5 REHABILITATION ENGINEERING AND ASSISTIVE TECHNOLOGY

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Chapter Contents

At the conclusion of this chapter, students will:

- Understand the role played by rehabilitation engineers and assistive technologists in the rehabilitation process.
- Be aware of the major activities in rehabilitation engineering.
- Be familiar with the physical and psychological consequences of disability.

- Know the principles of assistive technology assessment and its objectives and pitfalls.
- Discuss key engineering and ergonomic principles of the field.
- Describe career opportunities and information sources.

5.1 INTRODUCTION

Since the late 1970s, there has been major growth in the application of technology to ameliorate the problems faced by people with disabilities. Various terms have been used to describe this sphere of activity, including prosthetics/orthotics, rehabilitation engineering, assistive technology, assistive device design, rehabilitation technology, and even biomedical engineering applied to disability. With the gradual maturation of this field, several terms have become more widely used, bolstered by their use in some federal legislation.

The two most frequently used terms today are *assistive technology* and *rehabilitation engineering*. Although they are used somewhat interchangeably, they are not identical. In the words of James Reswick (1982), a pioneer in this field, ''rehabilitation engineering is the application of science and technology to ameliorate the handicaps of individuals with disabilities.'' In contrast, assistive technology can be viewed as a product of rehabilitation engineering activities. Such a relationship is analogous to health care being the product of the practice of medicine.

One widely used definition for assistive technology is found in Public Law 100-407. It defines assistive technology as ''any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase or improve functional capabilities of individuals with disabilities.'' Notice that this definition views assistive technology as a broad range of devices, strategies, and/or services that help an individual to better carry out a functional activity. Such devices can range from low-technology devices that are inexpensive and simple to make to high-technology devices that are complex and expensive to fabricate. Examples of low-tech devices include dual-handled utensils and mouth sticks for reaching. High-tech examples include computer-based communication devices, reading machines with artificial intelligence, and externally powered artificial arms (Fig. 5.1).

Several other terms often used in this field include rehabilitation technology and orthotics and prosthetics. Rehabilitation technology is that segment of assistive technology that is designed specifically to rehabilitate an individual from his or her present set of limitations due to some disabling condition, permanent or otherwise. In a classical sense, orthotics are devices that augment the function of an extremity, whereas prosthetics replace a body part both structurally and functionally. These two terms now broadly represent all devices that provide some sort of functional replacement. For example, an augmentative communication system is sometimes referred to as a speech prosthesis.

5.1.1 History

A brief discussion of the history of this field will explain how and why so many different yet similar terms have been used to denote the field of assistive technology

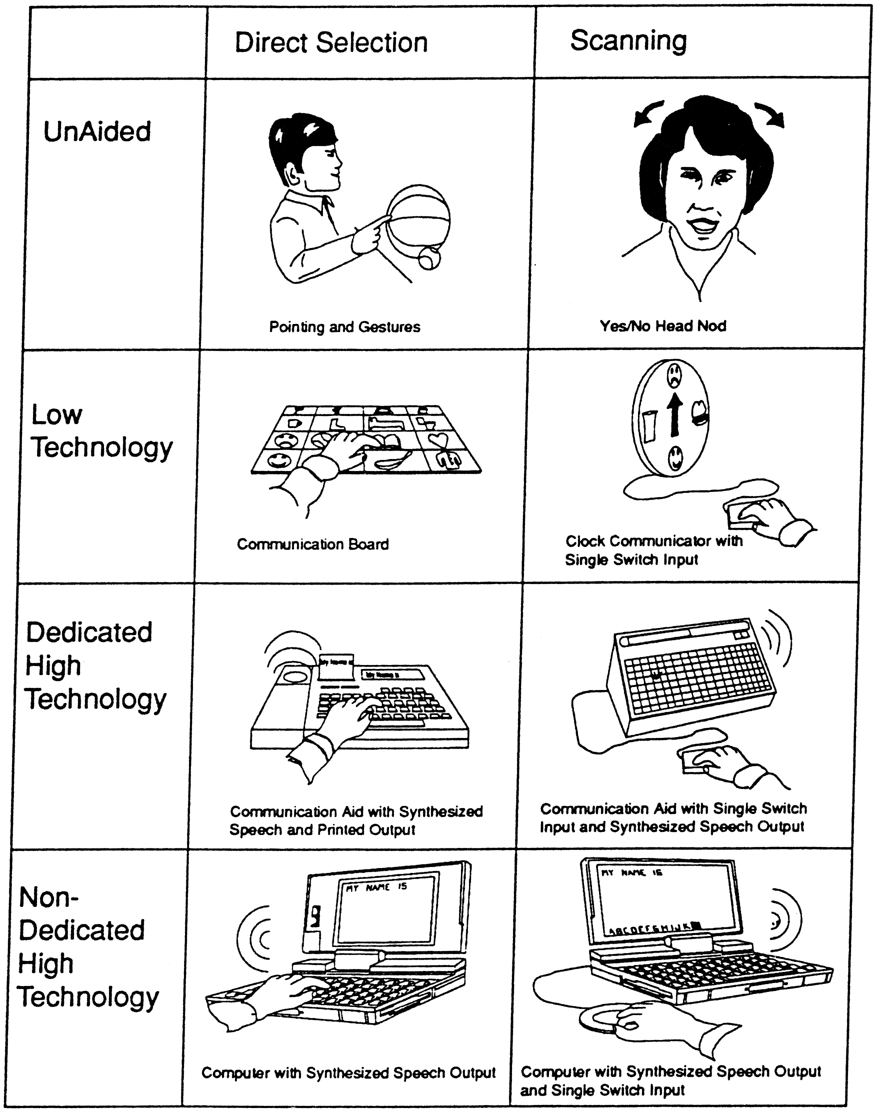


Figure 5.1 Augmentative communication classification system (from Church and Glennen, 1992).

and rehabilitation. Throughout history, people have sought to ameliorate the impact of disabilities by using technology. This effort became more pronounced and concerted in the United States after World War II. The Veterans Administration (VA) realized that something had to be done for the soldiers who returned from war with numerous and serious handicapping conditions. There were too few well-trained artificial limb and brace technicians to meet the needs of the returning soldiers. To train these much-needed providers, the federal government supported the establishment of a number of prosthetic and orthotic schools in the 1950s.

The VA also realized that the state of the art in limbs and braces was primitive and ineffectual. The orthoses and prostheses available in the 1940s were uncomfortable, heavy, and offered limited function. As a result, the federal government established the Veterans Administration Prosthetics Research Board, whose mission was to improve the orthotics and prosthetic appliances that were available. Scientists and engineers formerly engaged in defeating the Axis powers now turned their energies toward helping people, especially veterans with disabilities. As a result of their efforts, artificial limbs, electronic travel guides, and wheelchairs that were more rugged, lighter, cosmetically appealing, and effective were developed.

The field of assistive technology and rehabilitation engineering was nurtured by a two-pronged approach in the federal government. One approach directly funded research and development efforts that would utilize the technological advances created by the war effort toward improving the functioning and independence of injured veterans. The other approach helped to establish centers for the training of prosthetists and orthotists, forerunners of today's assistive technologists.

In the early 1960s, another impetus to rehabilitation engineering came from birth defects in infants born to expectant European women who took thalidomide to combat "morning sickness." The societal need to enable children with severe deformities to lead productive lives broadened the target population of assistive technology and rehabilitation engineering to encompass children as well as adult men. Subsequent medical and technical collaboration in research and development produced externally powered limbs for people of all sizes and genders, automobiles that could be driven by persons with no arms, sensory aids for the blind and deaf, and various assistive devices for controlling a person's environment.

Rehabilitation engineering received formal governmental recognition as an engineering discipline with the landmark passage of the federal Rehabilitation Act of 1973. The act specifically authorized the establishment of several centers of excellence in rehabilitation engineering. The formation and supervision of these centers were put under the jurisdiction of the National Institute for Handicapped Research, which later became the National Institute on Disability and Rehabilitation Research (NIDRR). By 1976, about 15 Rehabilitation Engineering Centers (RECs), each focusing on a different set of problems, were supported by grant funds totaling about $9 million per year. As the key federal agency in the field of rehabilitation, NIDRR also supports rehabilitation engineering and assistive technology through its Rehabilitation Research and Training Centers, Field Initiated Research grants, Research and Demonstration program, and Rehabilitation Fellowships (NIDRR, 1999).

The REC grants initially supported university-based rehabilitation engineering research and provided advanced training for graduate students. Beginning in the mid-1980s, the mandate of the RECs was broadened to include technology transfer and service delivery to persons with disabilities. During this period, the VA also established three of its own RECs to focus on some unique rehabilitation needs of veterans. Areas of investigation by VA and non-VA RECs include prosthetics and orthotics, spinal cord injury, lower and upper limb functional electrical stimulation, sensory aids for the blind and deaf, effects of pressure on tissue, rehabilitation robotics, technology transfer, personal licensed vehicles, accessible telecommunications, applications of wireless technology, and vocational rehabilitation. Another milestone, the formation of the Rehabilitation Engineering Society of North America (RESNA) in 1979, gave greater focus and visibility to rehabilitation engineering. Despite its name, RESNA is an inclusive professional society that welcomes everyone involved with the development, manufacturing, provision, and usage of technology for persons with disabilities. Members of RESNA include occupational and physical therapists, allied health professionals, special educators, and users of assistive technology. RESNA has become an adviser to the government, a developer of standards and credentials, and, via its annual conferences and its journal, a forum for exchange of information and a showcase for state-of-the art rehabilitation technology. In recognition of its expanding role and members who were not engineers, RESNA modified its name in 1995 to the Rehabilitation Engineering and Assistive Technology Society of North America.

Despite the need for and the benefits of providing rehabilitation engineering services, reimbursement for such services by third-party payers (e.g., insurance companies, social service agencies, and government programs) remained very difficult to obtain during much of the 1980s. Reimbursements for rehabilitation engineering services often had to be subsumed under more accepted categories of care such as client assessment, prosthetic/orthotic services, or miscellaneous evaluation. For this reason, the number of practicing rehabilitation engineers remained relatively static despite a steadily growing demand for their services.

The shortage of rehabilitation engineers with suitable training and experience was specifically addressed in the Rehab Act of 1986 and the Technology-Related Assistance Act of 1988. These laws mandated that rehabilitation engineering services had to be available and funded for disabled persons. They also required an individualized work and rehabilitation plan (IWRP) for each vocational rehabilitation client. These two laws were preceded by the original Rehab Act of 1973 which mandated reasonable accommodations in employment and secondary education as defined by a least restrictive environment (LRE). Public Law 95-142 in 1975 extended the reasonable accommodation requirement to children 5–21 years of age and mandated an individual educational plan (IEP) for each eligible child. Table 5.1 summarizes the major United Stated Federal legislation that has affected the field of assistive technology and rehabilitation engineering.

