration of function of those with neuromuscular deficits.

Brain damage and cerebral palsy are examples of neuromuscular disorders that present difficult and complex problems in the hundreds of thousands. Seating, communication aids, and mobility devices and customized work stations can contribute greatly to the productivity and well being of persons so afflicted.

In 1976, 120,000 persons received implanted artificial joints, usually the hip joint. This practice has made a tremendous difference in arthritic patients—often the difference between a useful life or a helpless, painful life. Rehabilitation Engineering efforts in this area are directed toward improving the design of the joints and in the determination of the causes of failure. This could save up to $100 million per year, thus showing a remarkable cost benefit.

The number of amputees requiring external prostheses remains at about 500,000; most of them are the elderly with legs amputated due to inadequate circulation. For these people, safer, easier walking is the expected result of research. Recent developments reduce the weight of a limb to about half, and this alone could reduce the energy requirements for walking—an important factor for geriatrics.

The number of brace wearers is not accurately known but is often estimated as ten times the number of amputees. Research in this area could lead to greater mobility, comfort, and improved appearance.

The work on the effect of pressure on tissue could apply to spinal cord patients, amputees, brace wearers, and others. An obvious objective is the prevention of pressure sores which cost

$400,000,000 each year in addition to the personal suffering involved. This work also has tremendous implication in foot problems which affect up to half the population in long term foot deformation due to ill-fitting shoes.

Over 6 million persons have visual impairment requiring more than ordinary glasses. The technical advances, particularly in reading machines, promises future benefits and productivity for a large number in this group. It is interesting to note that less than 30% of the blind of working age are in the labor force, compared to 70% for the sighted of working age. Over 6 million persons have significant bilateral deafness, and these, including the profoundly deaf can hope to benefit from improved hearing aids and tactile feedback displays.

The blind and the deaf, along with wheelchair users and others with physical limitations can also benefit from architectural design and public transport that are barrier free, and from a society whose attitude is barrier free.

In summation, there are several million persons whose life values and productivity could be significantly changed by the Rehabilitation Engineering Program described in this report. For hundreds of thousands of these persons the benefit could be profound and in some small way, particularly with respect to footwear, the effect could reach half the population of the U.S.

TABLE II

Number of Disabled People by Selected Types of Impairment and Age

(In Thousands)

	1	2	3	4	5	6	7	8
	Total	Under 17	17-44	Under 45	45-64	65 & Older	65-74	75 & Older
U.S. Population 1971	202,360	66,544	74,703	141,247	41,764	19,349	12,044	7,305
Blind and Visually Handicapped (all degrees of disability)	9,596	623	2,385	3,008	2,630	3,958	-	-
Blind and Visually Handicapped (causing limitation in activity)	495	-	-	54	99	342	-	-
Hearing Impairments (all degrees of disability)	14,491	863	3,167	4,030	4,765	5,695	2,783	2,912
Hearing Impairments (causing limitation in activity)	573	93	155	248	147	176	76	100
Speech Difficulty (all degrees of disability)	1,934	995	505	1,500	268	165	-	-
Speech Difficulty (causing limitation in activity)	188	57	29	86	54	46	-	-
Paralysis (all degrees of disability)	1,392	158	342	500	446	446	-	-
Paralysis (causing limitation in activity)	861	100	198	298	285	277	-	-
Absence of Major Extremity	274	-	-	70	127	77	-	-
Impairment of Back or Spine (all degrees of disabililty)	8,018	210	3,662	2,872	2,847	1,298	824	474
Impairment of Back and Spine (causing limitation in activity)	1,,976	55	857	912	776	288	189	99
Impairment of Upper Extremity and Shoulder, except paralysis or absence (all degrees of disability)	2,440	120	886	1,006	855	578	-	-
Impairment of Upper Extremity and Shoulder, except paralysis or absence (causing limitation in activity)	485	26	220	246	186	52	-	-
Impairment of Lower Extremity and Hip, except paralysis or absence (all degrees of disability)	7,387	1,281	2,544	3,825	2,017	1,544	853	691
Impairment of Lower Extremity and Hip except paralysis or absence (causing limitation in activity)	1,727	141	481	622	560	543	237	306

Note 1. Column 1 yields two totals: 45,532,000 disabled (all degrees of disability) and 6,579,000 disabled causing limitation in activity. This latter figure, approximately 3% of the total population, can be used as an estimate of those needing rehabilitation engineering services.

2. All data in this table were synthesized from the National Center for Health Statistics series on disability-Series 10, Number 99, Tables 1, 2, 4, 5, 7, 9, 10, 11, and 13.

3. The total listed in column 1 may not equal the sum of items in columns 4, 5 and 6 due to rounding effects.

STATE OF THE ART

It is difficult to be definitive about the state of the art for a profession so widely diverse as Rehabilitation Engineering—from wheelchairs to spinal monitoring or from house modifications to reading machines for the blind. Some areas are mature, based on long experience of service; some are developing; and some are barely past the conceptual stage.

Prosthetics and Orthotics are established professions, and as such are at levels of competence that, in spite of advancing technology, are rising at moderate rates. Most services are provided by small shops using components purchased from manufacturers. Pneumatic and hydraulic knee controls are in regular use and endo-skeletal prostheses with foam covers are becoming common. Externally powered upper limb prostheses have not made a significant impact although a number of myo-electric below elbow arms are in everyday use. Most arm amputees can manage very well with one good arm and hence desire a light weight comfortable cosmetic arm, with functional requirements a secondary consideration. Recent developments with vacuum formed polypropylene have produced below knee prostheses weighing only half as much as conventional and this may set a new trend for all levels of amputation. Central fabrication has been growing in the prosthetic industry and this will probably be enhanced with new studies in adjustable and standard size sockets which become more significant in view of the acute shortage of trained prosthetists.

Orthotics practice is not as well developed as prosthetics. Conventional metal lower limb orthoses are still in use, although polypropylene ankle foot orthoses are used extensively. Plastic is becoming more common in other types, particularly shoe inserts and spinal orthoses. Thus improvements have been largely in materials and fabrication procedures resulting in lighter weight more cosmetic devices. Better methods for prescription are also leading to a better understanding of the practice of orthotics and to the establishment of principles for prescription and design.

Closely related to this concept is the recent endeavor to introduce gait analysis into the clinical scene. This is now in practice in several rehabilitation centers where measuring systems and techniques are being evaluated and prepared for general use. This will result in better diagnostic and assessment procedures and more informed understanding of the musculo-skeletal problems. Another advantage from standard methods of gait analysis is that it will make it possible to compare results from various centers in the United States and abroad.

Studies on the effect of pressure on tissue can lead to improvements in the design and fitting of prostheses, orthoses, footwear, beds, and seating. Footwear has been a long neglected area where a modest effort could yield large scale results. Although the physiology of decubitus ulcers is not well understood, practical techniques for prevention have been developed. These include many commercially available beds and seat cushions which, although not thoroughly evaluated, can contribute to appropriate care. Systems for evaluating patients and seating have been developed at Rancho Los Amigos and The Texas Institute for Rehabilitation and Research.

One of the most successful endeavors in coping with pressure on tissue has been the introduction of plastazote vacuum formed shoes developed in Britain. These shoes have been instrumental in avoiding amputation in many cases of diabetes. Rocker shoes developed at the U.S. Public Health Services, Carville, La., have been successful with leprosy patients and probably have a much broader application. However, generally speaking the state of the art in special footwear falls far behind other areas of orthotics.

Tissue mechanics also extend to internal prostheses and joint replacement. The replacement of joints is now an effective and common procedure, especially for the hip, with over 120,000 patients so treated each year. However, joints other than hip still present very real problems and research at Northwestern University and other centers is continuing. Closely associated with this work is the possibility of anchoring external prostheses directly to the bone. In addition to bone fixation, problems associated with percutaneous structural members are presented. Work in this area continues at a low key and as yet no practical applications have been achieved.

The functional electrical stimulation of paralyzed muscles holds much promise for the rehabilitation of many disabilities due to stroke, spinal cord injury, scoliosis, etc. Although the electronic aspect of this procedure seems well within current technology, widespread acceptance has not occurred, probably due to questionable cost/ benefit ratios at this stage of development. Some progress is being made in specific applications such as the prevention of drop foot in stroke, the correction of scoliosis, and upper limb function for quadraplegia. Successful applications include both surface electrodes and implanted systems.

Surgical implants may also have application in the restoration of sensory deficits, but as yet none have gone beyond the stage of initial exploration. Existing aids for the blind such as the Telesensory Systems Inc. Optacon and Mauch Stereotoner are serving as reading aids while the Kurzweil Reading Machine with optical character recognition and speech output is being evaluated. In spite of these advances braille is still in use with some new developments in its storage and retrieval.

Major emphasis for the deaf is on hearing aids including speech analyzing systems (still in the experimental stage) for the profoundly deaf. Several telecommunication aids are available but not generally accepted except for the teletypewriter. Aids for the deaf blind have not progressed extensively beyond alarm and paging systems, but work in tactile displays may lead to effective communication in the future.

For those with proprioceptive loss due to stroke, cord injury or amputation, systems for indicating limb position are under development using auditory, visual, or cutaneous displays. Direct nerve stimulation with implanted electrodes has also been suggested.

Considerable progress has also been made in a large variety of aids to rehabilitation and daily living. For the spinal cord patient these include virtually every phase of the rehabilitation program from accident pickup, acute care, and recovery through to eventual employment. Although many of the existing devices and techniques have not reached general use due to lack of information, funding, and available services, the extent to which Rehabilitation Engineering can have an effective role is growing rapidly.

Perhaps the most generally recognized area for effectiveness is in mobility. Although this does include ambulation with orthoses, crutches and other aids, the wheelchair remains the major means of mobility for nearly 3/4 million persons. Although few advances have been made in hand propelled chairs, many new types of battery powered chairs are appearing. Many of these have been developed through private industry but others such as the Prahn from UCB are the result of federal funding. The net result is greater mobility indoors and out for severely handicapped individuals, with even the highest level quadraplegics able to operate their chairs through sip and puff and other sophisticated controls.

Mobility is further extended by vans modified with lifts and special controls so that quadraplegics can enter and operate their own vehicles. Meanwhile, government efforts, particularly through the Veterans Administration are developing standards for hand controls and working with industry to improve safety and availability of driving aids.

The wheelchair and the automobile are both serving to allow the disabled person access to the community at large and in particular to vocational possibilities. Public transport still has a long way to go before buses, trains, subways and aircraft can accommodate the disabled. Although new installations following recommended standards may be designed with the handicapped in mind, the refurbishing of older buildings and systems is often prohibitive. Mobility innovations such as stair climbing wheelchairs may help overcome some of these barriers. Once on location, other innovations may also assist the disabled in adjusting to work or school situations. The design of special desks and job-site modifications is more and more becoming a major role for Rehabilitation Engineering, a role where individual service is more important than the availability of devices.

With the exception of the more established aspects of Rehabilitation Engineering, such as prosthetics and orthotics, the service arm of Rehabilitation Engineering is sadly lacking. There are many reasons for this and suggestions for overcoming the problem appear elsewhere in this report. These include training programs for rehabilitation engineers, pilot systems for service delivery, and methods for information exchange.

Any statement on the state of the art must include the increasing awareness of the public and their changing attitudes as reflected in recent federal studies and legislation, and most important of all, the explosive self-fulfillment of disabled persons exemplified by efforts such as the Center for Independent Living in Berkeley, California. Nowhere is success in rehabilitation more apparent than when the disabled persons themselves take the initiative in attaining their rightful place in our society. To this end, virtually all phases of activity from research to legislation advocate strong consumer input to insure a correct emphasis on priorities and a real understanding of the human requirements.

KNOWLEDGE GAPS & RECOMMENDED RESEARCH

Perhaps the greatest knowledge gap is the access to knowledge itself. At all levels from recipients to researchers there has been a universal demand for a national system for the collection and dissemination of information. Reccomendations to this effect are included in this report in the section on National Organization.

Throughout the workshop series specific knowledge gaps have been identified which, if filled, could allow greater progress in many areas. The details are listed in the workshop summaries and more fully in the reports themselves. Most of the knowledge gaps fall in the area of physiology and biomechanics. Much more needs to be known about nerve and muscle stimulation, about monitoring the electrical activity in the spinal cord, and about the force and energy implications in electromyography. Closely related to this fundamental knowledge are the tactile display parameters which lend themselves to sensory aids for the deaf, the blind, and those lacking touch and proprioception.

There is also a need for more information on tissue mechanics, whether it concerns attaching artificial joints to bone, or the necrosis of soft tissue from sitting, lying in bed, or wearing a prosthesis. To this end there is a major need for an instrument to measure shear forces in soft tissue. Studies of the visco-elastic properties of normal and pathological tissues, (both on the foot and other weight bearing areas) should be included. The physiology of tissue surrounding percutaneous mechanical and electrical connectors also requires investigation.

Biomechanical studies are also needed to determine forces and motions at major joints to provide data for the design of implanted artificial joints. Anthropomorphic data is also required for the design of these joints and for the design of footwear.