In concert with federal legislation, several federal research programs have attempted to increase the availablity of rehabilitation engineering services for persons with disabilities. The National Science Foundation (NSA), for example, initiated a program called Bioengineering and Research to Aid the Disabled. The program's goals were (1) to provide student-engineered devices or software to disabled individuals that would improve their quality of life and degree of independence, (2) to enhance the education of student engineers through real-world design experiences, and (3) to allow the university an opportunity to serve the local community. The Office of Special Education and Rehabilitation Services in the U.S. Department of Education funded special projects and demonstration programs that addressed identified needs such as model assessment programs in assistive technology, the application of technology for deaf–blind children, interdisciplinary training for students of communicative

TABLE 5.1 Recent Major U.S. Federal Legislation Affecting Assistive Technologies

Legislation	Major Assistive Technology Impact
Rehabilitation Act of 1973, as amended	Mandates reasonable accommodation and least restricted environment in federally funded employment and higher education; requires both assistive technology devices and services be included in state plans and Individualized Written Rehabilitation Plans (IWRP) for each client; Section 508 mandates equal access to electronic office equipment for all federal employees; defines rehabilitation technology as rehabilitation engineering and assistive technology devices and services; mandates rehabilitation technology as primary benefit to be included in IWRP
Individuals with Disabilities Education Act Amendments of 1997	Recognizes the right of every child to a free and appropriate education; includes concept that children with disabilities are to be educated with their peers; extends reasonable accommodation, least restrictive environment (LRE), and assistive technology devices and services to age 3–21 education; mandates Individualized Educational Plan for each child, to include consideration of assistive technologies; also includes mandated services for children from birth to 2 and expanded emphasis on educationally related assistive technologies
Assistive Technology Act of 1998 (replaced Technology Related Assistance for Individuals with Disabilities Act of 1998)	First legislation to specifically address expansion of assistive technology devices and services; mandates consumer-driven assistive technology services, capacity building, advocacy activities, and statewide system change; supports grants to expand and administer alternative financing of assistive technology systems
Developmental Disabilities Assistance and Bill of Rights Act	Provides grants to states for developmental disabilities councils, university-affiliated programs, and protection and advocacy activities for persons with developmental disabilities; provides training and technical assistance to improve access to assistive technology services for individuals with developmental disabilities
Americans with Disabilities Act (ADA) of 1990	Prohibits discrimination on the basis of disability in employment, state and local government, public accommodations, commercial facilities, transportation, and telecommunications, all of which affect the application of assistive technology; use of assistive technology impacts requirement that Title II entities must communicate effectively with people who have hearing, vision, or speech disabilities; addresses telephone and television access for people with hearing and speech disabilities
Medicaid	Income-based (“means-tested”) program; eligibility and services differ from state to state; federal government sets general program requirements and provides financial assistance to the states by matching state expenditures; assistive technology benefits differ for adults and children from birth to age 21; assistive technology for adults must be included in state’s Medicaid plan or waiver program
Early Periodic Screening, Diagnosis, and Treatment Program	Mandatory service for children from birth through age 21; includes any required or optional service listed in the Medicaid Act; service need not be included in the state’s Medicaid plan
Medicare	Major funding source for assistive technology (durable medical equipment); includes individuals 65 or over and those who are permanently and totally disabled; federally administered with consistent rules for all states

From Cook and Hussey (2002).

disorders (speech pathologists), special education, and engineering. In 1993, NIDRR committed $38.6 million to support Rehabilitation Engineering Centers that would focus on the following areas: adaptive computers and information systems, augmentative and alternative communication devices, employability for persons with low back pain, hearing enhancement and assistive devices, prosthetics and orthotics, quantification of physical performance, rehabilitation robotics, technology transfer and evaluation, improving wheelchair mobility, work site modifications and accommodations, geriatric assistive technology, personal licensed vehicles for disabled persons, rehabilitation technology services in vocational rehabilitation, technological aids for blindness and low vision, and technology for children with orthopedic disabilities. In fiscal year 1996, NIDRR funded 16 Rehabilitation Engineering Research Centers at a total cost of $11 million dollars and 45 Rehabilitation Research and Training Centers at a cost of $23 million dollars (NIDRR, 1999).

5.1.2 Sources of Information

Like any other emerging discipline, the knowledge base for rehabilitation engineering was scattered in disparate publications in the early years. Owing to its interdisciplinary nature, rehabilitation engineering research papers appeared in such diverse publications as the *Archives of Physical Medicine & Rehabilitation, Human Factors, Annals of Biomedical Engineering, IEEE Transactions on Biomedical Engineering*, and *Biomechanics*. Some of the papers were very practical and application specific, whereas others were fundamental and philosophical. In the early 1970s, many important papers were published by the Veterans Administration in its *Bulletin of Prosthetic Research*, a highly respected and widely disseminated peer-reviewed periodical. This journal was renamed the *Journal of Rehabilitation R&D* in 1983. In 1989, RESNA began *Assistive Technology*, a quarterly journal that focused on the interests of practitioners engaged in technological service delivery rather than the concerns of engineers engaged in research and development. The IEEE Engineering in Medicine and Biology Society founded the *IEEE Transactions on Rehabilitation Engineering* in 1993 to give scientifically based rehabilitation engineering research papers a much-needed home. This journal, which was renamed *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, is published quarterly and covers the medical aspects of rehabilitation (rehabilitation medicine), its practical design concepts (rehabilitation technology), its scientific aspects (rehabilitation science), and neural systems.

5.1.3 Major Activities in Rehabilitation Engineering

The major activities in this field can be categorized in many ways. Perhaps the simplest way to grasp its breadth and depth is to categorize the main types of assistive technology that rehabilitation engineering has produced (Table 5.2). The development of these technological products required the contributions of mechanical, material, and electrical engineers, orthopedic surgeons, prosthetists and orthotists, allied health professionals, and computer professionals. For example, the use of voice in many assistive devices, as both inputs and outputs, depends on digital signal processing chips, memory chips, and sophisticated software developed by electrical and computer engineers. Figures 5.2 through 5.4 illustrate some of the assistive technologies currently available. As explained in subsequent sections of this chapter, the proper design, development, and application of assistive technology devices

TABLE 5.2 Categories of Assistive Devices

Prosthetics and Orthotics
Artificial hand, wrist, and arms
Artificial foot and legs
Hand splints and upper limb braces
Functional electrical stimulation orthoses
Assistive Devices for Persons with Severe Visual Impairments
Devices to aid reading and writing (e.g., closed circuit TV magnifiers, electronic Braille, reading machines, talking calculators, auditory and tactile vision substitution systems)
Devices to aid independent mobility (e.g., Laser cane, Binaural Ultrasonic Eyeglasses, Handheld Ultrasonic Torch, electronic enunciators, robotic guide dogs)
Assistive Devices for Persons with Severe Auditory Impairments
Digital hearing aids
Telephone aids (e.g., TDD and TTY)
Lipreading aids
Speech to text converters
Assistive Devices for Tactile Impairments
Cushions
Customized seating
Sensory substitution
Pressure relief pumps and alarms
Alternative and Augmentative Communication Devices
Interface and keyboard emulation
Specialized switches, sensors, and transducers
Computer-based communication devices
Linguistic tools and software
Manipulation and Mobility Aids
Grabbers, feeders, mounting systems, and page turners
Environmental controllers
Robotic aids
Manual and special-purpose wheelchairs
Powered wheelchairs, scooters, and recliners
Adaptive driving aids
Modified personal licensed vehicles
Recreational Assistive Devices
Arm-powered cycles
Sports and racing wheelchairs
Modified sit-down mono-ski

require the combined efforts of engineers, knowledgeable and competent clinicians, informed end users or consumers, and caregivers.

5.2 THE HUMAN COMPONENT

To knowledgeably apply engineering principles and fabricate devices that will help persons with disabling conditions, it is necessary to have a perspective on the

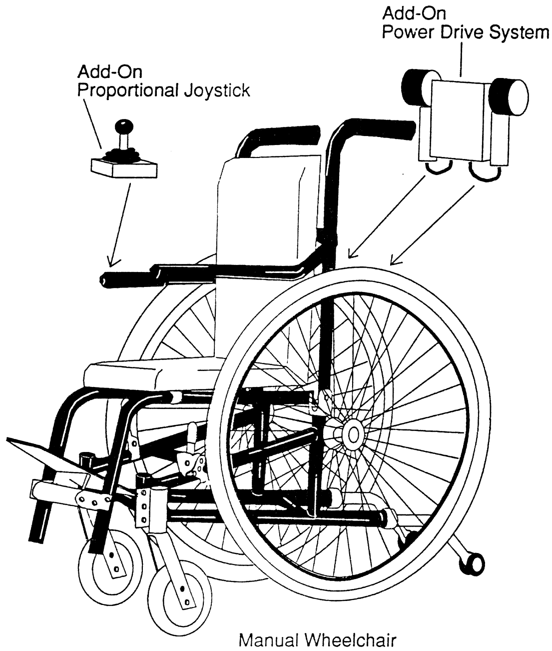


Figure 5.2 Add-on wheelchair system (from Church and Glennen, 1992).

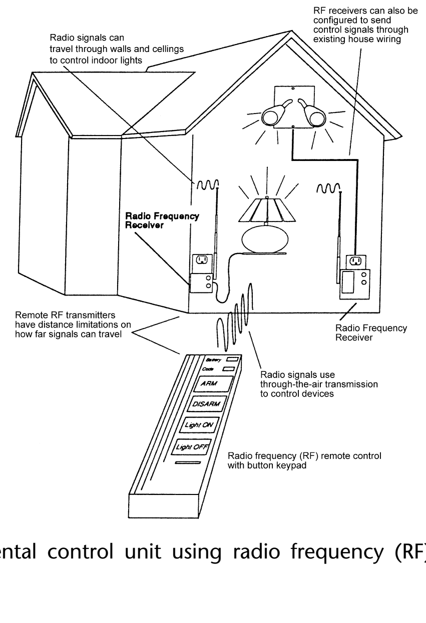


Figure 5.3 Environmental control unit using radio frequency (RF) control (from Church and Glennen, 1992).

human component and the consequence of various impairments. One way to view a human being is as a receptor, processor, and responder of information (Fig. 5.5). The human user of assistive technology perceives the environment via senses and responds or manipulates the environment via effectors. Interposed between the sensors and effectors are central processing functions that include perception, cognition, and movement control. *Perception* is the way in which the human being interprets the incoming sensory data. The mechanism of perception relies on the neural circuitry found in the peripheral nervous system and central psychological factors such as memory of previous sensory experiences. *Cognition* refers to activities that underlie problem solving, decision making, and language formation. *Movement control* utilizes the outcome of the processing functions described previously to form a motor pattern that is executed by the effectors (nerves, muscles, and joints). The impact of the effectors on the environment is then detected by the sensors, thereby providing feedback between the human and the environment. When something goes wrong in the information processing chain, disabilities often result. Table 5.3 lists the prevalence of various disabling conditions in terms of anatomic locations.

Interestingly, rehabilitation engineers have found a modicum of success when trauma or birth defects damage the input (sensory) end of this chain of information processing. When a sensory deficit is present in one of the three primary sensory channels (vision, hearing, and touch), assistive devices can detect important environmental information and present it via one or more of the other remaining senses. For example, sensory aids for severe visual impairments utilize tactile and/or auditory outputs to display important environmental information to the user. Examples of such sensory aids include laser canes, ultrasonic glasses, and robotic guide dogs. Rehabilitation engineers also have been modestly successful at replacing or augmenting some motoric (effector) disabilities (Fig. 5.6). As listed in Table 5.2, these include artificial arms and legs, wheelchairs of all types, environmental controllers, and, in the future, robotic assistants.

However, when dysfunction resides in the "higher information processing centers" of a human being, assistive technology has been much less successful in ameliorating the resultant limitations. For example, rehabilitation engineers and speech pathologists have been unsuccessful in enabling someone to communicate effectively when that person has difficulty formulating a message (aphasia) following a stroke. Despite the variety of modern and sophisticated alternative and augmentative communication devices that are available, none has been able to replace the volitional aspects of the human being. If the user is unable to cognitively formulate a message, an augmentative communication device is often powerless to help.

An awareness of the psychosocial adjustments to chronic disability is desirable because rehabilitation engineering and assistive technology seek to ameliorate the consequences of disabilities. Understanding the emotional and mental states of the person who is or becomes disabled is necessary so that offers of assistance and recommendations of solutions can be appropriate, timely, accepted, and, ultimately, used.