Closely related to this are human factor data such as dimensions, ranges of motion, reach, etc., for all types of disabled, for use in the design of vehicles, work sites, household aids, and in the design of a barrier-free environment in the home, work place, and community. To this end, more information is needed concerning the life styles, goals, attitudes, and motivation for all disabilities including the deaf, the blind, and the aged.

There are knowledge gaps in the area of transportation. Guidelines are needed for the manufacture of personal licensed vehicles and modifications to vehicles. A standard means for securing wheelchairs in private and public vehicles is required. The effect of modified driving mechanisms on vehicle control needs study.

In addition to these specific human and technical knowledge gaps there is one major area where very little is known and that is in cost/benefit data as it relates to Rehabilitation Engineering. Although the philosophy of rehabilitation extends beyond financial considerations, factual cost/benefit information is greatly needed to evaluate existing programs and in planning future activities.

Based partly on the knowledge gaps and partly on examination of patient needs, most of the workshops recommended areas for research and development during the next several years. These are listed under the headings Basic Research, and Devices and Techniques.

Basic Research

Concerning Activities of the Blind:

Study persons who are high performance braille readers and apply this knowledge in teaching others.
Investigate means for improving conceptual development in blind children.
Develop a comprehensive theory of the mobility process of the blind pedestrian.

Concerning Sensory Stimulation Substitutes:

Investigate the encoding/decoding process of the human nervous system.
Conduct studies pertaining to cutaneous sense characteristics.
Investigate sensory feedback as a training and functional aid for the physically disabled.

Concerning the Electrical Stimulation of Paralyzed Muscle:

Study the causes and prevention of tissue damage from implanted electrodes.
Study the mechanism of muscle fatigue.
Determine optimum electrical and electrode characteristics.
Study the biocybernetic considerations in the controlled stimulation of muscle fibers and nerves.
Study the effect of electrical stimulation on spasticity.
Study the carry-over effects of electrical stimulation.

Study the effects of electrical stimulation on the central nervous system.
Investigate alternate methods of stimulation—tactile, thermal, etc.

Concerning Tissue Mechanics:

Investigate the significance of temperature profiles (thermography, etc).
Study the effect on tissue of static and dynamic loading, including shear forces.
Study the effect of tissue depth and composition in resisting static and dynamic loading.
Investigate inter-cellular factors.
Investigate metabolic factors and nutrition.
Study the significance of neurotrophic conditions.
Investigate the role of lymphatic clearances.
Investigate neuro-endocrine effects.
Investigate aging factors.
Investigate psychological considerations.
Study the biomechanics of scar tissue.

Concerning Biomechanics:

Determine the forces and motion patterns (including ADL) in normal joints and joints with implants.
Develop methods for the structural analysis of implants and joints.
Investigate materials for implants.
Develop better methods for measuring energy costs of physical activity.
Conduct workshops to establish standards for obtaining and reporting biomechanical data.
Study the effect of weight and weight distribution in Prosthetics.

Concerning Surgical Procedures:

Develop methods for monitoring spinal activity.
Develop improved methods for spinal stabilization following trauma.
Determine the causes of failure in joint implants.
Continue investigations into direct skeletal attachment for external prostheses.
Investigate osteotomy procedures in upper limb amputees to improve suspension and control.

Devices and Techniques

In the workshop series, many items were identified as needed devices and techniques requiring research and development.

They are listed below in specific categories. These should be considered as major examples and not a complete list.

Accident Pickup

Rescue and extricating apparatus.
Spinal support systems for use in transit.
Monitoring and communication equipment for use at the scene and in transit.
System design for all rescue and transit apparatus.

Mobility Needs

(*Note:* Further information on wheelchairs will be published in a report on a Wheelchair Conference held in Washington, D.C., Dec. 6-9, 1977, obtainable from the Rehabilitation Engineering Center at Philadelphia.)
Transfer methods in home and in public.
Improved wheelchairs—better durability, less weight and bulk.
Wheelchairs suitable for use in a van.
Powered wheelchairs with better performance, transportability, and control.
Wheelchair securement system for use in vans and public transit.
Standards and prescription criteria for hand controls, door openings, seat adjustments, etc., for automobiles. Investigation into the modular concept (compatability) in mobility systems.
Means for removing or overcoming architectural barriers.

Home and Work Aids

Environmental control systems using micro-computers.
Devices for eating, reading, etc.
Manipulators or robot arms, possibly wheel-chair mounted, for severely disabled.
Beds and seating to allow change in position and avoid pressure sores.

Aids for the Blind

Smaller, lighter, weatherproof mobility aids.
New concepts for the next generation of mobility aids for the blind and deaf-blind.
Medical aids for use by the blind.
ADL, recreational, educational, and occupational aids for the young and old with visual problems.
Less expensive, more attractive devices for low vision problems.
Faster, quieter braille writers.
Continued development of reading machines.
Improved quality of synthetic speech.

Aids for the Deaf

Speech analyzing hearing aids with special preprocessing capabilities.
Improved hearing test procedures and test batteries for diagnosis and prescription.
Development of a device to process environmental sounds, other than speech, to enable their identification by the deaf.
Development of an adjunctive device to supplement lip reading or residual hearing.

Upper Limb Prosthetics

Improved body powered mechanical hand.
Improved elbow joints, including joints for endo-skeletal prostheses.
Multifunctional control system for above elbow, shoulder disarticulation, and forequarter amputations.
Frame type socket for shoulder disarticulation and forequarter amputations.
Lighter weight prostheses, possibly using polypropylene.
Improved harnessing and power transmission system.
Hybrid body and external power systems.
External power systems with sensory feedback.
Improved function in prostheses for high bilateral amputees.
Cosmetic prostheses to improve the body image for unilateral amputees.

Lower Limb Prosthetics

Adjustable sockets.
Artificial foot studies (improved SACH).
Improved joints for hip disarticulation and hemipelvectomy prostheses.
Improved knee joints.
Prostheses that can be adjusted in alignment by the amputee or remotely by a prosthetist.
Feedback and other training procedures for above knee amputees.
Voluntary control knee systems.
Survey of P.T.B. modifications.

Upper Limb Orthotics

Study of prehension patterns of quadraplegics.
Neuro-electric control systems for quadraplegics.
Hybrid systems (external powered and body powered functional arm orthoses.
Sensory control for flail arms in ambulatory patients.
Orthoses for C-6 level quadraplegics.

Lower Limb Orthotics

Improved joints—especially knee joints.
Joint systems to control spasticity.
Shoes as part of the orthotic system.

Spinal Orthotics

Means for distracting the spine and immobilizing the head without skull pins.
Orthoses for immobilization of the upper thoracic spine.
Semi-flexible lumbar support.
Improved means for pelvic fixation.
Improved corset supports.
Orthoses to correct scoliosis.
Kyphotic orthoses for the elderly with pain.
Improved orthoses for scoliosis in infants.
Improved design and materials for asensory patients.

EVALUATION

From the established Rehabilitation Engineering Centers, and the projects funded by the Rehabilitation Services Administration and the Veterans Administration, from private industry, and from research and development in other countries, new products, new devices and new techniques are appearing on the rehabilitation scene. Some of these are relatively simple and inexpensive items; others, although expensive and complex, may have profound effect on the lives of thousands of individuals. In all cases, in order to determine the safety, the effectiveness, the durability and recommended application, some type of testing or evaluation is indicated. This usually takes the form of laboratory testing or clinical evaluation or both. The laboratory testing is carried out to determine such things as strength and durability and to verify specifications and technical performance. The clinical evaluation is carried out to determine the performance, suitability, acceptability and durability for specific patient applications. Typically, this is conducted first with small numbers and then, if satisfactory, larger scale field evaluation will be carried out at several centers.

Evaluation is usually conducted independently from, but in cooperation with, the developers so that improvements can be made. Evaluation results usually include prescription criteria, indicating for whom it might be expected to be useful and for what purposes. Before an item actually enters the mainstream of rehabilitation, manufacturing and distributing will be involved or, in the case of techniques such as fitting procedures, the method must be taught through journal articles, lectures, short courses or school curriculum.

The process of evaluaton is often lengthy and expensive. The Committee on Prosthetics Research and Development of the National Academy of Sciences, through its Sub-committee on Evaluation and its staff, performed a coordinating function in the evaluation of prosthetic and orthotic devices, and in later years in other aspects of Rehabilitation Engineering. Such a national coordinating body is very much needed for a comprehensive evaluation program to ensure the proper and effective use of new devices and techniques as they are produced. The costs of evaluation are considerable for the purchase of test items, contracting for specific testing, for supplemental funding in clinical facilities, for coordinating the programs, and for publishing the results. The concern of the Federal Drug Administration and recent trends in legal suits give added urgency to the establishment of adequate evaluation programs.

One general area requiring evaluation is the cost effectiveness of the various aspects of Rehabilitation Engineering. The recommendations expressed in this report represent either directly or indirectly tremendous financial considerations, and the cost/benefit control of the process as a whole establishes a further reason for a national administrative and coordinating organization as proposed later in this report. This particularly applies to the delivery of services and should be included in any pilot programs that are established for that purpose.

A number of items have been identified as being ready for evaluation as follows:

Mobility Aids

Wheelchairs—Many models and makes are available and other than at the Veterans Administration Prosthetics Center little testing has been done in comparative evaluation or in determining prescription criteria.
Hand controls—Clinical studies are needed to augment Veterans Administration investigations.
Vehicles (cars, vans etc.)—Data is needed on the suitability of various models and makes.
Van lifts and controls—Clinical studies are needed to augment Veterans Administration investigations.
Driver Simulators—Studies are needed to determine their effectiveness for instructing various disability groups.

Sensory Aids

Sonar cane (Mowat Development, Ltd.)
Hearing aids having moderate bandwidth compression
Mowat sensor (Mowat Developments, Ltd.)
Nottingham obstacle detector
ELINFA portable braille recorder
Kurzweil reading machine
Upton eyeglass aids

Prosthetics

Adjustable above knee sockets (Rancho Los Amigos)

Polypropylene below knee prostheses (Moss)
Above elbow osteomy (Marquart)

Locomotion and Clinical Gait

Gait Analyser (Rancho Los Amigos)
Limb Load Monitor (Moss)

Tissue Mechanics

Seat Cushions (many commercial models)
Seating system (Rogers—Rancho Los Amigos)
Dynamic roller seat (Kosiak)
Mattress systems (several commercial models)
Pressure measuring pad (Texas Institute for Rehabilitation and Research)
Rigid sole rocker shoe (Carville)
Laser-doppler blood flow meter (University of Washington)
Low pressure support beds and turning beds (several commercial models)

Activities of Daily Living

Environmental Aids and Controls
(Prentke Romich)
(Veterans Administration)
(Fidelity)
Page Turners (several commercial models)

Functional Electrical Stimulation

Therapeutic (including biofeedback systems) devices and techniques for lower and upper extremity management in stroke
Pain control devices
Bladder evacuation and incontinence control systems
Cerebellar stimulation—(these devices are used extensively in some centers); extensive evaluation, undoubtedly costly, is needed to determine the effectiveness of the procedure, who might benefit, and adverse effects if any.

EDUCATION AND INFORMATION TRANSFER

Throughout the various centers and projects, many procedures, techniques, and devices have proven useful. The information concerning the application of these items must now be made available to clinicians and others in order to fully utilize the results of research and development.

Knowledge transfer can take many forms: personal contacts, reports, publications, films, slides, video tapes, seminars, short courses, additions to teaching curriculum, and complete teaching or training programs. A specific example of the latter is the recommendation for pilot courses for rehabilitation engineers. Details of these pilot courses can be found in the report of the workshop entitled "Rehabilitation Engineering Education" which is summarized in appendix A. The suggested program should train 25 rehabilitation engineers per year over a 3 year period and the graduates, following an internship, would be qualified engineers capable of accepting responsibility for the technical aspects of patient care either in rehabilitation facilities or in private practice. It was recommended that the trainees could be either graduate engineers who would be trained in rehabilitation procedures or health professionals such as therapists, prosthetists, and orthotists who would be trained in basic engineering. The creation of a number of rehabilitation engineers was considered to be essential in developing a service program for the many and varied devices and techniques used in the physical restoration of the disabled and to enhance functional performance at home and at work. Estimates of the total number of rehabilitation engineers varied widely but it was believed that placement of the 75 graduates of the pilot program would indicate the rate at which this new profession could be assimilated.

In addition to the training program for rehabilitation engineers, specific recommendations were made for short term instructional courses and additions to training programs. These can be summarized as follows:

1. Re-examine the information presented in formal prosthetic and orthotic programs and revise as required.
2. Encourage the American Academy of Orthotists and Prothetists to expand its role in continuing education.
3. Strengthen the education of general and vascular surgeons in the techniques of immediate post operative and early fitting of prostheses.
4. Introduce special short term courses and workshops in total joint replacement for resident and practicing surgeons, for bioengineers, and for other medical personnel.
5. Introduce into orthopedic residency programs instruction in clinical gait analysis and locomotion.
6. Strengthen the training for opthalmologists and optometrists in low vision diagnosis, prescription and management.
7. Cross disciplinary training of researchers as sensory specialists is needed, with post-graduate experience in fertile surroundings.
8. Training for rehabilitation engineers should include knowledge and experience in methods for employing the severely disabled in the mainstream industries and in newly developing employment systems. Rehabilitation engineers should also become employees of industry and, as such, support and provide methods for employing the disabled.
9. In the area of functional electrical stimulation, encourage training of scientists, at the professional level, in bio-materials, especially polymer insulation materials.
10. Develop standards for driver education and training programs and implement education for all members of the service team.
11. Provide reading rooms in OVR offices for use by recipients.
12. Form groups of institutions concerned with particular problems of the disabled, together with a cadre of investigators, which interested professionals could visit for extended periods.

To some degree, individual centers and projects can be held responsible for the publication of reports and manuals, the development of teaching material, and the dissemination of pertinent information. In addition to this, there is an often stated need for a central or national information center to collect and make available information to all interested parties including recipients, researchers, counsellors, physicians, therapists, nurses, engineers, prosthetists, orthotists and manufacturers. Recommendations to this effect are included in the section on National Organization. Specific requests for information include the following:

1. Information on personal licensed vehicles for researchers, administrators and clinicians.

2. Information on housing designs and alterations for the disabled.
3. Information on the availability of rehabilitation engineering services for use by recipients, rehabilitation staff, counsellors, and third party representatives.
4. A handbook on biomaterials for use by researchers in functional electrical stimulation and others.
5. A listing of locomotion laboratories with available resources and services.

Throughout the various workshops it was often expressed that the disabled themselves must play an active role in all aspects of the rehabilitation process. Thus, in addition to making information available, there is a need for an explicit program to educate the disabled public in Rehabilitation Engineering so that they can eventually participate actively and frequently in the leadership of this activity.

THE DELIVERY OF REHABILITATION ENGINEERING SERVICES

During the past several years, considerable emphasis has been placed on research and development with the result that many new and promising aids and techniques have appeared on the scene. At the same time, through the Rehabilitation Act of 1973 and subsequent revisions, public interest and government responsibility has been directed toward the rehabilitation of the physically disabled through access to public transportation, schooling and vocational pursuits. Unfortunately, no similar emphasis has been directed toward the development of a system for the delivery of Rehabilitation Engineering Services. Therefore, with the exception of the traditional areas of prosthetics, orthotics and orthopedics, no organized system for the delivery of services exists. Because of the importance and magnitude of this task, a special workshop was held in Pomona, California and a summary of the report may be found in appendix A. The workshop and report reflect the complexity and diverse opinion associated with service delivery. The lack of trained rehabilitation engineers is one obvious problem. Other factors contributing to an efficient program are access to information, comprehensive patient management, financial continuity and co-operation among all involved agencies be they government, private or charitable. In order to demonstrate possible solutions, two specific recommendations were made as follows:

Recommendations

A. Conduct a pilot study of a service delivery system using existing prosthetic and orthotic facilities. Joint funding by private industry and government would provide key personnel for patient services and for consulting services to government agencies and third party payers.

B. Conduct a pilot study of a service delivery system, using pool funding from various agencies to avoid procurement delays. Delays often occur when it cannot be decided who should pay for necessary services. The program calls for the pooling of funds from all involved agencies with money immediately available upon prescription. The division of expenses would be decided at a later date.

Many of the difficulties encountered in service delivery are reflected in the following statements:

1. There is great difficulty in obtaining information.
2. Problems arise in overlapping (and underlapping) between agencies.
3. There is a general lack of funds for services.
4. There is a lack of engineering service facilities and staff.
5. There is a lack of good product evaluation.
6. Price schedules for devices are often unrealistic.
7. There is a lack of market data and in general the market is low volume.
8. There is a lack of educational opportunities for rehabilitation engineers and other professionals.
9. Transportation for patients to and from service facilities is inadequate.

The above problem comments are typical and realistic. The recommendations for service delivery and the other recommendations in this report suggest solutions to many of these problems. Further recommendations were made throughout the workshop series and these are represented in the following quotations:

"Develop plans and take appropriate action to establish a national system for service delivery."
"Need interagency joint executive committee."
"A rehabilitation engineer should be a member of the team that designs the service delivery system."
"A loan system is needed for expensive aids."
"Government subsidy so that a piece of equipment would cost a handicapped person only as much as a comparable device would cost the average citizen."
"More and better low vision clinics."
"A company capitalized to procure, stock and deploy reasonable runs of simple aids."
"A model service and hearing aid delivery program having medical, audiometric and educational facilities at one clinic with engineering capability for design and construction of special aids."
"More emphasis on the development of milder corrective devices and procedures."
"A rehabilitation engineer should be on every spinal cord injury team."
"Special regional centers should be established for complex cases."

NATIONAL ORGANIZATION

It is apparent from the magnitude of the problem and the amount of work recommended that some form of leadership and organization at a national level is necessary. Several of the workshops specifically expressed such a need and at the Summary Workshop in Washington on May 12 and 13, 1977 the subject was discussed and recommendations were made. In former years the role of leadership and coordination was provided by the Committee on Prosthetics Research and Development (CPRD) of the National Academy of Sciences (NAS) with funding from the Veterans Administration and the Rehabilitation Services Administration. The demise of this committee has left a very obvious gap in the national effort and several reports have been written or published concerning recommendations for a national organization.

The first of these reports was produced by the ad hoc committee of the Division of Medical Sciences of NAS under the chairmanship of George T. Aitken during the latter part of 1972. The purpose of the report was to recommend changes in the organization and structure of CPRD to better serve the expanding role into Rehabilitation Engineering. The suggested organization called for the appointment of a Board on Rehabilitation Engineering for the Musculoskeletal and Sensory Systems. The Board will be responsible for the development of policy and would be composed of approximately ten individuals including representatives from medicine, engineering, prosthetics, orthotics, and sensory aids. A Committee on Operations and a permanent staff would be responsible for the implementation of policy established by the Board. The chairman of the Committee on Operations would serve on the Board and, insofar as possible, individual projects would be carried out by task or ad hoc groups with assistance from the staff or by the staff alone. The report of Dr. Aitken's committee was submitted to the President of the NAS through the Division of Medical Sciences.

"Science and Technology in the Service of the Physically Handicapped" was published by the Committee on National Needs for the Rehabilitation of the Physically Handicapped of the Division of Medical Sciences of the Assembly of Life Sciences of NAS in 1976. The Committee was chaired by Walter A. Rosenblith, and Volume I of the report makes recommendations concerning a national organization. The committee recommended the establishment of a "Board . . . within the framework of the National Research Council (most likely within the Division of Medical Sciences of the Assembly of Life Sciences) in cooperation with the several relevant NRC assemblies and commissions as well as in cooperation with the Institute of Medicine."

The report further describes the functions of the board in providing a focus for a community of disciplines in rehabilitation: in monitoring research, in assisting government agency planning and, with these agencies, in developing an agenda for research and development with systematic review and evaluation. The functions would also include the dissemination of information through publications and conferences, and activities would extend to cooperating with other countries. The Board would consist of some two dozen members drawn from medicine, engineering, allied health professions, biomedical sciences, social and behavioral sciences, and consumers.

National organization was also a consideration in the "Report of the Panel on Research Programs to Aid the Handicapped" to the Committee on Science and Technology of the U.S. House of Representatives under the chairmanship of Olin E. Teague. The report recomended the establishment of a "National Council for Research and the Handicapped." The Council would "consist of two bodies under one Director: one being a Government body and one a non-Government body. The responsibility of both bodies would be to assist the Director in carrying out the functions of the Council as a whole, and to act in liaison with each other. The Director of the Council would be appointed by the President with the approval of Congress. Supportive services would be developed by the Director under authorized appropriations for the operation of the organization."

According to the report, "the purpose of the council would be to produce for and with the handicapped, a coalition of Government and private activities which would develop and promote the implementation of a major national effort responsive to their needs." The formation of the government and non-government bodies is described in the report and the powers, functions, financing, and responsibilities are stated.

A further possibility for organization exists in that one specific government agency such as RSA or the VA might assume the responsibility for coordinating all activities at a national level; but this presents many difficulties in existing administrative structures. Traditionally the VA and RSA have been the chief supporters of Rehabilitation Engineering and the RSA has been given by law the lead role in the Department of Health, Education, and Welfare* for this field of activity. Cooperation among government agencies at the federal level is already in effect through an informal Interagency Policy Group which embraces the Veteran's Administration, the Rehabilitation Services Administration, the National Institutes of Health, the Office of Education, the Department of Housing and Urban Development, the National Aeronautics and Space Administration, the Department of Transportation, the Department of Defense, the National Science Foundation and others.

At the Summary Workshop, three concurrent panel sessions discussed the various proposals outlined above. Following a prepared format recommendations were prepared and subsequently reviewed in plenary session.

The following is a synthesis of the recommendations:

Organization

a. A Coordinating Body for a Rehabilitation Engineering National Program is very much needed and should be established as soon as possible.
b. The form and function of such a Coordinating Body might well change in the future and provision for such change should be made at the outset.
c. The Coordinating Body should be formed under some parent organization that is national and interdisciplinary in character and is independent from government agencies and is sufficiently prestigious to be recognized by government and private sectors. The parent organization might be the NAS,** in the Institute of Medicine or some other section. However, if the NAS is unable to accept the committment then some other independent organization should be sought to act under contract to RSA, the VA, and any other sponsoring agency.
d. The Coordinating Body should consist of a Board, Executive Committee, and Secretariat. The Board should be composed of a number of appointees with recognized achievement in engineering, medicine, related sciences, and health professions, plus at least two health care recipients.

The Executive Committee would be appointed by and be responsible to the Board in executing the policies established by the Board. The Executive Committee would consist of a small number of active professionals with proven executive ability and might also include recipients. The chairman of the Executive Committee should be a member of the Board, but not chairman of the Board. The Executive Committee would be supported by a Secretariat which should include professionals in the health care field. In carrying out its responsibilities the Executive Committee might appoint ad hoc committees or task groups as required. Members of the Board and Executive Committee should be appointed for a specific time period (for example three years) without immediate renewal, and appointments should be staggered to allow continuity.

Responsibilities

The Coordinating Body would be responsible to and be funded by the lead agencies of the Federal Government. At the present time this would specifically include, but not be limited to, the Rehabilitation Services Administration and Veterans Administration. The major responsibilities would be to advise sponsoring agencies, provide leadership in Rehabilitation Engineering in all its phases, coordinate activities, establish priorities, and develop plans for continued progress.

Functions

In exercising its responsibilities the Coordinating Body would perform the following functions:

1. Maintain an awareness of the needs and the work in progress in the United States and other countries.
2. Advise agencies sponsoring research by means of periodic and special reports on matters of research, evaluation, education, and the delivery of services.
3. Periodically develop and publish a national plan for the conduct and development of Rehabilitation Engineering.
4. Advise on legislative needs.
5. Conduct independent peer review of research and related proposals at the request of sponsoring agencies, and recommend priorities.
6. Maintain a system for the collection and dissemination of information for researchers, service providers, and recipients.
7. Organize workshops, meetings and conferences pertinent to the conduct of a national program on Rehabilitation Engineering and publish reports of same.
8. Specifically include plans and recommendations with respect to the training and education of health care profesionals in Rehabilitation Engineering in both preparatory and continuing education programs.
9. Coordinate evaluation activities, oversee the conduct of evaluation projects when appropriate, and publish the results.
10. Work toward the establishment of standards for performance and other factors in devices and products in Rehabiltation Engineering in co-operation with the Federal Drug Administration and other agencies and societies.
11. Specifically include the participation of pertinent state agencies, professional societies, manufacturers, and others fostering research utilization and service delivery functions.

* See appendix E—Section 202 (b) (2) of the Rehabilitation Act of 1973.

** See Appendix E—Section 3 (b) of the Rehabilitation Act of 1973.

APPENDICES

APPENDIX A
WORKSHOP SUMMARIES

THE ROLE OF ENGINEERING IN SPINAL CORD INJURY

VA Hospital
Castle Point, New York

May 3-5, 1973

Chairman: Frank W. Clippinger, Jr.

No. of Participants: 60

Representation: Medicine, engineering, life sciences, administration, and therapy.

Publisher: National Academy of Sciences, Washington, D.C.

Synopsis

Nineteen informal papers were presented covering the acute phase, the medical surgical stabilization phase, and the rehabilitation phase of spinal cord injury care. The report includes summaries and recommendations covering these three phases. Specific data regarding target groups and magnitude of the problem were not discussed, but a number of unsolved problems and some existing engineering solutions were presented.

General Recommendation

Engineering technology is required in all phases of management of spinal cord injury and a rehabilitation engineer should be a member of every spinal cord injury rehabilitation team.

Reported Needs

The following is a list of engineering needs as reported. In many instances work may already be in progress, but continued effort is indicated.