One of the biggest impacts of chronic disability is the minority status and socially devalued position that a disabled person experiences in society. Such loss of social

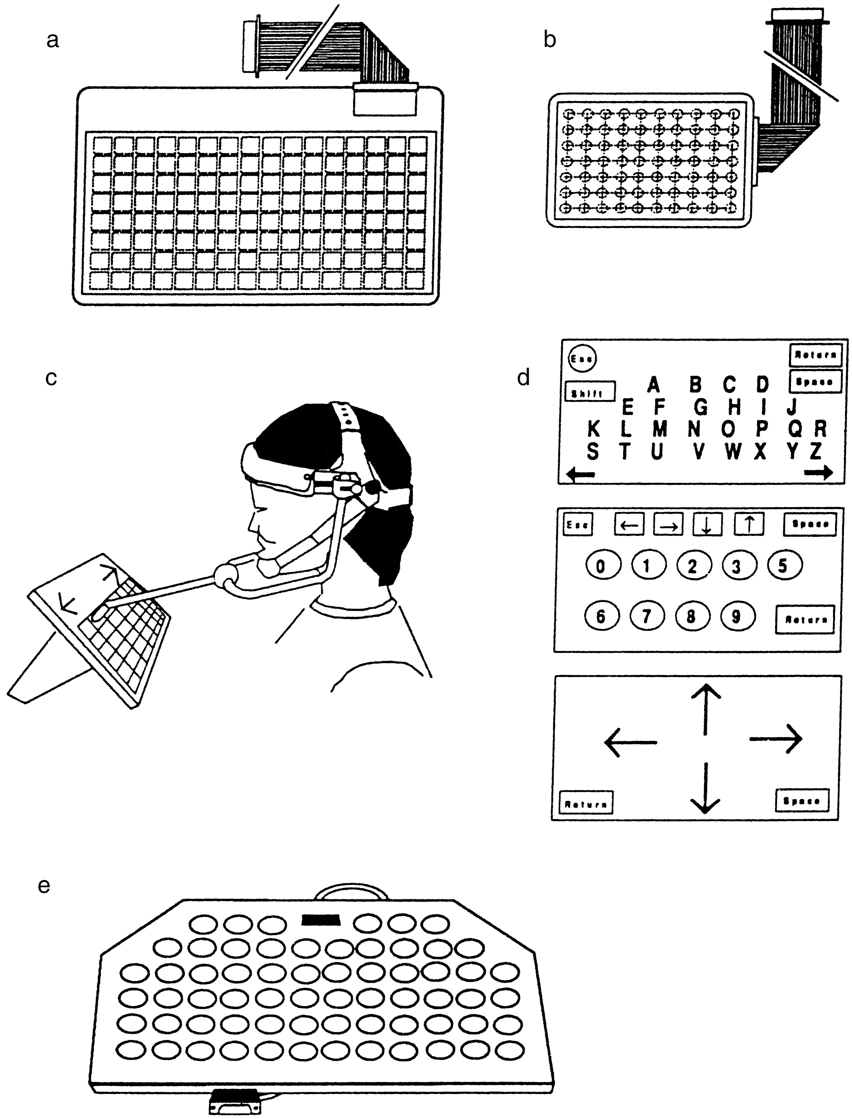


Figure 5.4 Alternative keyboards can replace or operate in addition to the standard keyboard. (a) Expanded keyboards have a matrix of touch-sensitive squares that can be grouped together to form larger squares. (b) Minikeyboards are small keyboards with a matrix of closely spaced touch-sensitive squares. (c) The small size of a minikeyboard ensures that a small range of movement can reach the entire keyboard. (d) Expanded and minikeyboards use standard or customized keyboard overlays. (e) Some alternative keyboards plug directly into the keyboard jack of the computer, needing no special interface or software (from Church and Glennen, 1992).

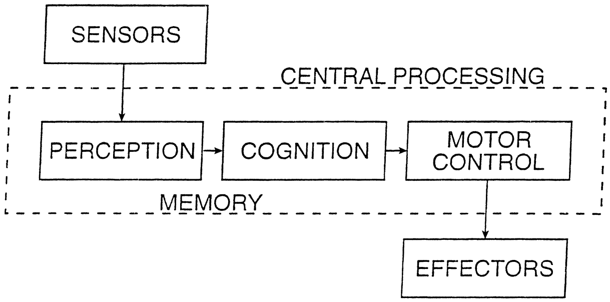


Figure 5.5 An information processing model of the human operator of assistive technologies. Each block represents a group of functions related to the use of technology.

TABLE 5.3 Prevalence of Disabling Conditions in the United States

45–50 million persons have disabilities that slightly limit their activities
32% hearing
21% sight
18% back or spine
16% leg and hip
5% arm and shoulder
4% speech
3% paralysis
1% limb amputation
7–11 million persons have disabilities that significantly limit their activities
30% back or spine
26% leg and hip
13% paralysis
9% hearing
8% sight
7% arm and shoulder
4% limb amputation
3% speech

Data from Stolov and Clowers (1981).

status may result from the direct effects of disability (social isolation) and the indirect effects of disability (economic setbacks). Thus, in addition to the tremendous drop in personal income, a person who is disabled must battle three main psychological consequences of disability: the loss of self-esteem, the tendency to be too dependent on others, and passivity.

For individuals who become disabled through traumatic injuries, the adjustment to disability generally passes through five phases: shock, realization, defensive retreat or denial, acknowledgment, and adaptation or acceptance. During the first days after the onset of disability, the individual is usually in shock, feeling and reacting minimally

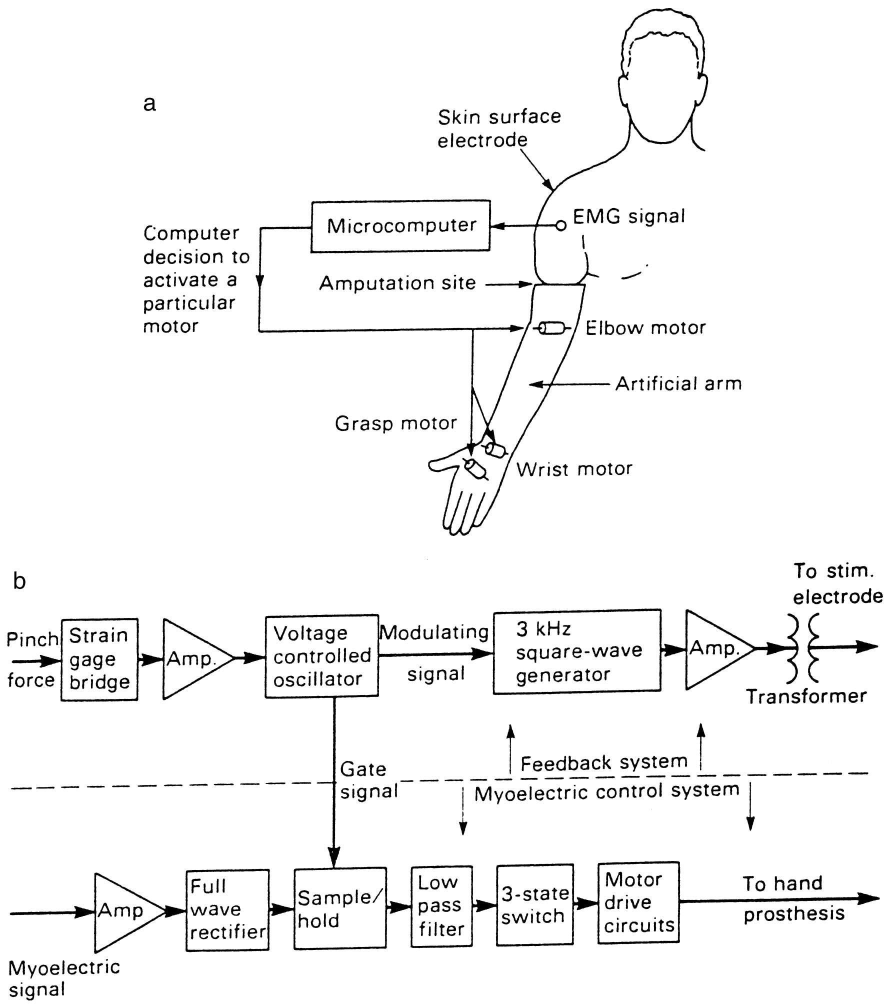


Figure 5.6 (a) This system generates temporal signatures from one set of myoelectric electrodes to control multiple actuators. (b) Electrical stimulaton of the forearm to provide force feedback may be carried out using a system like this one (from Webster et al., 1985).

with the surroundings and showing little awareness of what has happened. Counseling interventions or efforts of rehabilitation technologists are typically not very effective at this time.

After several weeks or months, the individual usually begins to acknowledge the reality and seriousness of the disability. Anxiety, fear, and even panic may be the predominant emotional reactions. Depression and anger may also occasionally appear during this phase. Because of the individual's emotional state, intense or sustained intervention efforts are not likely to be useful during this time.

In the next phase, the individual makes a defensive retreat in order to not be psychologically overwhelmed by anxiety and fear. Predominant among these defenses is denial—claiming that the disability is only temporary and that full recovery will occur. Such denial may persist or reappear occasionally long after the onset of disability.

Acknowledgment of the disability occurs when the individual achieves an accurate understanding of the nature of the disability in terms of its limitations and likely outcome. Persons in this phase may exhibit a thorough understanding of the disability but may not possess a full appreciation of its implications. The gradual recognition of reality is often accompanied by depression and a resultant loss of interest in many activities previously enjoyed.

Adaptation, or the acceptance phase, is the final and ultimate psychological goal of a person's adjustment to disability. An individual in this phase has worked through the major emotional reactions to disability. Such a person is realistic about the likely limitations and is psychologically ready to make the best use of his or her potential. Intervention by rehabilitation engineers or assistive technologists during the acknowledgment and acceptance phases of the psychosocial adjustment to disability is usually appropriate and effective. Involvement of the disabled individual in identifying needs, planning the approach, and choosing among possible alternatives can be very beneficial both psychologically and physically.

5.3 PRINCIPLES OF ASSISTIVE TECHNOLOGY ASSESSMENT

Rehabilitation engineers not only need to know the physical principles that govern their designs, but they also must adhere to some key principles that govern the applications of technology for people with disabilities. To be successful, the needs, preferences, abilities, limitations, and even environment of the individual seeking the assistive technology must be carefully considered. There are at least five major misconceptions that exist in the field of assistive technology:

Misconception #1. *Assistive technology can solve all the problems*. Although assistive devices can making accomplishing tasks easier, technology alone cannot mitigate all the difficulties that accompany a disability.

Misconception #2. *Persons with the same disability need the same assistive devices*. Assistive technology must be individualized because similarly disabled persons can have very different needs, wants, and preferences (Wessels et al., 2003).

Misconception #3. *Assistive technology is necessarily complicated and expensive*. Sometimes low-technology devices are the most appropriate and even preferred for their simplicity, ease of use and maintenance, and low cost.

Misconception #4. *Assistive technology prescriptions are always accurate and optimal*. Experiences clearly demonstrate that the application of technology for persons with disabilities is inexact and will change with time. Changes in the assistive technology user's health, living environment, preferences, and circumstances will require periodic reassessment by the user and those rehabilitation professionals who are giving assistance (Philips and Zhao, 1993).

Misconception #5. *Assistive technology will always be used*. According to data from the 1990 U.S. Census Bureau's National Health Interview Survey, about one-third of the assistive devices not needed for survival are unused or abandoned just 3 months after they were initially acquired.

In addition to avoiding common misconceptions, a rehabilitation engineer and technologist should follow several principles that have proven to be helpful in matching appropriate assistive technology to the person or consumer. Adherence to these principles will increase the likelihood that the resultant assistive technology will be welcomed and fully utilized.

Principle #1. *The user's goals, needs, and tasks must be clearly defined, listed, and incorporated as early as possible in the intervention process*. To avoid overlooking needs and goals, checklists and premade forms should be used. A number of helpful assessment forms can be found in the references given in the suggested reading list at the end of this chapter.

Principle #2. *Involvement of rehabilitation professionals with differing skills and know-how will maximize the probability for a successful outcome*. Depending on the purpose and environment in which the assistive technology device will be used, a number of professionals should participate in the process of matching technology to a person's needs. Table 5.4 lists various technology areas and the responsible professionals.

Principle #3. *The user's preferences, cognitive and physical abilities and limitations, living situation, tolerance for technology, and probable changes in the future must be thoroughly assessed, analyzed, and quantified*. Rehabilitation engineers will find that the highly descriptive vocabulary and qualitative language used by nontechnical professionals needs to be translated into attributes that can be measured and quantified. For example, whether a disabled person can use one or more upper limbs should be quantified in terms of each limb's ability to reach, lift, and grasp.