1. Equipment for extricating patients at the scene of the accident.
2. Immobilization techniques and devices for use during transport.
3. System design in transportation, monitoring, and communication during transport.
4. X-ray equipment for use without moving the patient.
5. Circulation and respiration monitoring systems.
6. Spinal cord cooling system.
7. Spinal stabilization instruments and methods.
8. Call systems, recreation systems, and therapeutic devices for the acute phase.
9. Spinal monitoring methods for determining level of lesion.
10. Beds for avoiding pressure sores but allowing changes in position.
11. Improved means for moving patients.
12. Automatic respiratory systems.
13. Improved environmental controls using mini-computers.
14. Improved arm function using external power, functional electrical stimulation, and micro-computer systems.
15. Investigation into the problems of proprioception and touch.
16. Investigation into electrical stimulation as an aid to ambulation.
17. Improved seating and other methods for avoiding decubitus ulcers.
18. Improved methods for transfer in home and in public.
19. Improved design of wheelchairs—durability, weight, bulk, and suitability for use in a van.
20. Powered wheelchairs with improved performance, transportability, and better control systems.
21. Standards and prescription criteria for hand controls for automobiles.
22. Devices for eating, reading, and other aids for daily living.

MOBILITY FOR SPINAL CORD IMPAIRED PEOPLE

Rancho Los Amigos Hospital, Downey, California

February 22-24, 1974

Chairmen: James B. Reswick
Maurice LeBlanc

No. of Participants: 74

Representation: Medicine, engineering, therapy, orthotics, manufacturing, architecture, transportation, government, and the handicapped public.

Publisher: National Academy of Sciences, Washington, D.C.

Synthesis

1. The number of people requiring special consideration in mobility is growing due to the improved care received by individuals subjected to trauma and suffering from birth defects.
2. The manually operated wheelchair that has evolved through the years has many good features, but its usefulness could be increased considerably by a few easily incorporated design changes. Consideration should also be given to providing more function by design changes that involve sophistication and ingenuity. Care must be exercised so that none of the positive features of the present designs are compromised in the zeal to provide a new function.
3. The use of exoskeletal orthoses, with and without external power, with and without electrical stimulation of the neuromuscular system, should be explored thoroughly.
4. Work on electrical stimulation of the neuromuscular system to preserve range of motion and muscle force as well as provide function should be expanded and accelerated.
5. The modular concept should be considered in the development of a mobility system useful in the home, in the immediate neighborhood, within the city, and between widely separated points. A system build around a customized, readily detachable seat that can be easily transferred along with the occupant, from chassis to chassis and on to other vehicles that contain safe attachments, should be studied. The design of other systems should be encouraged also.
6. Studies involving the effect of pressure on soft tissue with respect to the prevention and management of decubitus ulcers should be expanded and accelerated. This work should include the development of improved seating and bedding and effective techniques for their application. The body of knowledge already accumulated in the prevention and management of ulcers should be made available widely by publication and formal education programs.
7. Present movements to remove so-called architectural barriers and to make public transportation more available should be supported and accelerated.
8. Although many new models are being produced, there is a real need for powered chairs that have increased range, better control systems, improved outdoor performance, and are easier to fold or carry in automobiles.

FUNCTIONAL ELECTRICAL STIMULATION—APPLICATIONS IN NEURAL PROSTHESES

Kellogg-West Conference Center, Pomona, California

May 17-19, 1976

Chairmen: F. Terry Hambrecht
James B. Reswick

No. of Participants: 45

Representation: Medicine, engineering, life sciences, manufacturing.

Publisher: Functional Electrical Stiumlation—Applications in Neural Prostheses, Marcel-Dekker, 270 Madison Ave., New York, 1977.

Synthesis

Seven subjects were covered in separate panel sessions as follows:

(1) Striated muscle stimulation
(2) Micturition reflex stimulation
(3) Cerebellar stimulation
(4) Auditory prostheses
(5) Neurophysiological considerations
(6) Neural damage
(7) Electronics and electrodes

Discussion on the stimulation of striated muscle excluded the heart pacer, but did include applications in stroke and trauma, spinal injury, respiratory unresponsiveness, scoliosis, therapeutic applications (contractions etc.), cerebral palsy, peripheral lesions, micturation and defecation. Several fundamental research questions were identified such as tissue damage, mechanisms of fatigue, optimum electrical characteristics, electrodes, biocybernetic considerations in control, stimulation of muscle fibers and nerves, spasticity, carryover effects, and effect on the central nervous system. Also discussed were the problems associated with "bridging the gap" between successful research and demonstration and providing functional systems to patients.

Current research for the control of micturition includes stimulation of the detrusor muscle, a single sacral root of the detrusor, and the intermediolateral cell column. Patient application for these procedures is about a year away. Animal experiments in stimulating the anal sphincter have also been demonstrated.

Discussion regarding cerebellar stimulation raised many questions regarding the physiological mechanism, therapeutic efficacy, patient selection, optimal parameters and placement, and long term effects. The applications for this type of stimulation are for epilepsy and motor dysfunction such as cerebral palsy. The need is for carefully controlled and extensive clinical evaluation which would require considerable funding.

With auditory prostheses, the basic objective is to re-establish hearing of intelligible speech for the profoundly deaf. In spite of limited information on auditory nerve survival, feasibility studies using multi-channel, implanted electrode arrays are indicated. Some fundamental considerations in the development of such electrodes are the definition of excitation patterns, placement reliability, electrode survival, and induced intracochlear damage.

Discussion on neurophysiological factors focused on effecting progress through information exchange and professional interaction. It is believed that close collaboration between engineers and neuroscientists would be an effective way to achieve results in this complex area. Two specific topics discussed were peripheral nerve regeneration due to F.E.S. and muscle atrophy.

A panel on neural damage reported on surgical problems, stimulus protocols, and metabloic and circulatory changes resulting from electrical stimulation. Specific problems requiring investigation are fixation, encapsulation, intermittent discontinuous stimulation, and electrode shape. Intensive study of tissue subjected to stimulation is recommended together with metabolic and circulatory changes.

In discussing electronics and electrodes, it appears that the difficult, unsolved problems lie not primarily in the achievement of the necessary electronic function but in the packaging of the system for survival in the biologic environment, and in the characteristics of electrode materials and electrode arrays.

The fabrication of electrode arrays raises problems outside the current body of knowledge of biologically compatible metals, and specific recommendations were:

1. The compilation of a biomaterials handbook aimed specifically at electronic implant, electrode lead, and electrode plug technology.

2. The sponsoring of communication at the technician level perhaps with special training sessions.

3. The encouragement of training at the professional level of scientists in biomaterials, especially polymer insulation materials.

Although the state of the art is adequate for the development of electronic circuitry, development costs are in the hundreds of thousands of dollars, presenting financial difficulties for all but the largest firms.

In conclusion, the practical application of neural prostheses requires a great deal more sophisticated investigation, with multidisciplinary collaboration. Other means for stimulation should also be investigated including chemical, mechanical, optical, and thermal methods.

Other Research Areas Include:

(1) Criteria for patient selection.
(2) Mechanisms of therapy.
(3) Patient acceptance.
(4) Psychological effects relative to F.E.S.
(5) Batteries and other energy sources.

With respect to *cerebellar stimulation* for epilepsy and other motor disorders, research is recommended for the following:

(1) Evaluation of therapeutic efficacy.
(2) Optimal parameters and placement.
(3) Patient selection.

PERSONAL LICENSED VEHICLES FOR THE DISABLED

Washington, D.C.

June 14-17, 1976

Chairmen: Richard M. Herman
J. Raymond Pearson

No. of Participants: 70

Representation: Driver education, engineering, occupational and physical therapy, manufacturing, auto industry, medicine, handicapped drivers, government.

Publisher: Rehabilitation Engineering Center, Moss Rehabilitation Hospital, Philadelphia, Pennsylvania.

Synthesis of Panel Recommendations

1. Standard procedures should be developed for assessment of the disabled. It is felt that a number of potential drivers, especially among those with brain damage, are being excluded from training programs because of inadequate assessment methods. Improved assessment methods will also result in a more efficient screening and training program.
2. A multidisciplinary team should be established consisting of a physician, engineer, therapist, driver educator-trainer, and psychologist or social worker to carry out the assessment of disabled individuals seeking to be drivers.
3. Simulators used for use in driver evaluation and training should be evaluated. If found lacking for the purposes intended, a research and development program should be initiated.
4. A data bank should be maintained consisting of basic and other information needed by research, administrative, and clinical personnel.
5. Research, design, and development of electrical and manually operated wheelchairs is needed. Both types of chairs need to be designed so that they serve safely as either a driver's or passenger's seat for as many types of transportation vehicles as possible (i.e., personal vehicles, urban and interstate public buses, and trains). A powered wheelchair which folds for storage is also needed.
6. A "universal" or standardized wheelchair securement system is needed. This wheelchair hold-down system should be sufficient for as many types of transportation vehicles as possible.
7. An interagency joint executive committee should be appointed to coordinate an efficient program in research, development, evaluation, education, and service delivery.
8. The establishment of standard design guidelines meeting the current needs of the disabled driver should be explored with the automobile manufacturers. Standardized automobile floor and roof height to facilitate wheelchair activities, and wider door openings are examples of areas that should be investigated.
9. Servo-control designs should be evaluated. Redesign is probably necessary if they are to meet safety requirements. Also, it is suggested that new control equipment be designed by automobile manufaturers instead of other manufacturers.
10. The modular concept to mobility as set forth in "Mobility for Spinal Cord Impaired People" should be investigated.
11. Emergency situation safety should be studied.
12. A "Good Samaritan Law" with respect to equipment for the disabled should be promoted.
13. Improved systems for delivery of equipment and services need to be developed and established. Special regional centers should be considered for handling the more complex cases and should perhaps provide maintenance and inspection of equipment.
14. The current state of the art of driving for the disabled should be established as a basis for further research and development.
15. An education program should be implemented for members of the disabled community as an initial step in their involvement in further research and development.
16. Standard driver education and training programs should be developed.
17. The following changes to the proposed Veterans Administration 5 year plan are recommended:
    a. Expand the plan to include "Education of the Team."
    b. Shift activities of "Driver Training" in order that the training activities begin fiscal year 77.
18. Vocational opportunities should be explored for disabled individuals driving commercial vehicles through specialized licensing.

REHABILITATION ENGINEERING EDUCATION

Knoxville, Tennessee

November 3-5, 1976

Chairmen: Robert E. Tooms
Colin A. McLaurin

No. of Participants: 62

Representation: Engineering, education, rehabilitation engineering, orthotics and prosthetics, medicine, other health care professionals, architecture, vocational rehabilitation, government.

Publisher: University of Tennessee, Knoxville, Tennessee

Synthesis

Following background presentations in plenary session, panel groups discussed specific aspects of the problem and made recommendations that were presented in plenary as the basis for the report. The recommendations are largely concerned with post graduate training for engineers but suggests that as an alternative, other health care professionals such as prosthetists, orthotists and therapists, might also be trained in engineering. The major recommendations of the workshop are as follows:

1. It is recommended that a 3 year, federally-sponsored pilot educational program be initiated and administered at 3 or 4 universities with experience in medical and engineering education and the availability of clinical resources in rehabilitation. The major focus of the program should be to provide the post graduate education necessary for the engineer to immediately assume a primary responsibility for the delivery of engineering technology to disabled patients/clients. The support for this program should be in the form of institutional training grants.
2. It is recommended that a means be developed for the continuing education in Rehabilitation Engineering and other disciplines involved in Rehabilitation Engineering activities.
3. It is recommended that a certification process be instituted in Rehabilitation Engineering to insure adequate consumer protection and recognition of the qualified rehabilitation engineer.
4. It is recommended that a national coordinating body be established to advise and serve various agencies of government with respect to the delineation and development of national and international programs in Rehabilitation Engineering. One function of this body would be to coordinate the systematic development of the educational program as outlined in the above recommendations and in the body of the report.

The report also included secondary recommendations as follows:

1. It is recommended that plans be developed and the appropriate action taken in order to establish a national system for delivery of Rehabilitation Engineering services to physically handicapped individuals of all ages.
2. It is recommended that a system for information exchange be developed to serve the needs of those now practicing Rehabilitation Engineering and those seeking Rehabilitation Engineering services.
3. It is recommended that the scope of RSA Rehabilitation Engineering be expanded to provide increased effort toward solving problems of both pre-adults and geriatrics.
4. It is recommended that a federally-sponsored "Rehabilitation Engineering Week" be held to enhance the national visibility of Rehabilitation Engineering.

Following the meeting the editorial committee developed action plans for both a Pilot Education Program and a National Multi-agency Coordinating Body on Rehabilitation Engineering and these were included in the report.

The number of rehabilitation engineers required in the next several years was not established, but it was suggested that 25 new students per year for 3 years be trained in the pilot program.

LOCOMOTION AND THE CLINICAL ANALYSIS OF GAIT

Philadelphia, Pennsylvania

December 6-8, 1976

Chairmen: A. Bennett Wilson Jr.
Uros Stanic

No. of Participants: 62

Representation: Engineering, medicine, physical therapy, manufacturing, prosthetics and orthotics.

Publisher: Rehabilitation Engineering Center, Moss Rehabilitation Hospital, Philadelphia, Pennsylvania.

Recommendations

1. All gait laboratories should be urged to make their facilities available to clinical personnel for use in treatment of individual patients.
2. A workshop consisting of personnel from the fundamental studies laboratories should be held in the near future to:
   a. Work toward standardization of techniques and reporting methods. (The CPRD report should be used as a point of departure.)
   b. Review existing measuring devices and techniques.
   c. Interchange and correlate results.
   d. Further develop recommendations for future work.
3. "Locomotion" should be introduced into residency programs.
4. Meetings of "locomotion" personnel should be held annually.
5. A central clearing house is needed to accelerate progress and reduce redundancy.
6. Better methods of measuring energy costs are needed, so that energy costs can be correlated with locomotion data to provide more definitive goals of treatment.
7. The development of better means of relating EMG to force should be continued.
8. Present information on normal and pathological gait along with proper application and fabrication of currently available molded plastic orthoses should be disseminated.
9. The education of general and vascular surgeons in the techniques of immediate post-operative and early fitting techniques should be continued and strengthened.
10. The roster of Gait Laboratories should be brought up to date and made available generally.

DELIVERY OF REHABILITATION ENGINEERING SERVICES IN THE STATE OF CALIFORNIA

Kellog-West Convention Center

Pomona, California

January 16-18, 1977

Chairmen: Gordon Cumming
Herbert Leibowitz
James B. Reswick

No, of Participants: 50

Representation: Consumers, ombudsmen, agencies, suppliers, authorizers and providers, inventors, educators, legislators.

Publisher: "Development of a Model Rehabilitation Engineering Delivery Systems in California—A Beginning" State of California, Department of Rehabilitation.

Recommendations

1. The State Department of Health, the State Department of Rehabilitation, the Rehabilitation Services Administration, and the Veterans Administration should work together to establish a model system for the provision of delivering needed equipment for the disabled, being cognizant of existing systems.
2. A Council should be considered with representation from all groups at the conference to monitor and carry out the recommendations. The Council might well develop a proposal for an effective delivery system and present same to the Governor for action.
3. A pilot project should be initiated to provide Rehabilitation Engineering Services using the existing prosthetic and orthotic network.
4. The I and E funded employment development program for the blind at Opticon Fund, Inc., should be encouraged and made more permanent through continued support, either outside or within the Department of Rehabilitation.
5. A pilot program should be established wherein:
   a. In catastrophic situations, the physician is free to use the treatment of choice without prior authorization.
   b. A local team approach to allocation of costs is adopted by the Department of Health, the Department of Rehabilitation, Workman's Compensation, and other public and private agencies.
   c. Speed is assured in purchasing services and reimbursing vendors.
6. Legislation should be sought that will enable public bodies to pay a fair price for services.
7. The Tort System should be modified through legislative action to ease the product/professional liability problems.
8. Research should be conducted to indicate the cost/effectiveness of rehabilitation.
9. A non-profit consumers' union or other procedures and centers for the evaluation of engineering and clinical services should be established. Guildelines for consumer use should be formed and evaluation results should be disseminated through information centers.
   Government seed money from the Department of Consumer Affairs should be involved.
10. An Information Center should be established at the Medical Service Unit in Sacramento. Information should be distributed to all state and federal authorizing personnel and the center should be used as a referral source.
11. Reading rooms for consumers should be provided in all Department of Vocational Rehabilitation offices. A consumers newsletter should be published and telecommunication system set up for information access. The NASA Information Retrieval System should be utilized and NASA funded visits by rehabilitation engineers to NASA centers be encouraged.
12. Procedures for getting equipment on the authorization list of Medi-Cal should be publicized.
13. A state planning committee should be established to consider the profession of Rehabilitation Engineering with respect to job description, curriculum, practicum, certification of licensing, and recruitment.
14. Rehabilitation engineers should be encouraged to belong to a national organization, to establish relationships with other germane professionals, and to enter into private practice on a fee-for-service basis.

ENVIRONMENTAL BARRIERS AND THE PHYSICALLY DISABLED

Witchita, Kansas

February 6-8, 1977

Chairmen: Pamela Cluff
Thomas M. Moses

No. of Participants: 81

Representation: Physically disabled persons, architecture, engineering, community planning, life scientists, industry, medicine, occupational and physical therapy, vocational rehabilitation, government, private agencies, prosthetics and orthotics, industrial design.

Publisher: Rehabilitation Engineering Center, Cerebral Palsy Research Foundation of Kansas and Wichita State University, Wichita, Kansas

Recommendations

Housing

1. Rehabilitation Engineering should design and develop adaptions that allow the disabled to use the housing facilities provided.
2. Engineering should provide ways in which to modify the housing environment so as to reduce service delivery needs and, thereby, costs.
3. Rehabilitation Engineering should provide methods to assure that life safety standards are able to be met by the disabled individual.
4. Human factors data, as it relates to the disabled, should be developed and then incorporated into the design of fixtures, controls, etc.
5. Engineering methods should be utilized to establish service and maintenance standards, staffing patterns, and scheduling of personnel as is required by the service delivery system.
6. The Rehabilitation Services Administration, in conjunction with the Veterans Administration, should jointly sponsor a research effort to develop housing systems and hardware for the aged and the severely physically disabled.

Economic Factors

1. Rehabilitation Engineers should provide living systems and solutions that economically interface within societies' framework.
2. Engineering investigation of possible solutions for the disabled's life style should be encouraged, i.e.: employment, unemployment, levels of employment.
3. The engineer should engage in systems development to address various groupings of disability so as to include even the most severely disabled.
4. Solutions to the economic problems of the severely disabled should utilize the engineer's methodical logical application of existing components to build a more effective economy for each disabled segment involved.

Attitudinal Factors

1. The rehabilitation engineer may become an effective attitudinal barrier remover by designing and developing environmental devices and adaptations, and, in general, by providing systems whereby the handicapped population actively participates in everyday society.

Service Delivery

1. Rehabilitation Engineering must assist the service delivery systems with the design of equipment and adaptations for the physically disabled.
2. The rehabilitation engineer should be a member of the team that designs the service delivery system, so that the advantages of engineering become a working part of the system.

Education

1. Rehabilitation Engineering personnel should design and develop methods and equipment by which the severely involved, non-verbal handicapped person may participate in the classroom and obtain an education.
2. Rehabilitation Engineering should interact with the educational community to provide assistance in developing systems that allow all handicapped individuals to obtain an education that would be channeled toward a vocation.
3. Rehabilitation Engineering should become involved with the child's early learning systems and follow through so as to support the student throughout his educational years.

Transportation

1. Rehabilitation Engineering should become involved in all transportation systems for the disabled and elderly, whether private or public, from the standpoint of accessibility, economy, and energy saving devices.
2. The methodical analysis ability of the engineer should be applied to the operational methods of public and private transportation.
3. The rehabilitation engineer should be incorporated into the manufacturing process to provide methods and types of adjustments to hardware so that it is made accessible and usable by the elderly and the disabled.
4. Rehabilitation Engineering should work with manufacturers so as to enhance their production capability to incorporate devices for the handicapped, without such devices becoming a cost burden for the manufacturer or the consumer.
5. An engineering analysis of the levels of transportation for various levels of disabililty should be made so as to determine what is expected of society for the disabled or elderly.
6. Engineering systems should be developed that would make the surrounding environment accessible by methods that would not put an extreme cost burden on the consumer or specific segments of society.
7. Items of legislation have been passed and the engineer should work to the best of his ability within that legislation before further legislation is requested.

Recreation

1. Rehabilitation Engineering through the design of adaptive devices should allow the handicapped to be more included in recreational activities.
2. Engineering should become involved in the modification of wheelchairs for use in specific sports and athletic activities.
3. Rehabilitation Engineering can become involved in the design and development of new and additional equipment, devices, and materials for use in various activities.
4. Engineering should make equipment adaptable for the various segments of the handicapped population, including the most severe physically and the profoundly mentally retarded.
5. The value of swimming to the handicapped is beneficial to the extent that the engineer should become involved in the facilities, devices, and equipment to make swimming more economical and useful by the handicapped.
6. Rehabilitation Engineering should become involved in designing facilities, equipment, devices, and materials to enable the disabled and handicapped to participate in regular program settings to the maximum degree possible.
7. Rehabilitation Engineering should address outdoor recreational facilities such as camps and wilderness areas, so that the disabled and handicapped can effectively utilize these areas.
8. Engineering should concentrate on providing adaptive means whereby the disabled may participate in seasonal activities, no matter what the season.

Aging

1. Environmental controls and control systems specifically designed for the aged and disabled aged should be researched and developed.
2. The environment, and possible modifications to it, should be researched so as to determine what degree of an adaptive environment is available.
3. After knowing the research results and the requirement for adaptive devices, methods for developing same should be improved.
4. A more stimulating environment should be engineered for the elderly person.
5. The rehabilitation engineer must become involved immediately in the definition of problems, the development of solutions, and distributions of those solutions, along with the general information dissemination of all research activities.
6. The feasibility of a Rehabilitation Engineering Center being established to address the problems of the aging should be a priority of the Rehabilitation Services Administration jointly with the Veterans Administration.
7. Rehabilitation research activities for the aged should be centered in areas where there is a heavy concentration of aged population.

Employment

1. Rehabilitation Engineering must accept the challenge of being the catalyst that brings employer, employee, and support agencies to a workable solution.
2. Rehabilitation Engineering must be instrumental in developing employment alternatives.

3. Engineering must utilize the basic fundamentals of the discipline to research, develop, and implement employment management systems.
4. Rehabilitation Engineering must become an integral part of the educational system of the severely physically disabled, using engineering foresight to design the systems and tools that will result in vocational preparation.
5. Engineering must design adaptive devices that will allow the severely physically disabled to participate and obtain an education.
6. Practical vocational training utilizing adaptive devices or systems to obtain an acceptable skill level will require sizable engineering support.
7. A system of training rehabilitation engineers in methods of employing the severely disabled in mainstream industries should be a function of the Rehabilitation Services Administration.
8. Rehabilitation Services Administration should train rehabilitation engineers so they can become employees of industry and then support and provide methods of employing the disabled.
9. Rehabilitation Engineering should develop methods of evaluating clients to determine the optimum job placement.
10. The rehabilitaition engineer must be trained and continually updated to be current with newly developing employment systems.

TOTAL JOINT REPLACEMENT

Rehabilitation Engineering Center, Northwestern University

Chicago, Illinois

March 3-5, 1977

Chairman: Clinton L. Compere

No. of Participants: 60

Representation: Orthopedics, engineering, health sciences, rehabilitation, Federal Drug Administration, other government agencies.

Publisher: Northwestern University Rehabilitation Engineering Center, Chicago, Illinois

Magnitude of the Problem

During 1976 approximately 120.000 total joints were implanted in patients in the United States. This included 80,000 hips, 30,000 knees, 8,000 fingers and 2,000 other joints (ankles, shoulders, elbows, wrists).

It is estimated that if more reliable prostheses were available, the annual figure would rise to approximately 180,000.

Patient costs for failed implants are estimated to be $100 million per year. Since most of the patients receiving total joints are over 65, most of this cost is borne directly by the Federal government through Medicare.

The patient target groups are composed of people with joint disabilities from rheumatoid arthritis, osteoarthritis, traumatic arthritis, and other joint diseases. These diseases affect men and women from all socio-economic levels and professions but are particularly predominant in the elderly.

State of the Art

Many artificial joint designs are available for implantation in patients. The current status of prostheses for each joint can be summarized as follows:

Hips: There are many relatively reliable prostheses available and in use. The 2 years failure rate is approximately 5%. Later failures do occur and the long-term failure rate (greater that 5 years) is not well known. The major problem is loosening of the femoral component from the femur and the main causes are related to technique and infection.

Knees: Many types of prostheses are available and being implanted but the designs in most frequent use are changing rapidly, since the design process is still very active. Two year failure rate is between 10 and 15%. Loosening of the tibial component is the major problem but the cause of this is not well known, although prothesis design and technical problems in insertion appear to be the major causes.

Ankles: Several designs are available, but only a few hundred prostheses have been implanted in patients. This procedure continues to be experimental and short- and long-term failure rates are poorly known.

Shoulders: Shoulder prostheses are still in the experimental stage similar to the ankle and relatively few have been put in patients. The question of whether a shoulder replacement should be constrained or non-constrained has not been settled and there are many different opinions in regard to the indications or contradictions for shoulder replacement. Design and biomechanical studies are needed.

Elbows: The problems and usage are similar to those for the shoulder. Certain centers are developing non-constrained elbow replacements and other centers continue to use constrained hinged joints. The Workshop was in agreement that fixed hinged joints for the elbow tend to loosen over a long period of time. Design, biomechanical, and technique studies are needed.

Wrist: Replacement of the wrist joint with an implant is not widely accepted as a routine procedure; only 3 or 4 centers have developed any clinical experience. Further development in design and technique is needed.

Fingers: Finger joint replacement has been used in many arthritic centers for the past fifteen years, but results are often unsatisfactory. Cosmesis is often improved without functional improvement. Short-term research and long-term evaluation is necessary in this area.