Principle #4. *Careful and thorough consideration of available technology for meeting the user's needs must be carried out to avoid overlooking potentially useful solutions*. Electronic databases (e.g., assistive technology websites and websites of major technology vendors) can often provide the rehabilitation engineer or assistive technologist with an initial overview of potentially useful devices to prescribe, modify, and deliver to the consumer.

Principle #5. *The user's preferences and choice must be considered in the selection of the assistive technology device*. Surveys indicate that the main reason assistive technology is rejected or poorly utilized is inadequate consideration of the user's

TABLE 5.4 Professional Areas in Assistive Technology

Technology Area	Responsible Professionals*
Academic and vocational skills	Special education
	Vocational rehabilitation
	Psychology
Augmentative communication	Speech–language pathology
	Special education
Computer access	Computer technology
	Vocational rehabilitation
Daily living skills	Occupational therapy
	Rehabilitation technology
Specialized adaptations	Rehabilitation engineering
	Computer technology
	Prosthetics/orthotics
Mobility	Occupational therapy
	Physical therapy
Seating and positioning	Occupational therapy
	Physical therapy
Written communication	Speech–language pathology
	Special education

*Depending on the complexity of technical challenges encountered, an assistive technologist or a rehabilitation engineer can be added to the list of responsible professionals.

needs and preferences. Throughout the process of searching for appropriate technology, the ultimate consumer of that technology should be viewed as a partner and stakeholder rather than as a passive, disinterested recipient of services.

Principle #6. *The assistive technology device must be customized and installed in the location and setting where it primarily will be used*. Often seemingly minor or innocuous situations at the usage site can spell success or failure in the application of assistive technology.

Principle #7. *Not only must the user be trained to use the assistive device, but also the attendants or family members must be made aware of the device's intended purpose, benefits, and limitations*. For example, an augmentative communication device usually will require that the communication partners adopt a different mode of communication and modify their behavior so that the user of this device can communicate a wider array of thoughts and even assume a more active role in the communication paradigm, such as initiating a conversation or changing the conversational topic. Unless the attendants or family members alter their ways of interacting, the newly empowered individual will be dissuaded from utilizing the communication device, regardless of how powerful it may be.

Principle #8. *Follow-up, readjustment, and reassessment of the user's usage patterns and needs are necessary at periodic intervals*. During the first 6 months following the delivery of the assistive technology device, the user and others in that environment learn to accommodate to the new device. As people and the environment change, what worked initially may become inappropriate, and the assistive device may need to be reconfigured or reoptimized. Periodic follow-up and adjustments will lessen technology abandonment and the resultant waste of time and resources.

5.4 PRINCIPLES OF REHABILITATION ENGINEERING

Knowledge and techniques from different disciplines must be utilized to design technological solutions that can alleviate problems caused by various disabling conditions. Since rehabilitation engineering is intrinsically multidisciplinary, identifying universally applicable principles for this emerging field is difficult. Often the most relevant principles depend on the particular problem being examined. For example, principles from the fields of electronic and communication engineering are paramount when designing an environmental control system that is to be integrated with the user's battery-powered wheelchair. However, when the goal is to develop an implanted functional electrical stimulation orthosis for an upper limb impaired by spinal cord injury, principles from neuromuscular physiology, biomechanics, biomaterials, and control systems would be the most applicable.

Whatever the disability to be overcome, however, rehabilitation engineering is inherently design oriented. Rehabilitation engineering design is the creative process of identifying needs and then devising an assistive device to fill those needs. A systematic approach is essential to successfully complete a rehabilitation project. Key elements of the design process involve the following sequential steps: analysis, synthesis, evaluation, decision, and implementation.

Analysis

Inexperienced but enthusiastic rehabilitation engineering students often respond to a plea for help from someone with a disability by immediately thinking about possible solutions. They overlook the important first step of doing a careful analysis of the problem or need. What they discover after much ineffectual effort is that a thorough investigation of the problem is necessary before any meaningful solution can be found. Rehabilitation engineers first must ascertain where, when, and how often the problem arises. What is the environment or the task situation? How have others performed the task? What are the environmental constraints (size, speed, weight, location, physical interface, etc.)? What are the psychosocial constraints (user preferences, support of others, gadget tolerance, cognitive abilities, and limitations)? What are the financial considerations (purchase price, rental fees, trial periods, maintenance and repair arrangements)? Answers to these questions will require diligent investigation and quantitative data such as the weight and size to be lifted, the shape and texture of the object to be manipulated, and the operational features of the desired device. An excellent endpoint of problem analysis would be a list of operational features or performance specifications that the "ideal" solution should possess.

Such a list of performance specifications can serve as a valuable guide for choosing the best solution during later phases of the design process.

Example Problem 5.1

Develop a set of performance specifications for an electromechanical device to raise and lower the lower leg of a wheelchair user (to prevent edema).

Solution

A sample set of performance specifications about the ideal mechanism might be written as follows:

- Be able to raise or lower leg in 5 s
- Independently operable by the wheelchair occupant
- Have an emergency stop switch
- Compatible with existing wheelchair and its leg rests
- Quiet operation
- Entire adaptation weighs no more than five pounds ■

Synthesis

A rehabilitation engineer who is able to describe in writing the nature of the problem is likely to have some ideas for solving the problem. Although not strictly sequential, the synthesis of possible solutions usually follows the analysis of the problem. The synthesis of possible solutions is a creative activity that is guided by previously learned engineering principles and supported by handbooks, design magazines, product catalogs, and consultation with other professionals. While making and evaluating the list of possible solutions, a deeper understanding of the problem usually is reached and other, previously not apparent, solutions arise. A recommended endpoint for the synthesis phase of the design process includes sketches and technical descriptions of each trial solution.

Evaluation

Depending on the complexity of the problem and other constraints such as time and money, the two or three most promising solutions should undergo further evaluation, possibly via field trials with mockups, computer simulations, and/or detailed mechanical drawings. Throughout the evaluation process, the end user and other stakeholders in the problem and solution should be consulted. Experimental results from field trials should be carefully recorded, possibly on videotape, for later review. One useful method for evaluating promising solutions is to use a quantitative comparison chart to rate how well each solution meets or exceeds the performance specifications and operational characteristics based on the analysis of the problem.

Decision

The choice of the final solution is often made easier when it is understood that the final solution usually involves a compromise. After comparing the various promising solutions, more than one may appear equally satisfactory. At this point, the final decision may be made based on the preference of the user or some other intangible factor that is difficult to anticipate. Sometimes choosing the final solution may involve consulting with someone else who may have encountered a similar problem. What is most important, however, is careful consideration of the user's preference (principle 5 of assistive technology).

Implementation

To fabricate, fit, and install the final (or best) solution requires additional project planning that, depending on the size of the project, may range from a simple list of tasks to a complex set of scheduled activities involving many people with different skills.

Example Problem 5.2

List the major technical design steps needed to build the automatic battery-powered leg raiser described in Example Problem 5.1.

Solution

The following are some of the key design steps:

- Mechanical design of the linkages to raise the wheelchair's leg rests
- Static determination of the forces needed to raise the occupant's leg
- Determination of the gear ratios and torque needed from the electric motor
- Estimation of the power drain from the wheelchair batteries
- Purchase of the electromechanical components
- Fabrication of custom parts and electronic components
- Assembly, testing, and possible redesign
- Field trials and evaluation of prototype device ■

5.4.1 Key Engineering Principles

Each discipline and subdiscipline that contributes to rehabilitation engineering has its own set of key principles that should be considered when a design project is begun. For example, a logic family must be selected and a decision whether to use synchronous or asynchronous sequential circuits must be made at the outset in digital design. A few general hardware issues are applicable to a wide variety of design tasks, including worst-case design, computer simulation, temperature effects, reliability, and product safety. In worst-case design, the electronic or mechanical system must continue to operate adequately even when variations in component values degrade performance. Computer simulation and computer-aided design (CAD) software often can be used to predict how well an overall electronic system will perform under different combinations of component values or sizes.

The design also should take into account the effects of temperature and environmental conditions on performance and reliability. For example, temperature extremes can reduce a battery's capacity. Temperature also may affect reliability, so proper venting and use of heat sinks should be employed to prevent excessive temperature increases. For reliability and durability, proper strain relief of wires and connectors should be used in the final design.

Product safety is another very important design principle, especially for rehabilitative or assistive technology. An electromechanical system should always incorporate a panic switch that will quickly halt a device's operation if an emergency arises. Fuses and heavy-duty gauge wiring should be employed throughout for extra margins of safety. Mechanical stops and interlocks should be incorporated to ensure proper interconnections and to prevent dangerous or inappropriate movement.

When the required assistive device must lift or support some part of the body, an analysis of the static and dynamic forces (biomechanics) that are involved should be performed. The simplest analysis is to determine the static forces needed to hold the object or body part in a steady and stable manner. The basic engineering principles needed for static and dynamic analysis usually involve the following steps: (1) Determine the force vectors acting on the object or body part, (2) determine the moment arms, and (3) ascertain the centers of gravity for various components and body segments. Under static conditions, all the forces and moment vectors sum to zero. For dynamic conditions, the governing equation is Newton's second law of motion in which the vector sum of the forces equals mass times an acceleration vector ($F = ma$).

Example Problem 5.3

Suppose a 125-lb person lies supine on a board resting on knife edges spaced 72 in. apart (Fig. 5.7). Assume that the center of gravity of the lower limb is located through the center line of the limb and 1.5 in. above the knee cap. Estimate the weight of this person's right leg.

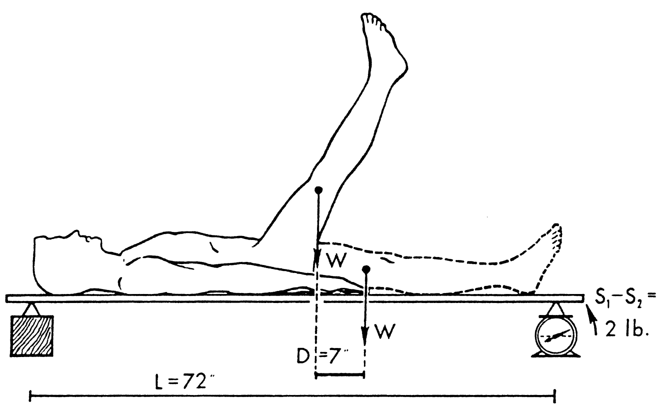


Figure 5.7 Method of weighing body segments with board and scale (from Le Veau, 1976).

Solution

Record the scale reading with both legs resting comfortably on the board and when the right leg is raised almost straight up. Sum the moments about the left knife edge pivot to yield the following static equation:

$$WD = L(S_1 - S_2)$$

where W is the weight of the right limb, L is the length of the board between the supports, S_1 is the scale reading with both legs resting on the board, S_2 is the scale reading with the right leg raised, and D is the horizontal distance through which the limb's center of gravity was moved when the limb was raised. Suppose the two scale readings were 58 lbs for S_1 and 56 lbs for S_2 and $D = 7$ in. Substituting these values into the equations would yield an estimate of 20.6 lbs as the weight of the right leg. ■

Example Problem 5.4

A patient is exercising his shoulder extensor muscles with wall pulleys (Fig. 5.8). Weights of 20, 10, and 5 lbs are loaded on the weight pan, which weighs 4 lbs. The patient is able to exert 45 lbs on the pulley. What is the resultant force of the entire system? What are the magnitude and direction of acceleration of the weights?

Solution

All the weights and the pan act straight down, whereas the 45 lbs of tension on the pulley's cable exerts an upward force. The net force (F) is 6 lbs upward. Using Newton's second law of motion, $F = ma$, where m is the mass of the weights and the pan and a is the acceleration of the weights and pan. The mass, m, is found by dividing the weight of 39 lbs by the acceleration of gravity (32.2 ft/s^2) to yield $m =$ 1.21 slugs. Substituting these values into $a = F / m$ yields an acceleration of 4.96 ft/s^2 in the upward direction.