Causes of Failure

The causes of implant failure in each joint area are similar, with variation in the relative importance of failure from joint to joint. The following are the causes that have the greatest potential importance:

(1) *COMPONENT FIXATION TO BONE*
Loss of this fixation is a major problem area. The exact cause of single failure may be difficult to determine; but component impingement, constraint forces due to ligament tightening, technical problems during insertion, bone interface failure due to poor design, and bone response to the implant are possible causes.

(2) *COMPONENT FAILURE*
Fracture or permanent deformation of components is an occasional problem. This may occasionally be due to component design, but it may also be caused by long-term fatigue, corrosion, or other material degradation.

(3) *INFECTION*
When present, infection usually results in failure with subsequent removal of the prosthetic components. Infection most frequently is attributed to external or environmental contamination. Late infections do occur and are possibly hematogenous in origin with localization in the area of the implant. Wear particles, and ischemic tissue due to the toxicity and from the heat of the methylmethacrylate, are also factors, although documented cases are rare.

(4) *INSTABILITY*
Dislocation and subluxation have been problems of varying degree, depending on the particular joint. The cause is occasionally attributed to the design of the component which was used for the implant, or improper surgical placement. Of primary importance is the post-operative care routine with specific regard to the muscle and ligament stability provided by the patient.

(5) *POOR JOINT MOTION*
Patients with joint implant procedures are not expected to regain full joint motion. This is specifically true when there are preoperative soft tissue contractures and a long standing history of joint disability. However, poor post-operative joint motion is partially due to prosthesis design and this needs further study.

(6) *IDIOPATHIC PAIN*
The cardinal expected result of any joint implant is relief of pain which is routinely accomplished when the procedure is properly chosen and implemented with good techniques. However, failure sometimes occurs due to pain of unknown origin.

(7) *SALVAGE*
Although not a cause of failure, the continued failure of many joint implants has made salvage procedures a current major clinical problem. Innovations are usually required for salvage, particularly when a reoperation for replacement is possible.

Specific Research Activities in Internal Joint Replacement

Because total joints will continue to be used, failures will continue. The goal of research must be to eliminate these failures, prevent future failures, and make total joint replacement available to a wider patient population. Areas in need of research are suggested by the previous state of the art review. Some of these areas involve basic questions in physiology which will require many years to answer. Others are of a short-term nature. To put these in a useful framework, the following is a list of research areas of highest priority, including goals which appear feasible. This list contains only the major problems. There are many additional important goals listed in the panel reports.

(1) *CAUSES OF IMPLANT FAILURE*
The type and relative frequencies of implant failures need to be determined. Failures include those implants that give poor performance but do not require removal. An immediate goal is the formation of a multi-institutional implant retrieval program for analysis of removed implants. A similar effort is needed to evaluate patients with both successful and poorly performing prostheses. At least five medical centers are desired for this effort. In both of these activities, a common method of evaluation is needed with centralized control of data collection.

(2) *MECHANICS OF NORMAL JOINTS AND JOINTS WITH IMPLANTS*
Many of the problems with current implants involve questions of joint motion, forces in the ligaments and muscles around the joints, and forces on the implants. Much remains unknown about these subjects. Methods for determining the forces and motions are needed. Work in this area is well underway and the plan for future work is clear. A significant need is for collaborative efforts among institutions.

(3) *MOTIONS AND FORCES DURING ACTIVITIES OF DAILY LIVING*
The design criteria for artificial joints depend on the functional demands put on the prostheses by the patient. The magnitude and frequency of these motions and forces need to be established. Measuring techniques and devices should be developed and then applied to normal and total joint patients.

(4) *STRUCTURAL ANALYSIS OF IMPLANT SYSTEMS*
For a given load on a joint implant, the stresses at the bone-prosthesis interface, and therefore, the loosening tendency of the prosthesis, depends on the geometry or shape of the implant. Prediction of the stresses at the interface using computer models will allow evaluating a prosthesis for loosening before it goes into a patient, and also allow a comparison of different prostheses for potential loosening. Computer programs for performing the stress analysis need to be developed, their accuracy checked both theoretically and experimentally, and then utilized to analyze specific prostheses.

(5) *COMPARATIVE EVALUATION OF PROSTHESES*
There are many designs of prostheses for each joint available. Unfortunately, it is difficult to know which is better. A method for objective comparison of prostheses is needed. This will require completion of several of the other research areas, but must proceed independent of them. This evaluation would include both a theoretical measure of fixation, as described in (4), and an experimental measure of fixation.

(6) *MATERIALS*
An understanding of the nature of the interface between bone and bone cement is needed so that fixation of the prosthesis can be maintained. Porous implants should continue to be explored. Methods for analyzing material behavior and change over a long-term (20 years) need to be developed and used to test current materials.

Overall Conclusions

In addition to the detailed recommendations described, several general positions emerged from the Workshop discussions, the understanding of which are essential for adequate planning of future support for total joint replacement research and development.

(1) Total joint replacement is a highly successful procedure, giving relief of pain and improved function to many people. It will continue to be used in the future. An unfortunate concomitant to this success, however, is too frequent implant failure, estimated to cost the patients, insurance carriers, and government over $100 million per year. Continued research along established lines can cut the failure rate significantly. The major impediment to achieving this is money to support the research. The current government funding rate of approximately $2.4 million per year is grossly inadequate for the problem and potential improvement.
(2) Reduction of implant failure rate will require research into the causes and cures of the failures. There is little to be gained by applying currently available devices and techniques that is not already being done.
(3) Separation of support for basic research from Rehabilitation Engineering obstructs research and development in the field of internal joint prostheses. Research is needed to rehabilitate the patients.
(4) Existing work needs to be better coordinated, especially work funded by different agencies. Similarly, effective collaboration between institutions needs to be improved and fostered to maximize short-term clinical application of productive research experiences.

SENSORY DEFICITS AND SENSORY AIDS

San Francisco, California

March 23-25, 1977

Chairmen: Carl E. Sherrick, Co-Chairman
Howard Freiberger, Co-Chairman
Lawrence Scadden, Host REC

No. of Participants: 66

Representation: Acoustics, audiology, electronics, government, marketing, medicine, ophthalmology, sensory aids developers, sensory physiology, sensory psychology, work for the blind, work for the deaf, work for the deaf-blind.

Publisher: Rehabilitation Engineering Center, Smith-Kettlewell Institute of Visual Sciences, San Francisco, California

State of the Art

THE VISUALLY HANDICAPPED

The majority of technical advances have been in the areas of mobility and reading aids, with somewhat slower progress taking place in the areas of information retrieval and special devices for vocational and recreational activities. Several electronic mobility aids are currently under test or in use. A number of suggestions for modifications were made at the Workshop, including requests for careful attention to training and evaluation procedures. The latter theme formed a *leitmotif* for this workshop, for it permeated nearly every discussion.

Reading aids with speech outputs are now available for evaluation, and direct aids such as the Optacon or the Mauch Stereotoner are currently in field use. Speech output is the more desirable of course, requiring less training for use. Despite the progress in such aids, the feeling prevailed that braille was not ready for retirement, and continued efforts to upgrade its storage and retrieval technology were encouraged.

THE AUDITORY HANDICAPPED

Major emphasis was placed on the hearing aid and its offspring, the sophisticated speech-analyzing aids now in experimental form. Tactile aids and implanted cochlear prostheses received some attention, but are considered for one or another reason to be strictly developmental at this point. Telecommunication aids are numerous, but mainly unsatisfactory, with the exception of the Teletypewriter. This device is popular in part because the deaf have themselves had a hand in its development.

THE DEAF-BLIND

Whereas some of the devices used by the blind or the deaf are available to this group, it is obvious that only those providing tactile displays are suitable for the severely impaired deaf-blind. Besides the restriction on available technology thus resulting, there is the additional distressing fact that the cognitive capabilities of deaf-blind persons are reduced by their handicaps. As a result, training procedures must be modified in applications of devices to use by the deaf-blind. It was suggested that simple devices, e.g., alarm and paging systems, could be developed by low technology to solve some of the immediate problems of communication and mobility in the home or at work.

THE PROPRIOCEPTIVELY HANDICAPPED

The pesent state of research and development in this area is relatively low. Two major approaches to feedback for limb and postural adjustments exist: one involves the use of visual, auditory, or cutaneous signals that code limb position and prehension, the second the implantation of electrodes in active sensory nerve tracts to provide "natural" feedback to the patient. Both approaches embody advantages and disadvantages, but neither has been examined at sufficient length to permit an intelligent choice between them.

Knowledge Gaps

In nearly every discussion at the Workshop attention was drawn to areas of ignorance in theory, practice, and in the psychology and sociology of the handicapped. Some of the major areas are listed below:

1. More exhaustive surveys of the handicapped population are needed, describing not simply their condition and state of adaptation, but providing knowledge of their attitudes, motivations, and life goals. With such surveys, more intelligent planning and priority settings may be made.
2. In connection with (1), we need to learn more about the level of understanding of consumers, counseling personnel, and practitioners of the availability of devices, possible services, and their rights to get them.
3. For all mobility and communication aids, there is a serious need for more substantial theoretical underpinnings in the research and development of devices and systems.
4. In connection with (3), one participant noted that the next generation of mobility aids has not even been defined as yet. Presumably, the definition could emerge from theory better than from experience.
5. In hearing aid research, a major need is for the development of performance evaluation standards, and diagnostic and prescription tests.
6. The problem of improving the reliability of devices without prohibitive cost increases remains unsolved, but seems at least amenable to study.
7. For sensory aids that substitute one sense for another, e.g., tactile aids for speech processing, the need continues for specification of the proper display parameters, i.e., coding speech so that the skin understands it.

Identification of Specific Research Activities Projected Over Five Years or More.

1. Smaller, lighter, weatherproof mobility aids are needed.
2. A theory of the mobility process of the blind pedestrian should be developed.
3. The concept of, and specifications for, the next generation of mobility aids for the blind should be developed.
4. Electronic travel aids for the deaf-blind are needed.
5. Daily-living aids and recreational aids for older people with visual problems should be developed.
6. Occupational and educational aids for younger people with visual problems should be developed.
7. Less expensive more attractive devices for the low vision client should be designed.
8. Improved speech analyzing hearing aids with special pre-processing capabilities should be developed.
9. Improved hearing testing procedures, and diagnostic and prescription test batteries are required.
10. The quality of synthetic speech needs improving.
11. A device to process environmental sounds other than speech to enable their identification by the deaf should be developed.
12. An adjunctive device to supplement lip reading or residual hearing is needed.
13. Cutaneous sense studies should be pursued.
14. Studies are needed for understanding of the encoding/decoding processes of the human nervous system.
15. High-performance braille readers should be studied and the findings should be applied in teaching others.
16. Research should be conducted to improve concept development in blind children.
17. A fast, quiet braillewriter should be developed.
18. Medical aids for use by the blind need to be developed.
19. The application of redundancy principles to improve device reliability should be studied.
20. Fatigue-resistant conducting materials need to be developed.
21. The reliability of inserts and "packaging" for implanting in living systems should be improved.
22. Research on communicative handicaps should involve teams comprising engineers, physicians, psychologists, linguists as well as educators.
23. Development of reading machines for the blind should be continued.

THE EFFECTS OF PRESSURE ON HUMAN TISSUE

U.S. Public Health Service Hospital

Carville, Louisiana

March 24-26, 1977

Chairmen: Paul Brand
Vert Mooney
William Spencer

No. of Participants: 34

Representation: Medicine, engineering, prosthetics and orthotics, government,

Publisher: U.S. Public Health Services Hospital
Carville, Louisiana

Chairmans Summary

There is need here for down-to-earth clinical-engineering collaboration in the world of real people to develop systems that may be applicable in the homes of the elderly in order to minimize the problem before it starts. It must not be forgotten that the patient must be part of the team or we shall find that when too much is done to the patient and for the patient, he or she may lose the will to be up and about.

It was in the field of footwear that the workshop recognized the most profound lack of current research and development. This is probably because there is usually no clear-cut beginning to foot problems as there is when an amputation forces the need for a prosthesis. By the time most people begin to suffer real problems with their feet, they have already developed distortions of their toes, with bunions and hammertoes and corns and attenuated tissues under their metatarsal heads. It is the elderly citizen who suffers loss of mobility and independence from these causes, but is in youth that the direction of the problem is set.

This workshop first faced the fact that diabetics and others with insensitive feet often develop ulcers and gangrene if they are not provided with specially fitted shoes. The great difficulty such patients and their doctors experience in obtaining special shoes stems from the fact that there are no guidelines or standards anywhere in the industry to define how much pressure is acceptable on the foot. If the physician prescribed a standard for the patient, there is no instrumentation even in a prescription shoe store to measure it.