5.4.2 Key Ergonomic Principles

Ergonomics or human factors is another indispensable part of rehabilitation engineering and assistive technology design. Applying information about human behavior, abilities, limitations, and other characteristics to the design of tools, adaptations, electronic devices, tasks, and interfaces is especially important when designing assistive technology because persons with disabilities generally will be less able to accommodate poorly designed or ill-fitted assistive devices. Several ergonomic principles that are especially germane to rehabilitation engineering are discussed in the following sections.

Principle of Proper Positioning

Without proper positioning or support, an individual who has lost the ability to maintain a stable posture against gravity may appear to have greater deformities and functional limitations than truly exist. For example, the lack of proper arm support may make the operation of even an enlarged keyboard unnecessarily slow

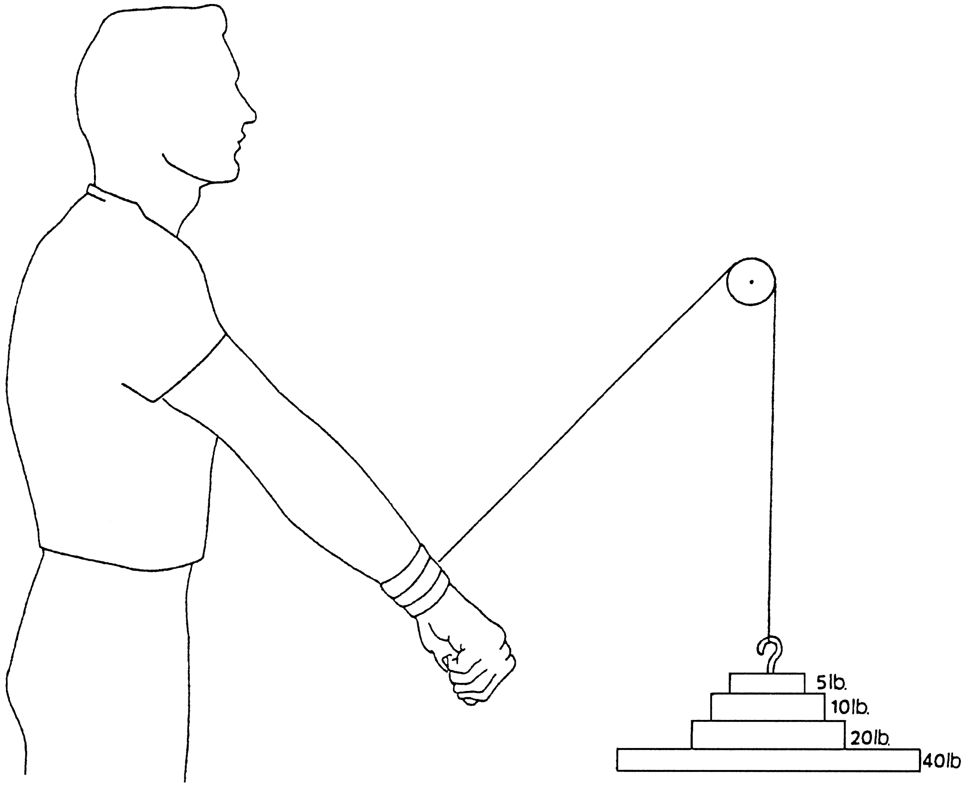


Figure 5.8 Patient exercising his shoulder extensor muscles with wall pulleys (from Le Veau, 1976).

or mistake prone. Also, the lack of proper upper trunk stability may unduly limit the use of an individual's arms because the person is relying on them for support.

During all phases of the design process, the rehabilitation engineer must ensure that whatever adaptation or assistive technology is being planned, the person's trunk, lower back, legs, and arms will have the necessary stability and support at all times (Fig. 5.9). Consultation with a physical therapist or occupational therapist familiar with the focus individual during the initial design phases should be considered if postural support appears to be a concern. Common conditions that require considerations of seating and positioning are listed in Table 5.5.

Principle of the Anatomical Control Site

Since assistive devices receive command signals from the users, users must be able to reliably indicate their intent by using overt, volitional actions. Given the variety of switches and sensors that are available, any part of the body over which the user has reliable control in terms of speed and dependability can serve as the anatomical control site. Once the best site has been chosen, an appropriate interface for that

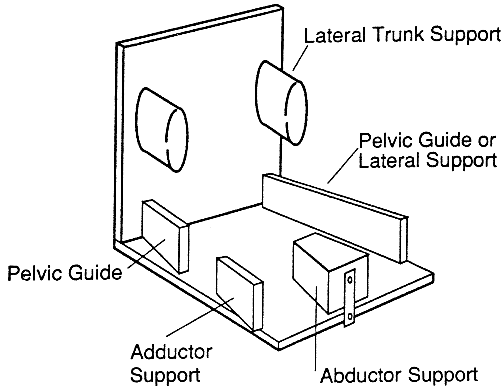


Figure 5.9 Chair adaptations for proper positioning (from Church and Glennen, 1992).

TABLE 5.5 Conditions That Require Consideration of Seating and Positioning

Condition	Description and Characteristics	Seating Considerations
Cerebral palsy	Nonprogressive neuromuscular	
Increased tone (high tone)	Fixed deformity, decreased movements, abnormal patterns	Correct deformities, improve alignment, decrease tone
Decreased tone (low tone)	Subluxations, decreased active movement, hypermobility	Provide support for upright positioning, promote development of muscular control
Athetoid (mixed tone)	Excessive active movement, decreased stability	Provide stability, but allow controlled mobility for function
Muscular dystrophies	Degenerative neuromuscular	
Duchenne	Loss of muscular control proximal to distal	Provide stable seating base, allow person to find balance point
Multiple sclerosis	Series of exacerbations and remissions	Prepare for flexibility of system to follow needs
Spina bifida	Congenital anomaly consisting of a deficit in one or more of the vertebral arches, decreased or absent sensation	Reduce high risk for pressure concerns, allow for typically good upper extremity and head control
Spinal cord injury	Insult to spinal cord, partial or complete loss of function below level of injury, nonprogressive once stabilized, decreased or absent sensation, possible scoliosis/kyphosis	Reduce high risk for pressure concerns, allow for trunk movements used for function
Osteogenesis imperfecta	Connective tissue disorder, brittle bone disease, limited functional range, multiple fractures	Provide protection
Orthopedic impairments	Fixed or flexible	If fixed, support, if flexible, correct

(continued)

TABLE 5.5 Conditions That Require Consideration of Seating and Positioning (Continued)

Condition	Description and Characteristics	Seating Considerations
Traumatic brain injury	Severity dependent on extent of central nervous system damage, may have cognitive component, nonprogressive once stabilized	Allow for functional improvement as rehabilitation progresses, establish a system that is flexible to changing needs
Elderly		
Typical aged	Often, fixed kyphosis, decreased bone mass, and decreased strength, incontinence	Provide comfort and visual orientation, moisture-proof, accommodate kyphosis
Aged secondary to primary disability	Example—older patients with cerebral palsy may have fixed deformities	Provide comfort, support deformities

Adapted with permission from *Evaluating, Selecting, and Using Appropriate Assistive Technology,* J. C. Galvin, M. J. Scherer, p. 66, © 1996 Aspen Publishers, Inc.

site can be designed by using various transducers, switches, joysticks, and keyboards. In addition to the obvious control sites such as the finger, elbow, shoulder, and knee, subtle movements such as raising an eyebrow or tensing a particular muscle can also be employed as the control signal for an assistive device. Often, the potential control sites can and should be analyzed and quantitatively compared for their relative speed, reliability, distinctiveness, and repeatability of control actions. Field trials using mock-ups, stopwatches, measuring tapes, and a video camera can be very helpful for collecting such performance data.

When an individual's physical abilities do not permit direct selection from among a set of possible choices, single switch activation by the anatomical control site in combination with automated row-column scanning of a matrix is often used. In row-column scanning, each row of a matrix lights up sequentially from the top to the bottom. When the row containing the desired item is highlighted, the user selects it using a switch. Then each item in that row is scanned (from left to right) until the desired item is chosen by a second switch activation. The speed with which a two-dimensional array can be used to compose messages depends on the placement of the letters in that array. Two popular arrangements of alphanumeric symbols—the alphabetic arrangement and the frequency of occurrence arrangement of the alphabet—are shown in Example Problem 5.5.

Example Problem 5.5

Assume that a communication device has either an alphabetical arrangement of letters or a frequency arrangement and does row-column scanning as follows: (1) Two switch activations are needed to select a particular item in the array; (2) The dwell time for each row (starting at the top) is 1.5 s; (3) The dwell time along a selected row (starting from the left) is 1.5 s; and (4) The scan begins at the top row after a successful selection.

For both arrangements, calculate the predicted time needed to generate the phrase "I WANT TO GO TO SEA WORLD." Assume zero errors or missed opportunities.

Alphabetical Arrangement of Letters

SPACE	A	B	C	D	E	F
G	H	I	J	K	L	M
N	O	P	Q	R	S	T
U	V	W	X	Y	Z	TH
IN	ER	RE	AN	HE	.	,

Frequency Arrangement of Letters

SPACE	E	A	I	L	HE	Y
T	O	S	D	P	AN	ER
N	R	C	F	IN	ES	Q
H	TH	M	B	V	X	Z
U	W	G	K	J	.	,

Solution

The time needed to compose the target sentence is equal to the number of steps needed to select each letter and space in that sentence. For the alphabetically arranged array, 5 dwell steps (2nd row plus 3rd column) at 1.5 s per step are needed to reach the letter *I*. For the frequency of occurrence array, 5 dwell steps (1st row plus 4th column) also are needed to reach the letter *I*. To insert a space, both arrays require 2 dwell steps (1st row plus 1st column). For the letter *W*, the same number of dwell steps (7) are needed in both arrays. For the letter *T*, however, 10 dwell steps are needed in the alphabetical array but just 3 dwell steps are needed in the frequency of occurrence array. Each time the letter *T* is used, 7 dwell steps (or 10.5 s) are saved with the frequency of occurrence array. Thus, the time needed to produce the sample sentence, assuming no errors, is 213 s when using the alphabetical array and 180 s when using the frequency array. Notice that even for a 7-word sentence, over half a minute can be saved with the faster frequency arrangement array and that additional time was saved by using the double letter combination *AN* rather than selecting the single letters *A* and *N* separately. ■

Principle of Simplicity and Intuitive Operation

The universal goal of equipment design is to achieve intuitively simple operation, and this is especially true for electronic and computer-based assistive devices. The key to intuitively simple operation lies in the proper choice of compatible and optimal controls and displays. *Compatibility* refers to the degree to which relationships between the control actions and indicator movements are consistent, respectively, with expectations of the equipment's response and behavior. When compatibility relationships are incorporated into an assistive device, learning is faster, reaction time is shorter, fewer errors occur, and the user's satisfaction is higher. Although people can and do learn to use adaptations that do not conform to their expectations, they do so at a price (producing more errors, working more slowly, and/or requiring more attention). Hence, the rehabilitation engineer needs to be aware of and follow some common compatibility relationships and basic ergonomic guidelines, such as:

- The display and corresponding control should bear a physical resemblance to each other.
- The display and corresponding control should have similar physical arrangements and/or be aided by guides or markers.
- The display and corresponding control should move in the same direction and within the same spatial plane (e.g., rotary dials matched with rotary displays, linear vertical sliders matched with vertical displays).
- The relative movement between a switch or dial should be mindful of population stereotypic expectations (e.g., an upward activation to turn something on, a clockwise rotation to increase something, and scale numbers that increase from left to right).

Additional guidelines for choosing among various types of visual displays are given in Table 5.6.