Research on decubitus ulcers, or pressure sores that occur in bed and the same type of ulcer that results from the prolonged sitting of paraplegic patients in wheelchairs is still in a rather backward state. Very beautiful and advanced studies were presented on the physiology of microcirculation in and under the skin. Very sophisticated studies on the evaluation of the effects of pressure on the rate of circulation and on the measurements of pressure under body surfaces are available, and more are needed in order to improve our knowledge of the mechanisms of tissue death from ischemia. Special beds are available that can equalize pressure under a recumbent patient by such modern techniques as air-fluidization of sand or ceramic beads. However, the state of the art for practical bedsore pevention in the hospitals of the nation is probably in a poorer state now than it has ever been. The evaluation techniques are too expensive and too fragile to apply in the turbulent interface under the backside of an incontinent and disoriented old man. The special beds are too expensive for general use. The dedicated and disciplined nursing that held the problem at bay a few decades ago is a victim of rising costs and changing professional objectives, while a higher proportion of our population lives to the age when decubitus ulcers are likely to occur and difficult to heal. We have no firm figures for the USA but careful studies on total populations in Denmark and in the United Kingdom suggest that here in the USA we may be spending from half a billion to one billion dollars on patients with pressure sores.

If this is difficult for a patient or doctor who knows what is needed, what is the plight of the average young person shopping for a smart shoe? By constraint of economics and fashion he or she probably purchases an imported shoe made of unyielding plastic, shaped to a last that has never had medical or bioengineering approval and which is based on style rather than anatomy.

This workshop deplores the fact that we would find it difficult to document our disapproval of many recent shoe fashions in strictly bioengineering terms, or give good advice about improvement except in general terms. This demonstrates the backwardness of the state of the art at the shoe-foot interface. We wish to state with a sense of urgency the need to develop at least three national centers for shoe technology in which bioengineers and physicians may work together with industry representatives to develop guidelines for special shoes for hyposensitive, for hypersensitive, and fordeformed feet. There is also the need to study the natural history of the deformities of the foot of the elderly American so that guidelines may be developed for the shoemaking industry that will allow Americans to grow up without deformity and, when they reach old age, to walk without pain.

EXTERNAL PROSTHETICS AND ORTHOTICS

Miami, Florida

April 1-3, 1977

Chairmen: Newton McCullough
Raplh R. Snell

No. of Participants: 57

Representation: Orthopedics, physical medicine, prosthetics, orthotics, engineering, occupational and physical therapy.

Publisher: Rehabilitation Engineering Center
Moss Rehabilitation Hospital
Philadelphia, Pa.

General Observations and Recommendations:

1. A tremendous void has been left by the departure of the Committee on Prosthetics Research and Development. Some of the functions that are missed which were provided by CPRD are:
   a. Central clearing house for information
   b. Evaluation program for devices and techniques
   c. Organization of workshops, conferences, etc.
   d. Peer review of research and development
   e. Correlation of activites.

   It is recommended that a new group be established to carry out these functions.
2. The curricula of the formal prosthetics and orthotics education programs need to be brought up to date. The education programs should be more deeply involved in research and evaluation than is the case presently, if the schools are expected to continue to meet the needs of rehabilitation.
3. The American Academy of Orthotists and Prosthetists should expand its role in continuing education, and should become involved in evaluation of new devices and techniques that many emerge from research and development groups and practitioners.
4. The buyers of services need to be better informed about prosthetics, orthotics, and the potentials of prophylaxis. Representatives of third party payers often seem to have a very narrow view of the benefits made possible by treatment that falls outside of present regulations.
5. Special Centers are needed to provide for the requirements of the severely handicapped. Research and teaching should be included in the responsibility of these Centers.
6. Improved cosmesis is needed in practically all aspects of prosthetics and orthotics. Cosmetic covers have presented problems, especially economic ones, for years.
7. Improved connections between the patient and the appliances are indicated. More information about the effects of pressure on human tissues is needed in order for significant progress to be made in this area. Support of work on skeletal attachment of prostheses should be continued.
8. Improved sensory feedback is needed for practically every type of externally powered prostheses and orthoses. Without sensory feedback, the patient is not able to control his appliance without conscious thought and visual cues, and even highly motivated patients often discard their appliances feeling that the effort required for operation is not worth the functions obtained.
9. Summary and review articles gleaned from orthopedic journals should be published in orthotic and prosthetic publications and vice versa.

Recommendations of the Panels:

Upper-Limb Prosthetics

1. A more efficient mechanical (body-powered) hand is needed.
2. Provisions should be made for interchangeability of externally powered hands and hooks.
3. An improved joint for the elbow-disarticulation prosthesis is needed. The strength of present joints is marginal.
4. An "active" elbow for the endoskeletal above-elbow prosthesis is needed. Present devices are passive, and therefore provide very little function.
5. Multifunctional control systems are needed for above-elbow, shoulder-disarticulation, forequarter, and high bilateral cases.
6. An externally powered shoulder joint is needed. All shoulder joints available are passive.
7. A study in socket design for shoulder-disarticulation and forequarter patients is needed. Present designs are uncomfortably warm and possibly unnecessarily restric-

tive. The designs suggested by Ring and Kiessling should be evaluated.

8. Studies to improve sensory feedback are needed. No doubt, the low acceptance rate of externally powered prostheses and orthoses is due to the low order of sensory feedback present.
9. The effects of weight reduction in upper-limb prostheses should be studied. This aspect of upper-limb prosthetics has been overlooked completely.
10. Harnessing techniques and power transmission systems need study and improvement. The harness systems for the above-elbow unilateral amputee is notoriously uncomfortable and inefficient.
11. The osteotomy technique developed by Marquardt to provide better connection between humeral stump and prosthesis should be evaluated.
12. Systems consisting of both externally powered and body powered components should be considered. Such hybrid systems may be able to take advantage of the positive attributes of both body power and external power.
13. Research and development in externally powered systems should be continued with emphasis on sensory feedback, including proprioception, and control by myoelectric and neuroelectric signals.

Lower-Limb Prosthetics

1. A workshop is needed to provide the basis for an advanced text on amputation surgery. The latest experiences in amputation surgery need to be published to provide the guidelines for all surgeons who are to perform amputations.
2. Definitive sockets that can be adjusted readily for daily changes in stump volume are needed. Sporadic attempts have not been successful, but it is felt that an appropriate group concentration on the problem could be productive.
3. Studies of the design of artificial feet need to be reinstituted. Scientific inquiry into the design of artificial feet seems to have subsided after the introduction of the SACH foot.
4. An up-to-date protocol for management of patients pre-surgery, during, and post-surgery, including prescription principles, needs to be published.
5. The effects of weight and weight distribution of artificial legs needs to be studied. The need for light artificial legs seems to have been obscured by the introduction of improved methods of fitting, alignment, and knee-control units. Such studies are possible and practical now that ultralight lower-limb prostheses are available.
6. Improved hip joints for the hip-disarticulation and hemipelvectomy patients are needed. Although the present designs are well received it is felt that refinements are possible.
7. An improved knee joint to provide braking is needed. Refinement of present designs seems possible and practical.
8. An adjustable alignment leg that can be controlled remotely, and also by the patient, is needed. Hobson and Foort demonstrated that such an approach has the potential for providing useful information.
9. A workshop is needed to bring up to date above-knee casting, fitting, and alignment procedures. Although the basic principles set forth by the University of California in the late '50s are still valid, a number of refinements in procedures have been introduced but have not been published adequately for teaching.
10. A workshop on training patients to use lower-limb prostheses is needed. The available texts on training lower-limb amputees to use their prostheses are more general than it seems that they need to be.
11. An electronic knee unit that permits voluntary control of the knee by above-knee amputees is needed. Presently the above-knee amputee has less than adequate control of the artificial knee. Experience with myoelectric control systems and microcomputers suggests that voluntary control of the artificial knee might be possible and practical.
12. A workshop on management of partial-foot and Syme amputees is needed. Many refinements and some significant advances have been made since the last guidelines for management of these patients were published.
13. A survey should be made concerning the PTB socket modifications currently in use. It is well known that a number of variations of the PTB are being used successfully throughout the world but no comprehensive evaluation has been made of the individual techniques. Data useful in teaching could be obtained by a comprehensive survey.

Upper-Limb Orthotics

1. A study of the prehension patterns of quadraplegic patients is needed to determine better approaches to prehension that might be provided by orthoses.
2. The use of electromyographic and neuroelectric signals for control of orthoses should be studied. Experience with EMG in prosthetics should be helpful. New information concerning the neuroelectric signals should be investigated with respect to application to control of orthoses.
3. Hybrid systems should be developed and evaluated. Combinations of external power and body power should be explored to determine if the advantages of both systems can be preserved in one, at least on an interim basis.
4. Manipulators should be evaluated. Several systems designed to provide functions for the quadraplegic, but not connected to his body, are available in the prototype stage.
5. The development of more functional orthoses for quadraplegics with lesions at or about the C-6 level should be given priority.
6. Improved arm swing designs should be developed.
7. An elbow flexion assist is needed for ambulatory patients with flail arms.

Lower-Limb Orthotics

1. Improved designs for joints, especially knee joints, are required. A special joint is needed for patients with spasticity.
2. Systems for maintenance of the integrity of the knee joint, such as the Martin, Lenox Hill, and Veterans Administration systems should be evaluated.
3. The shoe should be considered as a component in the lower-limb orthotic system in education programs and in delivery systems.

Spinal Orthotics

1. A method of analysis and evaluation using objective engineering principles should be developed.
2. A method to "unload" or distract the spine and immobilize the head without skull pins should be developed. Mandible and anterior neck should be free.
3. A new orthosis for immobilization of the upper thoracic spine, (T-1—T-8) should be developed.
4. Development of a semi-flexible lumbar support (probably of molded plastic) is needed.
5. A better method of orthotic fixation of the pelvis should be developed for lumbosacral orthoses.
6. Corset supports should be re-designed to be more comfortable, more stable, more easily applied, more easily adjusted, and constructed from better fabrics.
7. For scoliosis and kyphosis an orthosis is needed to *correct* deformities, preferably without a neck ring.
8. Improvement is needed in scoliosis and kyphosis orthoses for treatment of rib deformity and rotation, in upper thoracic and cervical curves.
9. An improved orthosis for scoliosis in infants should be developed.
10. Improved cosmesis is needed in spinal orthotics for adolescents.
11. An improved orthosis for the elderly kyphotic person is needed.
12. Improved materials and design for orthoses is needed for patients with sensory deficit.
13. Specialized local treatment centers for scoliosis and kyphosis should be established.
14. An organization of orthotists interested in scoliosis should be formed to work with the Scoliosis Research Society.
15. The education of orthotists should include the x-ray evaluation of spinal deformities.
16. Coordination is required between G.U. and general surgery and the orthotic profession to accomplish more optimal placement of urinary ostomies.

APPENDIX B

LIST OF REHABILITATION ENGINEERING CENTERS

RSA Rehabilitation Engineers Centers

PGN 23-P-55442/9
Dr. James B. Reswick
Project Director
Rehabilitation Engineering Center
Rancho Los Amigos Hospital
7601 East Imperial Highway
Downey, California 90242
Telephone 213-922-7167
Core Area: "Functional Electrical Stimulation of Paralyzed Nerves and Muscles"

PGN 23-P-55518/3
Mr. A. Bennett Wilson, Jr.
Project Director
Rehabilitation Engineering Center
Krusen Research Center
Moss Rehabilitation Hospital
12th Street and Tabor Road
Philadelphia, Pennsylvania 19141
Telephone 215-329-9580
Core Area: "Locomotion and Mobility"

PGN 23-P-55854/1
Dr. William Berenberg
Project Director
Rehabilitation Engineering Center
Children's Hospital Medical Center
300 Longwood Avenue
Boston, Massachusetts 02115
Telephone 617-734-6000, Ext. 2866
Core Area: "Neuromuscular Control Using Sensory Feedback Systems"

PGN 23-P-57888/6
Dr. William A. Spencer
Project Director
Rehabilitation Engineering Center
Texas Institute for Rehabilitation and Research
1333 Moursund Avenue
Houston, Texas 77025
Telephone 713-797-1440
Core Area: "Effects of Pressure on Tissue"

PGN 23-P-55898/5
Dr. Clinton L. Compere
Project Director
Rehabilitation Engineer Center
Northwestern University
345 East Superior Street
Room 1441
Chicago, Illinois 60611
Telephone 312-649-8560
Core Area: "Internal Total Joint Replacement"

PGN 23-P-57176/7
Dr. Carroll B. Larson
Project Director
Rehabilitation Engineer Center
University of Iowa
Orthopedics Department
Dill Children's Hospital
Iowa City, Iowa 52242
Telephone 319-356-3468
Core Area: "Low Back Pain"

PGN 23-P-57590/9
Dr. Lawrence A. Scadden
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Rehabilitation Engineer Center
Smith-Kettlewell Institute of Visual Sciences
2232 Webster Street
San Francisco, California 94115
Telephone 415-563-2323
Core Area: "Sensory Aids Blind and Deaf"

PGN 23-P-57937/4
Dr. Robert E. Tooms
Project Diector
Rehabilitation Engineer Center
The University of Tennessee
Department of Orthopedic Surgery
1248 LaPaloma Street
Memphis, Tennessee 38114
Telephone 901-525-2531
Core Area: "Mobility Systems for Severely Disabled"

RECs Con't.