Principle of Display Suitability

In selecting or designing displays for transmission of information, the selection of the sensory modality is sometimes a foregone conclusion, such as when designing a warning signal for a visually impaired person. When there is an option, however, the rehabilitation engineer must take advantage of the intrinsic advantages of one sensory modality over another for the type of message or information to be conveyed. For example, audition tends to have an advantage over vision in vigilance types of warnings because of its attention-getting qualities. A more extensive comparison of auditory and visual forms of message presentation is presented in Table 5.7.

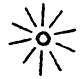
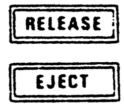
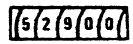
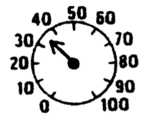
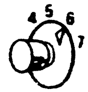
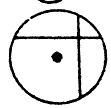
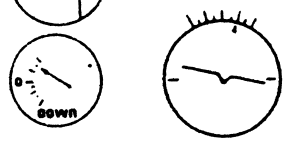
Principle of Allowance for Recovery from Errors

Both rehabilitation engineering and human factors or ergonomics seek to design assistive technology that will expand an individual's capabilities while minimizing errors. However, human error is unavoidable no matter how well something is designed. Hence, the assistive device must provide some sort of allowance for errors without seriously compromising system performance or safety. Errors can be classified as errors of omission, errors of commission, sequencing errors, and timing errors.

A well-designed computer-based electronic assistive device will incorporate one or more of the following attributes:

- The design makes it inherently impossible to commit the error (e.g., using jacks and plugs that can fit together only one way or the device automatically rejects inappropriate responses while giving a warning).
- The design makes it less likely, but not impossible to commit the error (e.g., using color-coded wires accompanied by easily understood wiring diagrams).
- The design reduces the damaging consequences of errors without necessarily reducing the likelihood of errors (e.g., using fuses and mechanical stops that limit excessive electrical current, mechanical movement, or speed).

TABLE 5.6 General Guide to Visual Display Selection

To Display	Select	Because	Example
Go, no go, start, stop, on, off	Light	Normally easy to tell if it is on or off.	
Identification	Light	Easy to see (may be coded by spacing, color, location, or flashing rate; may also have label for panel applications).	
Warning or caution	Light	Attracts attention and can be seen at great distance if bright enough (may flash intermittently to increase conspicuity).	
Verbal instruction (operating sequence)	Enunciator light	Simple "action instruction" reduces time required for decision making.	
Exact quantity	Digital counter	Only one number can be seen, thus reducing chance of reading error.	
Approximate quantity	Moving pointer against fixed scale	General position of pointer gives rapid clue to the quantity plus relative rate of change.	
Set-in quantity	Moving pointer against fixed scale	Natural relationship between control and display motions.	
Tracking	Single pointer or cross pointers against fixed index	Provides error information for easy correction.	
Vehicle attitude	Either mechanical or electronic display of position of vehicle against established reference (may be graphic or pictorial)	Provides direct comparison of own position against known reference or base line.	

Abstracted from Human Factors in Engineering and Design, 7th Ed., by Sanders and McCormick, 1993.

TABLE 5.7 Choosing Between Auditory and Visual Forms of Presentation

Use Auditory Presentation if	Use Visual Presentation if
The message is simple.	The message is complex.
The message is short.	The message is long.
The message will not be referred to later.	The message will be referred to later.
The message deals with events in time.	The message deals with location in space.
The message calls for immediate action.	The message does not call for immediate action.
The visual system of the person is overburdened.	The auditory system of the person is overburdened.
The message is to be perceived by persons not in the area.	The message is to be perceived by someone very close by.
Use artificially generated speech if the listener cannot read.	Use visual display if the message contains graphical elements.

Adapted and modified from Saunders and McCormick (1993, p. 53, Table 3-1).

- The design incorporates an "undo," "escape," or "go-back" command in devices that involve the selection of options within menus.

Principle of Adaptability and Flexibility

One fundamental assumption in ergonomics is that devices should be designed to accommodate the user and not vice versa. As circumstances change and/or as the user gains greater skill and facility in the operation of an assistive device, its operational characteristics must adapt accordingly. In the case of an augmentative electronic communication device, its vocabulary set should be changed easily as the user's needs, skills, or communication environment change. The method of selection and feedback also should be flexible, perhaps offering direct selection of the vocabulary choices in one situation while reverting to a simpler row-column scanning in another setting. The user should also be given the choice of having auditory, visual, or a combination of both as feedback indicators.

Principle of Mental and Chronological Age Appropriateness

When working with someone who has had lifelong and significant disabilities, the rehabilitation engineer cannot presume that the mental and behavioral age of the individual with disabilities will correspond closely with that person's chronological age. In general, people with congenital disabilities tend to have more limited variety, diversity, and quantity of life experiences. Consequently, their reactions and behavioral tendencies often mimic those of someone much younger. Thus, during assessment and problem definition, the rehabilitation engineer should ascertain the functional age of the individual to be helped. Behavioral and biographical information can be gathered by direct observation and by interviewing family members, teachers, and social workers.

Special human factor considerations also need to be employed when designing assistive technology for very young children and elderly individuals. When designing adaptations for such individuals, the rehabilitation engineer must consider that they may have a reduced ability to process and retain information. For example, generally more time is required for very young children and older people to retrieve information from long-term memory, to choose among response alternatives, and to execute correct responses. Studies have shown that elderly persons are much slower in searching for material in long-term memory, in shifting attention from one task to another, and in coping with conceptual, spatial, and movement incongruities.

The preceding findings suggest that the following design guidelines be incorporated into any assistive device intended for an elderly person:

- Strengthen the displayed signals by making them louder, brighter, larger, etc.
- Simplify the controls and displays to reduce irrelevant details that could act as sources of confusion.
- Maintain a high level of conceptual, spatial, and movement congruity, i.e., compatibility between the controls, display, and device's response.
- Reduce the requirements for monitoring and responding to multiple tasks.
- Provide more time between the execution of a response and the need for the next response. Where possible, let the user set the pace of the task.
- Allow more time and practice for learning the material or task to be performed.

5.5 PRACTICE OF REHABILITATION ENGINEERING AND ASSISTIVE TECHNOLOGY

5.5.1 Career Opportunities

As efforts to constrain health care costs intensify, it is reasonable to wonder whether career opportunities will exist for rehabilitation engineers and assistive technologists. Given an aging population, the rising number of children born with cognitive and physical developmental disorders, the impact of recent legislative mandates (Table 5.1), and the proven cost benefits of successful rehabilitation, the demand for assistive technology (new and existent) will likely increase rather than decrease. Correspondingly, employment opportunities for technically oriented persons interested in the development and delivery of assistive technology should steadily increase as well.

In the early 1980s, the value of rehabilitation engineers and assistive technologists was unappreciated and thus required significant educational efforts. Although the battle for proper recognition may not be entirely over, much progress has been made during the last two decades. For example, Medi-Cal, the California version of the federally funded medical assistance program, now funds the purchase and customization of augmentative communication devices. Many states routinely fund technology devices that enable people with impairments to function more independently or to achieve gainful employment.

Career opportunities for rehabilitation engineers and assistive technologists currently can be found in hospital-based rehabilitation centers, public schools, vocational rehabilitation agencies, manufacturers, and community-based rehabilitation technology suppliers; opportunities also exist as independent contractors. For example, a job announcement for a rehabilitation engineer contained the following job description (Department of Rehabilitative Services, Commonwealth of Virginia, 1997):

> Provide rehabilitation engineering services and technical assistance to persons with disabilities, staff, community agencies, and employers in the area of employment and reasonable accommodations. Manage and design modifications and manufacture of adaptive equipment.... Requires working knowledge of the design, manufacturing techniques, and appropriate engineering problem-solving techniques for persons with disabilities. Skill in the operation of equipment and tools and the ability to direct others involved in the manufacturing of assistive devices. Ability to develop and effectively present educational programs related to rehabilitation engineering. Formal training in engineering with a concentration in rehabilitation engineering, mechanical engineering, or biomedical engineering or demonstrated equivalent experience a requirement.

The salary and benefits of the job in this announcement were competitive with other types of engineering employment opportunities. Similar announcements regularly appear in trade magazines such as *Rehab Management* and *TeamRehab* and in newsletters of RESNA.

An example of employment opportunities in a hospital-based rehabilitation center can be seen in the Bryn Mawr Rehabilitation Center in Malvern, Pennsylvania. The Center is part of the Jefferson Health System, a nonprofit network of hospitals and long-term, home care, and nursing agencies. Bryn Mawr's assistive technology center provides rehabilitation engineering and assistive technology services. Its geriatric rehabilitation clinic brings together several of the facility's departments to work at keeping senior citizens in their own homes longer. This clinic charges Medicare for assessments and the technology needed for independent living. Support for this program stems from the potential cost savings related to keeping older people well and in their own homes.

Rehabilitation engineers and assistive technologists also can work for school districts that need to comply with the Individuals with Disabilities Education Act. A rehabilitation engineer working in such an environment would perform assessments, make equipment modifications, customize assistive devices, assist special education professionals in classroom adaptations, and advocate to funding agencies for needed educationally related technologies. An ability to work well with nontechnical people such as teachers, parents, students, and school administrators is a must.

One promising employment opportunity for rehabilitation engineers and assistive technologists is in community-based service providers such as the local United Cerebral Palsy Association or the local chapter of the National Easter Seals Society. Through the combination of fees for service, donations, and insurance payments, shared rehabilitation engineering services in a community service center can be financially viable. The center would employ assistive technology professionals to provide information, assessments, customized adaptations, and training.

Rehabilitation engineers also can work as independent contractors or as employees of companies that manufacture assistive technology. Because rehabilitation engineers understand technology and the nature of many disabling conditions, they can serve as a liaison between the manufacturer and its potential consumers. In this capacity, they could help identify and evaluate new product opportunities. Rehabilitation engineers, as independent consultants, also could offer knowledgeable and trusted advice to consumers, funding agencies, and worker compensation insurance companies. Such consultation work often involves providing information about relevant assistive technologies, performing client evaluations, and assessing the appropriateness of assistive devices. It is important that a rehabilitation engineer who wishes to work as an independent consultant be properly licensed as a Professional Engineer (PE) and be certified through RESNA as described in the next section. The usual first step in attaining the Professional Engineer's license is to pass the Fundamentals of Engineering Examination given by each state's licensing board.

5.5.2 Rehabilitation Engineering Outlook

Rehabilitation engineering has reached adolescence as a separate discipline. It has a clearly defined application. For example, rehabilitation engineering research and development has been responsible for the application of new materials in the design of wheelchairs and orthotic and prosthetic limbs, the development of assistive technology that provides a better and more independent quality of life and better employment outcomes for people with disabilities, the removal of barriers to telecommunications and information technology through the application of universal design principles, the development of hearing aids and communication devices that exploit digital technology and advanced signal processing techniques, and the commercialization of neural prostheses that aid hand function, respiration, standing, and even limited walking.

Beginning with the Rehabilitation Act of 1973 and its subsequent amendments in 1992 and 1998, rehabilitation engineering in the United States has been recognized as an activity that is worthy of support by many governments, and many universities offer formal graduate programs in this field. Fees for such services have been reimbursed by public and private insurance policies. Job advertisements for rehabilitation engineers appear regularly in newsletters and employment notices. In 1990, the Americans with Disabilities Act granted civil rights to persons with disabilities and made reasonable accommodations mandatory for all companies having more than 25 employees. Archival journals publish research papers that deal with all facets of rehabilitation engineering. Student interest in this field is rising. What is next?

Based on some recent developments, several trends will likely dominate the practice of rehabilitation engineering and its research and development activities during the next decade.

- Certification of rehabilitation engineers will be fully established in the United States. Certification is the process by which a nongovernmental agency or professional association validates an individual's qualifications and knowledge in a defined functional or clinical area. RESNA is leading such a credentialing effort for providers of assistive technology. RESNA will certify someone as a Professional Rehabilitation Engineer if that person is a registered Professional Engineer (a legally recognized title), possesses the requisite relevant work experience in rehabilitation technology, and passes an examination that contains 200 multiple-choice questions. For nonengineers, certification as an Assistive Technology Practitioner (ATP) or Assistant Technology Supplier (ATS) is available. Sample questions from RESNA's credentialing examination are provided at the end of the chapter.

- Education and training of rehabilitation technologists and engineers will expand worldwide. International exchange of information has been occurring informally. Initiatives by government entities and professional associations such as RESNA have given impetus to this trend. For example, the U.S. Department of Education supports a consortium of several American and European universities in the training of rehabilitation engineers. One indirect goal of this initiative is to foster formal exchanges of information, students, and investigators.
- Universal access and universal design of consumer items will become commonplace. Technological advances in the consumer field have greatly benefited people with disabilities. Voice-recognition systems have enabled people with limited movement to use their computers as an interface to their homes and the world. Telecommuting permits gainful employment without requiring a disabled person to be physically at a specified location. Ironically, benefits are beginning to flow in the opposite direction. Consumer items that once were earmarked for the disabled population (e.g., larger knobs, easy-to-use door and cabinet handles, curb cuts, closed-caption television programming, larger visual displays) have become popular with everyone. In the future, the trend toward universal access and products that can be used easily by everyone will expand as the citizenry ages and the number of people with limitations increases. Universal design—which includes interchangeability, component modularity, and user friendliness—will be expected and widespread.
- Ergonomic issues will play a more visible role in rehabilitation engineering. When designing for people with limitations, ergonomics and human factors play crucial roles, often determining the success of a product. In recognition of this, *IEEE Transactions on Rehabilitation Engineering* published a special issue on "Rehabilitation Ergonomics and Human Factors" in September 1994. The Human Factors and Ergonomics Society has a special interest group on "Medical Systems and Rehabilitation." In the next decade, more and more rehabilitation engineering training programs will offer required courses in ergonomics and human factors. The understanding and appreciation of human factors by rehabilitation engineers will be commonplace. The integration of good human factors designed into specialized products for people with disabilities will be expected.
- Cost-benefit analysis regarding the impact of rehabilitation engineering services will become imperative. This trend parallels the medical field in that cost containment and improved efficiency have become everyone's concern. Econometric models and socioeconomic analysis of intervention efforts by rehabilitation engineers and assistive technologists will soon be mandated by the federal government. It is inevitable that health maintenance organizations and managed care groups will not continue to accept anecdotal reports as sufficient justification for supporting rehabilitation engineering and assistive technology (Gelderbom & de Witte, 2002; Andrich, 2002). Longitudinal and quantitative studies in rehabilitation, performed by unbiased investigators, will likely be the next major initiative from funding agencies.

- Quality assurance and performance standards for categories of assistive devices will be established. As expenditures for rehabilitation engineering services and assistive devices increase, there will undoubtedly be demand for some objective assurance of quality and skill level. One example of this trend is the ongoing work of the Wheelchair Standards Committee jointly formed by RESNA and the American National Standards Institute. Another example of this trend is the drive for certifying assistive technology providers and assistive technology suppliers.
- Applications of wireless technology will greatly increase the independence and capabilities of persons with disabilities. For example, navigational aids that utilize the Global Positioning System, Internet maps, cellular base station triangulation, and ubiquitous radio frequency identification tags will enable the blind to find their way indoors and outdoors as easily as their sighted counterparts. Wireless technology also will assist people with cognitive limitations in their performance of daily activities. Reminders, cueing devices, trackers and wandering devices, and portable personal data assistants will enable them to remember appointments and medications, locate themselves positionally, follow common instructions, and obtain assistance.
- Technology will become a powerful equalizer as it reduces the limitations of manipulation, distance, location, mobility, and communication that are the common consequences of disabilities. Sometime in the next 20 years, rehabilitation engineers will utilize technologies that will enable disabled individuals to manipulate data and information and to alter system behavior remotely through their voice-controlled, Internet-based, wireless computer workstation embedded in their nuclear-powered wheelchairs. Rather than commuting daily to work, persons with disabilities will or can work at home in an environment uniquely suited to their needs. They will possess assistive technology that will expand their abilities. Their dysarthric speech will be automatically recognized and converted into intelligible speech in real time by a powerful voice-recognition system. Given the breathtaking speed at which technological advances occur, these futuristic devices are not mere dreams but realistic extrapolations of the current rate of progress.

Students interested in rehabilitation engineering and assistive technology R & D will be able to contribute toward making such dreams a reality shortly after they complete their formal training. The overall role of future practicing rehabilitation engineers, however, will not change. They still will need to assess someone's needs and limitations, apply many of the principles outlined in this chapter, and design, prescribe, modify, or build assistive devices.

EXERCISES

Like the engineering design process described earlier in this chapter, answers to the following study questions may require searching beyond this textbook for the necessary information. A good place to begin is the Suggested Reading section. You also may try looking for the desired information using the Internet.

1. The fields of rehabilitation engineering and assistive technology have been strongly influenced by the federal government. Describe the impact federal legislation has had on the prevalence of rehabilitation engineers and the market for their work in assistive technology. Explain and provide examples.
2. As a school-based rehabilitation engineer, you received a request from a teacher to design and build a gadget that would enable an 8-year-old, second-grade student to signal her desire to respond to questions or make a request in class. This young student uses a powered wheelchair, has multiple disabilities, cannot move her upper arms very much, and is unable to produce understandable speech. Prepare a list of quantitative and qualitative questions that will guide your detailed analysis of this problem. Produce a hypothetical set of performance specifications for such a signaling device.
3. Write a sample set of performance specifications for a voice-output oscilloscope to be used by a visually impaired electrical engineering student for a laboratory exercise having to do with operational amplifiers. What features would be needed in the proposed oscilloscope?
4. Write a sample set of performance specifications for a foldable lap tray that will mount on a manual wheelchair. Hints: What should its maximum and minimum dimensions be? How much weight must it bear? Will your add-on lap tray user make the wheelchair user more or less independent? What type of materials should be used?
5. Sketch how the leg raiser described in Example Problem 5.1 might fit onto a battery-powered wheelchair. Draw a side view and rear view of the leg-raiser-equipped wheelchair.
6. Do a careful search of commercially available electronic communication devices that meet the following performance specifications: speech output, icon-based membrane keyboard, portable, weigh less than 7.5 lbs, no more than 2.5 in. thick, no larger than a standard three-ring binder, and able to be customized by the user to quickly produce frequently used phrases. Hints: Consult "The Closing the Gap Product Directory" and the "Cooperative Electronic Library on Disability." The latter is available from the Trace Research and Development Center at the University of Wisconsin, Madison. Also try visiting the applicable websites.
7. A person's disabilities and abilities often depend on his or her medical condition.
   a) A person is known to have spinal cord injury (SCI) at the C5–C6 level. What does this mean in terms of this person's probable motoric and sensory abilities and limitations?
   b) Repeat part (a) for a person with multiple sclerosis. Include the prognosis of the second individual in contrast to the person with SCI.
8. To be portable, an electronic assistive device must be battery powered. Based on your study of technical manuals and battery handbooks, list the pros and cons of using disposable alkaline batteries versus lithium-hydride rechargeable batteries. Include in your comparison an analysis of the technical issues (e.g., battery capacity, weight, and charging circuitry), cost issues, and

practicality issues (e.g., user preferences, potential for misplacement or improper usage of charger, and user convenience).

9. A young person with paraplegia wishes to resume skiing, canoeing, sailing, and golfing. For each of these sports, list four or five adaptations or equipment modifications that are likely to be needed. Sketch and briefly describe these adaptations.

10. A 21-year-old female who has muscular dystrophy requested assistance with computer access, particularly for writing, using spreadsheets, and playing computer games. She lacks movement in all four extremities except for some wrist and finger movements. With her left hand, she is able to reach about 6 in. past her midline. With her right hand, she is able to reach only 2 in. past her midline. Both her hands can reach out about 8 in. from the body. If given wrist support, she has good control of both index fingers. Based on this description, sketch the work area that she appears able to reach with her two hands. Describe the adaptations to a standard or contracted keyboard that she would need to access her home computer. For additional information, consult the "Closing the Gap Product Directory," the "Cooperative Electronic Library on Disability," and the suggested reading materials listed at the end of this chapter.

11. The two main computer user interfaces are the command line interface (CLI), as exemplified by UNIX commands, and the graphical user interface (GUI), as exemplified by the Windows XP or Apple's OS X operating systems. For someone with limited motoric abilities, each type of interface has its advantages and disadvantages. List and compare the advantages and disadvantages of CLI and GUI. Under what circumstances and for what kinds of disabilities would the CLI be superior to or be preferred over the GUI?

12. One of the major categories of assistive devices is alternative and augmentative communication devices. Describe the electronic data processing steps needed for text-to-speech conversion. How have the technological advances in personal computing made this conversion faster and the speech output more lifelike?

13. What would the second scale reading (S_2) be if the person in Example Problem 5.3 raised both of his legs straight up and D was known to be 14 in.?

14. How much tension would be exerted on the pulley in Example Problem 5.4 if the weights were observed to be falling at 1.5 ft/s^2?

15. How much contraction force must the flexor muscles generate in order for a person to hold a 25-lb weight in his hand, 14 in. from the elbow joint? Assume that the flexor muscle inserts at 90° to the forearm 2 in. from the elbow joint and that his forearm weighs 4.4 lbs. Use the equilibrium equation, $\Sigma F_X = \Sigma F_y = \Sigma M = 0$, and Figure 5.10 to aid your analysis.

16. How much force will the head of the femur experience when a 200-lb person stands on one foot? Hint: Apply the equilibrium equation, $\Sigma F_X = \Sigma F_y = \Sigma M = 0$, to the skeletal force diagram in Figure 5.11 in your analysis.

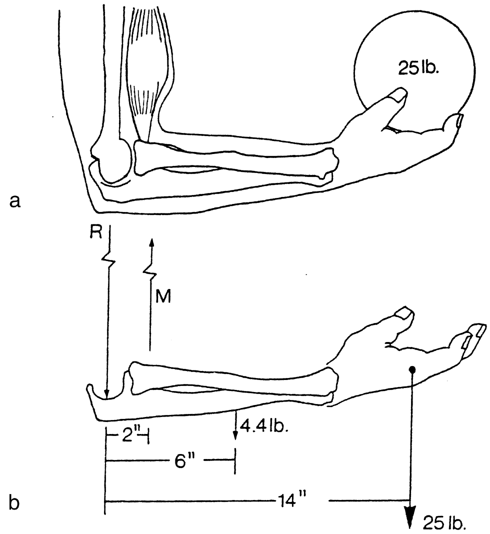


Figure 5.10 Static forces about the elbow joint during an elbow flexor exercise (from Le Veau, 1976).

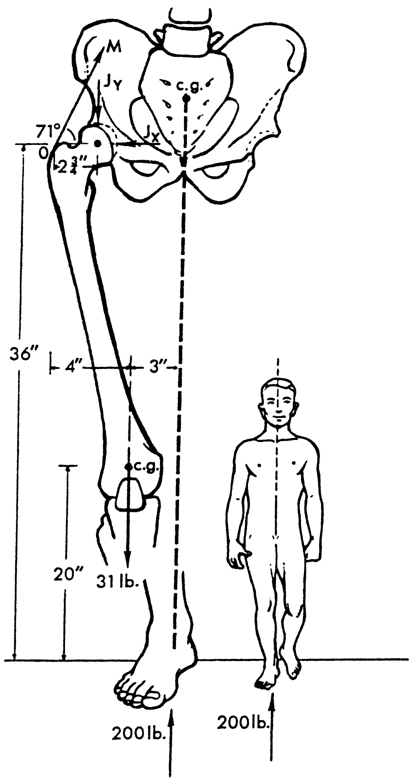


Figure 5.11 Determination of the compression force on the supporting femoral head in unilateral weight bearing (from Le Veau, 1976).