PGN 23-P-57957/5
Dr. Charles H. Herndon
Project Director
Rehabilitation Engineering Center
Case Western Reserve University
School of Medicine
2219 Adelbert Road
Cleveland, Ohio 44106
Telephone 216-791-7300
Core Area: "Upper Extremity Functional Electrical Stimulation"

PGN 23-P-57960/7
Mr. John F. Jonas, Jr.
Project Director
Rehabilitation Engineering Center
Cerebral Palsy Research Foundation of Kansas, Inc.
4320 East Kellogg Street
Wichita, Kansas 67218
Telephone 316-683-5627
Core Area: "Vocational Aspects of Rehabilitation"

PGN 23-P-57961/5
Prof. J. Raymond Pearson
Project Director
Rehabilitation Engineering Center
The University of Michigan
College of Engineering
225 West Engineering
Ann Arbor, Michigan 48109
Telephone 313-764-8464
Core Area: "Automotive Transportation for the Handicapped"

PGN 23-P- 57995/3 Dr Colin McLaurin
Dr. Warren G. Stamp
Project Director
Rehabilitation Engineering Center
School of Medicine
University of Virginia
P.O. Box 3368, University Station
Charlottesville, Virginia 22903
Telephone 804-977-6730
Core Area: "Spinal Cord Injury"

Rehabilitation Engineering at RSA Research and Training Centers

RT-1

PGN 16-P-56801/)2
Dr. Howard A. Rusk
Project Director
Medical Rehabilitation R&T Center
New York University
400 East 34th Street
New York, New York 10016
Telephone 212-679-3200
Core Area: "Evaluation of Functional Performance of Devices for Severely Disabled Individuals"

RT-7

PGN 16-P-56800/1
Dr. Paul Corcoran
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Medical Rehabilitation R&T Center
Tufts University
171 Harrison Avenue
Boston, Massachusetts 02111
Telephone 617-956-5625
Core Area: "Communication Systems for Individuals with Nonvocal Disabilities"

RSA Rehabilitation Engineering Centers International

PGN 19-P-58030
Dr. Salah Hommossani
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Ministry of Social Affairs
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Rehabilitation Engineering Center
Wafa Wa Amal
Core Area: "Architectural Barriers"

PGN 19-P-58345
Prof. A. Senger, M.D.
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Rehabilitation Engineering Center
Core Area: "Upper Extremity Disabilities"

PGN 19-P-58451
Dr. Lojze Vodovnik
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61001 Ljubljana, Trzaska 25
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Project Director
Rehabilitation Engineering Center
Core Area: "Functional Electrical Stimulation"

Rehabilitation Engineering Centers In The Veterans Administration

Anthony Staros
Director
VA Prosthetics Center
252 Seventh Avenue
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Dr. Wilton Bunch
Acting Director
Hines Rehabilitative Engineering
R&D Center
VA Hospital
Hines, Illinois 60141
Telephone 312-531-3280

APPENDIX C
LIST OF REHABILITATION ENGINEERING PROJECTS
VAPC* Medical Care Extramural Contracts FY 76

INSTITUTION	*PROJECT TITLE*
Jet Propulsion Laboratory	Wheelchair Mounted Manipulator Systems
Rancho Los Amigos Hospital	Functional Electric Stimulation Wrist and Finger Hemiplegic
Southwest Research Institute	Lunar Rover Controls
Whittaker Corp.	Physiological Monitor
Southwest Research Institute	Cardio Respiratory Alarm System
Biomedical Engineering Institute University of Southern California	Physiological Monitors
Center for Concerned Engineering	Parapodium/Transporter
Scientific Systems International	5-Station Food Server
Browning Mfg. Co.	Graphite Composite Sach Foot Keel
Southwest Research Institute	High Strength Light Weight Joints
Scope Electronics, Inc.	Mechanically Operated Voice Synthesizer
Unite De Recherches Biomechaniques	Force Sensitive Automotive Controller
Dialog System, Inc.	Voice Recognition and Control System
Threshold Technology	Voice Recognition Manipulator Controller
Research Foundation of the City University of New York (Queens College)	Speech Activated Controller (SAC)
University of Belgrade	Three Analog Electronic Control

VAPC R&D Extramural Contracts (Interim Qtr.)

INSTITUTION	*PROJECT TITLE*
George Washington University Medical Center	Improved Cosmetic Gloves
Texas A&M University	Advanced Automotive Adaptive Equipment

*VAPC—Veterans Administration Prosthetics Center

VAPC R&D Extramural Contracts FY 77

INSTITUTION	*PROJECT TITLE*
Rancho Los Amigos Hospital	Biofeedback Clinical Application in Conjunction with F.E.S. for Hemiplegics
Center for Concerned Engineering	Standing, Sitting, Squatting Mobility
Center For Orthotics Design	VA Adult Parapodium with Matching Transporter
Rancho Los Amigos Hospital	Gait Analyzer Mark II
Helen Hayes Hospital	Biofeedback F.E.S.
Naval Ocean Systems Center	Standup Wheelchair
Sharpe Health School	Driving by Means of a Foot Steering Control
George Washington University Medical Center	Coatings for Artificial Limbs
University of California at Santa Barbara	Voice Controlled Manipulator
National Aeronautics and Space Administration	Automotive Control

VAPC Medical Care Extramural Contracts FY 77

INSTITUTION	*PROJECT TITLE*
Helen Hayes Hospital	Cushion Evaluation for Wheelchairs and Beds
Rancho Los Amigos Hospital	Sensory Feedback in Upper Extremity Prostheses
Southwest Research Institute	Testing of Wheelchair Restraint Systems
Staircat Incorporated	Analyses of Stair-Climbing Wheelchair
Department of Physical Education University of Seattle	Sports Activities
AOPA-ABC-AAOP	Evaluation of Prosthetic and Orthotic Devices (Prosthetic Skin)
National Amputation Foundation	Survey of Amputees

VAPC Medical Care Extramural Contracts (Interim Qtr.)

INSTITUTION	*PROJECT TITLE*
Threshold Technology	Voice Recognition Manipulator Controller
University of California at Los Angeles	Evaluation of Medical Manipulator

Rehabilitation Engineering Projects Sponsored by RSA

INSTITUTION	*PROJECT TITLE*
Electronic Industries Foundation	A production and marketing strategy for prototype devices developed under the Rehabilitation Engineering Program.
Hospital for Special Surgery	Rehabilitation of the knee and finger joints.
Virginia Polytechnic Institute	Designs of bathroom fixtures and controls for the able-bodied and disabled.
Southwest Research Institute	Employability restoration engineering program for severely handicapped.
George Washington University Research & Training Center	1. Job development and enhanced productivity for severely disabled. 2. Opening science careers to the handicapped. 3. Job development and bio-engineering for severely disabled persons.
Tufts New England Medical Center	1. Research in upper and lower extremities orthotics. 2. Tufts Interactive Communicator.
Helen Hayes Hospital	Identification and control of biophysical factors responsible for soft tissue breakdown.
Stanford Research Institute	Communication device for deaf or mute persons.

APPENDIX D

BIBLIOGRAPHY

Related to the Disabled Population

The following Social Security administration reports are published by their Office of Research and Statistics. They can be ordered from the Office of Publications, Room 1120, Universal Building North, 1875 Connecticut Avenue, N.W., Washington, D.C. 20009.

1. Disability Survey 69. Followup of Disabled Adults, Report No. 1. October 1975.
2. Changes in Personal Care Needs and Living Arrangements of the Noninstitutionalized Disabled, 1966-69. Mary Ellen Burdette. Report No. 2, January 1976.
3. Work experience of the Disabled, 1966 and 1969: A Followup Study. Edward Steinberg. Report No. 3, March 1976.
4. Changes in the Income of Disabled Persons, 1965 and 1968. Philip Frohlich. Report No. 4, May 1976.
5. Changes in Severity of Disability, 1966-69: Relationship to Characteristics of the Disabled Population. Donald T. Ferron. Report No. 5, June 1976.
6. Changes in Selected Aspects of Health Care Among the Disabled, 1966-69. Charles Croner and Edward Steinberg.
7. Disability Survey 71. Recently Disabled Adults. Income of the Newly Disabled: Survey of Recently Disabled Adults. Philip Frohlich. Reprinted from the Social Security Bulletin, September 1975. Report No. 2, September 1975.
8. Selected Health Characteristics. Charles M. Croner, Report No. 3, January 1976.
9. Work adjustment of the Recently Disabled. Edward Steinberg. Report No. 4, April 1976
10. General Characteristics of the Recently Disabled. Mildred Cinsky and Edward Steinberg. Report No. 5, May 1976.
11. Personal Care and Household Help Needs of Recently Disabled Adults. Mary Ellen Burdette.
12. Disability Survey 72. Disabled and Nondisabled Adults. First Findings of the 1972 Survey of the Disabled: General Characteristics. Kathryn H. Allan, Report No. 2, March 1977.
13. Functional Capacity Limitations and Disability, 1972. Iris Posner.

The following is a Bureau of the Census report:

1. Persons with Work Disabilities. P.C. (2)-6C. Order from: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. $3.20.

The following is a Veterans Administration report:

1. The Biometrics Division of the Veterans Administration has detailed information on service and nonservice connected disabilities for veterans. Contact them at 810 Vermont Avenue, Washington, D.C. 20402.

The following is a Natonal Association of the Deaf report:

1. The Deaf Population of the United States. Jerome D. Schein and Marcus T. Delk, Jr. Conducted by the Association in cooperation with the Deafness Research and Training Center, New York University. Available for $11.50 hardcover and $7.50 paperback. Pub. No. RS-009. National Association of the Deaf, 814 Thayer avenue, Silver Spring, Maryland 20910.

The following reports were issued by the Natonal Center for Health Statistics and may be ordered from them at Room 157 Center Building, 3700 East-West Highway, Hyattsville, Maryland 20782.

1. Limitation of Activity Due to Chronic Conditions, United States 1969 and 1970. Series 10, number 80.
2. Current Estimates from the Health Interview Survey, United States 1972. Series 10, number 85.
3. Prevalence of Selected Impairments, United States 1971. Series 10, number 99.

APPENDIX E

Excerpt from the

REHABILITATION ACT OF 1973

(as amended by Public Law 93-516)

Section 3 (b)

The Secretary, through the Commissioner in coordination with other appropriate programs in the Department of Health, Education, and Welfare, in carrying out research under this Act shall establish the expertise and technological competence to, and shall, in consultation with, the National Science Foundation and the National Academy of Sciences develop and support, and stimulate the development and utilization (including production and distribution of new and existing devices) of, innovative methods of applying advanced medical technology, scientific achievement, and psychological and social knowledge to solve rehabilitation problems, and be responsible for carrying out the activities described in section 202 (b) (2).

Section 202 (b) (2)

Establishment and support of Rehabilitation Engineering research Centers to (A) develop innovative methods of applying advanced medical technology, scientific achievement, and psychological and social knowledge to solve rehabilitation problems through planning and conducting research, including cooperative research with public or private agencies and organizations, designed to produce new scientific knowledge, equipment, and devices suitable for solving problems in the rehabilitation of handicapped individuals and for reducing environmental barriers, and to (B) cooperate with State agencies designated pursuant to section 101 in developing systems of information exchange and coordination to promote the prompt utilization of engineering and other scientific research to assist in solving problems in the rehabilitation of handicapped individuals.

APPENDIX F

FEDERAL GOVERNMENT AGENCIES CONCERNED WITH REHABILITATION ENGINEERING

Veterans Administration
Vermont Ave. and H Streets, N.W.
Washington, D.C. 20420

Rehabilitation Services Administration
Office of Human Development Services
Department of Health, Education, and Welfare
Mary E. Switzer Building
Washington, D.C.

Biomedical Engineering Program
National Institute of Neurological and Communicative Disorders and Stroke
Room 1016A, Federal Building
7550 Wisconsin Avenue
Bethesda, Maryland 20015

National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

Office of Environmental Affairs
Office of Assistant Secretary for Environmental Safety
Department of Transportation
Room 9420, 400 Seventh Street, S.W.
Washington, D.C. 20024

Committee of Technology Utilization
U.S. House of Representatives
Washington, D.C. 20515

National Aeronautics and Space Administration
600 Independence Avenue, S.W.
Washington, D.C. 20546

Division of Medical Device Standards and Research
Bureau of Medical Devices and Diagnostic Products
Food and Drug Administration
Washington, D.C. 20204

Office for Handicapped Individuals
Office of Human Development Services
Room 3511, Mary E. Switzer Building
Washington, D.C. 20201

Bureau of Education of the Handicapped
Office of Education
Room 2010, Regional Office Building
7th and D Streets, S.W.
Washington, D.C. 20201

Architectural and Transportation Barriers Compliance Board
Office of Human Development Services
Room 1010, Mary E. Switzer Building
Washington, D.C. 20201

Director, Office of Developmental Disabilities
Office of Human Development Services
Room 3070, Mary E, Switzer Building
Washington,D.C. 20201

Programs for the Elderly and Handicapped
Department of Housing and Urban Development
7th and D Streets, S.W.
Washington, D.C. 20410