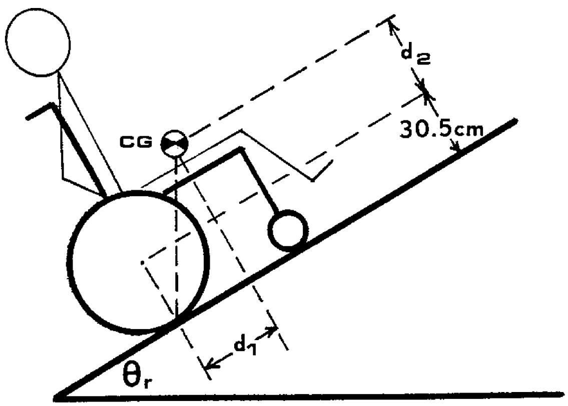
17. Under static or constant velocity conditions, the wheelchair will tip backwards if the vertical projection of the combined center of gravity (*CG*) of the wheelchair and occupant falls behind the point of contact between the rear wheels and the ramp surfaces. As shown in Figure 5.12, the rearward tipover angle (θ_r) is determined by the horizontal distance (d_1) and the vertical distance (d_2) between *CG* and the wheelchair's rear axles.

a) Using static analysis, derive the equation relating θ_r, d_1, and d_2.

b) Using the platform approach depicted in Figure 5.7, suggest a method for determining d_1.

c) Assuming that d_1 and d_2 averaged 13 cm and 24 cm, respectively, for able-bodied individuals, what would θ_r be?

d) How would d_1 and d_2 change if the wheelchair occupant leaned forward instead of sitting back against the chair? How would θ_r be affected by this postural shift?



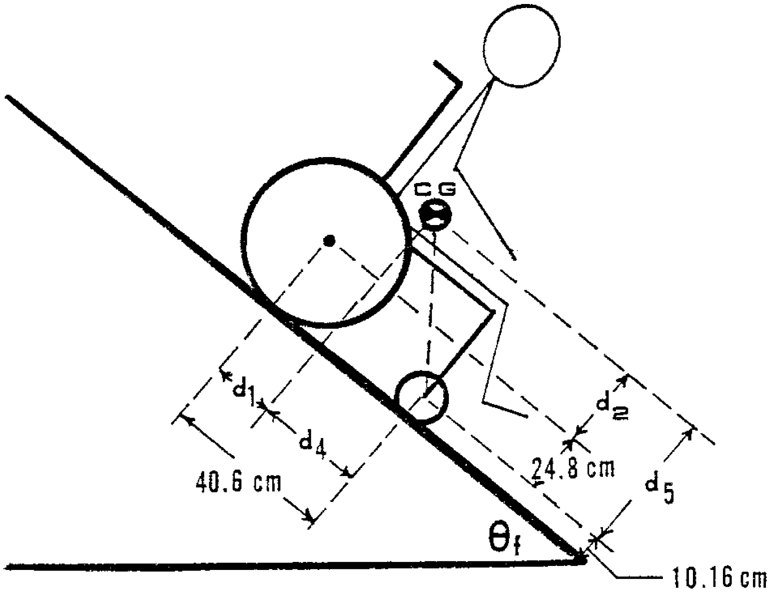
d_1 = horizontal distance in cm (relative to the incline) between the CG and the rear axles.

d_2 = vertical distance in cm (relative to the incline) between the CG and the rear axles.

θ_r = static rearward tipover angle.

Figure 5.12 Conditions under which the occupied wheelchair will begin to tip backwards. The tipover threshold occurs when the vertical projection of the combined *CG* falls behind the rearwheel's contact point with the inclined surface (from Szeto and White, 1983).

18. Perform a static analysis of the situation depicted in Figure 5.13 and derive the equation for the probable forward tipover angle (θ_r) using the data and dimensions shown. Assuming that d_1 and d_2 were the same as given in problem 17 and d_4 and d_5 averaged 27 cm and 49 cm, respectively, what would θ_r be?



d_1 = horizontal distance in cm (relative to the incline) between the *CG* and the rear axles.

d_2 = vertical distance in cm (relative to the incline) between the *CG* and the rear axles.

d_4 = horizontal distance in cm (relative to the incline) between the *CG* and the casters.

d_5 = vertical distance in cm (relative to the incline) between the *CG* and the rear axles.

θ_f = forward tipover angle.

Figure 5.13 Conditions under which the occupied wheelchair will begin to tip forward. The tipover threshold occurs when the vertical projection of the combined *CG* falls behind the caster wheel's contact point with the inclined surface (from Szeto and White, 1983).

19. For persons with good head control and little else, the Head Master (by Prentke Romich Co., Wooster, OH) has been used to emulate the mouse input signals for a computer. The Head Master consists of a headset connected to the computer by a cable. The headset includes a sensor that detects head movements and translates such movements into a signal interpreted as 2-dimensional movements of the mouse. A puff-and-sip pneumatic switch is also attached to headset and substitutes for clicking of the mouse. Based on this brief description of the Head Master, draw a block diagram of how this device might work and the basic components that might be needed in the Head Master. Include in your block diagram the ultrasonic signal source, detectors, timers, and signal processors that would be needed.

20. Based on the frequency of use data shown in Tables 5.8, 5.9, and 5.10, design an optimized general purpose communication array using row-column scanning. Recall that row-column scanning is a technique whereby a vocabulary element is first highlighted row by row from the top to bottom of the array. When the row containing the desired element is highlighted, the user activates a switch to select it. Following the switch activation, the scanning proceeds within the selected row from left to right. When the desired vocabulary element is highlighted again, a second switch activation is made. In row-column scanning, the first press of a switch selects the row and the second press selects the column. Hint: Arrange the most frequently

TABLE 5.8 Simple English Letter Frequency from 10,000 Letters of English Literary Text

E =1231	L = 403	B = 162
T = 959	D = 365	G = 161
A = 805	C = 320	V = 93
O = 794	U = 310	K = 52
N = 719	P = 229	Q = 20
I = 718	F = 228	X = 20
S = 659	M = 225	J = 10
R = 603	W = 203	Z = 9
H = 514	Y = 188	

Data from Webster et al. (1985).

TABLE 5.9 Frequency of English Two- and Three-Letter Combinations from 25,000 Letters of English Literary Text

Two-letter Combinations

TH = 1582	HE = 542	ON = 420	NT = 337	RA = 275
IN = 784	EN = 511	OU = 361	HI = 330	RO = 275
ER = 667	TI = 510	IT = 356	VE = 321	LI = 273
RE = 625	TE = 492	ES = 343	CO = 296	IO = 270
AN = 542	AT = 440	OR = 339	DE = 275	

Three-letter Combinations

THE = 1182	ERE = 173	HAT = 138	NCE = 113	MAN = 01
ING = 356	HER = 170	ERS = 135	ALL = 111	RED = 101
AND = 284	ATE = 165	HIS = 130	EVE = 111	THI = 100
ION = 252	VER = 159	RES = 125	ITH = 111	IVE = 96
ENT = 246	TER = 157	ILL = 118	TED = 110	
FOR = 246	THA = 155	ARE = 117	AIN = 108	
TIO = 188	ATI = 148	CON = 114	EST = 106	

Data from Webster et al. (1985).

TABLE 5.10 Frequency of English Words from 242,432 Words of English Literary Text

THE = 15,568	FOR = 1869	HAVE = 1344	THIS = 1021
OF = 9757	AS = 1853	YOU = 1336	MY = 963
AND = 7638	WITH = 1849	WHICH = 1291	THEY = 959
TO = 5739	WAS = 1761	ARE = 1222	ALL = 881
A = 5074	HIS = 1732	ON = 1155	THEIR = 824
IN = 4312	HE = 1721	OR = 1101	AN = 789
THAT = 3017	BE = 1535	HER = 1093	SHE = 775
IS = 2509	NOT = 1496	HAD = 1062	HAS = 753
I = 2292	BY = 1392	AT = 1053	WHERE = 753
IT = 2255	BUT = 1379	FROM = 1039	ME = 752

Data from Webster et al. (1985).

used vocabulary elements earliest in the scanning order. See Example Problem 5.5.

21. An electronic guide dog has been proposed as an electronic travel aid for a blind person. List some of the specific tasks that such a device must perform and the information processing steps involved in performing these tasks. List as many items and give as many details as possible. Hints: Consider the problems of obstacle detection, information display, propulsion system, inertial guidance, route recall, power supply, etc.

22. The ability of the user to visually scan an array of options and make appropriate choices is fundamental to many assistive devices. Analyze the difference between visual pursuit tracking and visual scanning in terms of the oculomotor mechanisms that underlie these two activities.

23. Based on Table 5.7, what type of speech synthesis technology would be the most appropriate for the following situations: (a) an augmentative communication system capable of unlimited vocabulary for someone who can spell? (b) a voice output system for a blind person that reads the entire screen of a computer display? (c) an augmentative communication system for a young girl who needs a limited vocabulary set? (d) voice feedback for an environmental control system that echoes back simple one-word commands, such as "on," "off," "lights," "bed," "TV," and "drapes." Explain or justify your answer.

24. Safe and independent mobility by persons with severe visual impairments remains a challenge. To relieve such persons of their dependence on guide dogs or a sighted human guide, various portable navigational aids using a Global Positioning System (GPS) receiver have been marketed.

a) Conduct an Internet investigation of GPS as the basis for a portable navigational aid for the blind. Address the following issues: How does GPS work? Can GPS signals be reliably received at every location? How accurate are GPS signals in terms of resolution? Is this level of resolution sufficient for finding the entrance to a building? Can dead reckoning and inertial guidance help when GPS signals are lost?

b) Describe the various operational requirements of an ideal portable navigational aid for the blind. Consider such ergonomic issues as the user interface, input and output requirements, and target retail price. List some of the human factor design issues involved.

Sample Multiple-Choice Questions from RESNA's Credentialing Examination in Assistive Technology

1. Which of the following abilities is necessary for development of skilled upper-extremity movements?
   a. Equilibrium reactions in the standing position
   b. Ability to cross midline
   c. Good postural control of the trunk and head
   d. Pincer grasp
2. A 12-year-old male with Duchenne's muscular dystrophy is being evaluated for a mobility system. The therapist notes that he has lateral bending of the trunk and leans to the left. The most appropriate next step is assessment for
   a. Kyphosis
   b. Lordosis
   c. Left-sided weakness
   d. Scoliosis
3. The most appropriate location for training and instruction in functional use of an assistive technology device is
   a. A quiet area with few distractions
   b. The individual's home environment
   c. The environment in which the device will be used
   d. A training center where several therapists are available
4. An architect with C4–C5 quadriplegia would like to use a computer-assisted design (autoCAD) system when he returns to work. The most appropriate first step is assessment of the client's ability to use
   a. Mouthstick
   b. Eye-blink switch
   c. Alternate mouse input
   d. Sip-and-puff switch
5. Under the Individuals with Disabilities Education Act, assistive technology is defined as a device that
   a. Increases functional capability
   b. Improves mobility or communication
   c. Compensates for physical or sensory impairment
   d. Is considered durable medical equipment
6. In addition to the diagnosis, which information must be included in a physician's letter of medical necessity?
   a. Cost of assistive technology requested
   b. Client's prognosis
   c. Client's range of motion
   d. Client's muscle tone

7. Plastic is an ideal seat base for the person with incontinence because it is
   a. Light weight
   b. Less costly than wood
   c. Nonabsorbent
   d. Detachable from wheelchair
8. When considering structural modification of a newly purchased commercial device, which of the following is the *most* important concern?
   a. Future use by other individuals
   b. Voidance of warranty
   c. Resale value
   d. Product appearance
9. A client is interested in using a voice-recognition system to access the computer. Which of the following factors is *least* critical to success with this method?
   a. Hand function
   b. Voice clarity
   c. Voice-recognition system training
   d. Type of computer system used
10. A 9-year-old is no longer able to drive her power-base wheelchair. Training was provided following delivery of the wheelchair 2 years ago. Which of the following is the first step in evaluation?
    a. Interview the parents and child
    b. Perform a cognitive evaluation
    c. Reevaluate access in the wheelchair
    d. Contact the wheelchair manufacturer

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