Honeywell

Human Factors Design Guidelines for the Elderly and People with Disabilities

Revison 3—Draft

May 1992

Honeywell SSDC
3660 Technology Drive
Minneapolis, MN 55418

SSDC-SYS/AI-C92-009

C920317

Honeywell

Human Factors Design Guidelines for the Elderly and People with Disabilities

Revision 3 Draft

Prepared by:

Sandra Denno
Brian A. Isle
Ginny Ju
Christopher G. Koch
Stephen V. Metz
Robin Penner
Li Wang
John Ward

May 1992

Brian Isle
MN65-2300
Honeywell Inc.
3660 Technology Drive
Minneapolis, Minnesota 55418

SSDC-SYS/AI-C92-009

C920317

Table of Contents

Table of Contents (concluded)

List of Figures

Acknowledgments

The authors would like to acknowledge the various groups who have supported and encouraged the project since its inception:

- The Honeywell Foundation;
- The Southeastern Minnesota Center for Independent Living;
- Rachel Wobschall, Executive Director of the Minnesota STAR Program;
- The management at Honeywell SSDC.

Section 1
Introduction and Scope

Individuals with physical, sensory, or cognitive disabilities have special needs for interacting with their environment. Effective design of controls and displays in the residence and workplace used by individuals with disabilities is critical for maximizing their abilities; in reality, however, the design of these devices often fails to account for their special needs.

People with disabilities are accustomed to accommodating to their environment or inventing ways around it. They need devices that either require only their abilities or can be modified. With good planning, most devices can be designed for use by individuals with limited abilities.

Background

This document reflects the work of a group of engineers and designers who are studying the needs of the elderly and people with disabilities and designing solutions. Their activities include extensive literature review, analysis of population demographics, interviews with individuals with disability, and controlled research.

The group's shared vision is the availability of a wide variety of affordable controls and products for the home and work environment that are usable or adaptable for all people, including the elderly and those with disabilities.

The problem is defined below:

- *All* individuals need affordable access to controls, tools, communication devices, and other equipment and components in the home and work environments to interact effectively with their world.

- Manufacturers often do not understand the special needs of the elderly or those with disabilities.

- Currently, highly specialized devices have low volume and high cost.

Needs of a Special Population

There are three principal categories of disabilities:

- Physical/motor limitations that impair an individual's ability to reach and manipulate controls;

- Sensory limitations that impair an individual's ability to receive information and feedback;

- Cognitive limitations that impair an individual's ability to process information.

There are unique challenges to the engineering and design of controls and displays for people with disabilities. Those with physical limitations need a usable control device in an accessible location. For this group, conventional displays and feedback mechanisms may be satisfactory. For people with sensory limitations, adequate displays and feedback from devices are needed. Individuals with cognitive disabilities can use most well-designed controls and displays but take longer to learn to use them and need error protection.

Human Factors Issues

Human factors engineering is the study and practice of designing equipment, machines, and environments to accommodate human users. Human factors encompasses physical requirements of size and force as well as mathematical models of human information processing and control.

Issues of operability and consistency affect design for special populations. Operability involves the amount of effort required to use a component or device. The accessibility of controls, the readability of displays, and the logical sequence of actions required to produce any desired result are all operability issues. For example, a control panel is poorly designed if it is too high for a person in a wheelchair to reach, requires too much force on the keys for a person with limited strength, or requires memorization of a complex sequence of control inputs. Even if all components and devices within a residence are easy and convenient to operate, confusion may still result from the differences in the way similar functions are controlled in different components and devices. For instance, a variety of procedures exists for storing numbers in the memory dialers of telephones currently on the market. Learning the procedures for one product may not help in learning the procedures for another, and in fact, may even inhibit such learning.

There are several general human factors design goals that address operability and consistency in controls/displays design and operation:

- Use a minimized set of unique controls or keys and avoid the use of the same controls or keys for different functions.

- Reduce the number of potential operating parameters while providing powerful functionality. For example, use the fewest and simplest set of steps necessary to accomplish a function and avoid unnecessary options.

- Design operating procedures to be fault tolerant. For example, allow entry of a sequence of inputs in any order.

- Strive for standard operating procedures across dissimilar devices to promote consistency.

The Role of Design Guidelines

Our premise is that devices can be made user friendly for the elderly and those with disabilities by applying good human factors design principles and limiting the set of unique abilities required to use an interface. Furthermore, equipment design that is consistent with this premise is also effective and often preferable for people without disabilities.

The purpose of this document is to provide a preliminary set of appropriate design guidelines for components and devices found in the home and workplace that can accommodate the abilities of the elderly and individuals with disabilities as well as enhance the usability of products. The guidelines are intended to ensure that the products designed, selected, and built by various manufacturers (who voluntarily choose to apply the guidelines) will be safe, convenient, and easy to use. The human factors guidelines are not intended to establish specific and inflexible standards for device design; rather, to promote good design practice, and allow a variety of effective solutions to each design requirement.

Many of the values identified in this document for parameters such as size, force, coding, and tonal amplitude are derived from published standards, textbooks, or other human factors guidelines. These sources are listed in the References section. Although exceptions may be encountered for some design problems, the use of the word "should" indicates general applicability of the guideline item; the word "preferred" indicates a recommendation.

Topics for Human Factors Design Guidelines

The scope of the human factors guidelines for component and device design includes the following topics:

- Controls

  - Finger-operated pushbutton
  - Palm-operated pushbutton
  - Push-pull controls
  - Membrane touch keys—pushbuttons
  - Keypad keys—pushbuttons
  - Toggle switches
  - Rocker switches
  - Slide switches
  - Detented rotary selectors
  - Continuous rotary controls

- Visual displays

  - Alphanumeric text displays
  - Light indicators
  - Labels

  - Color
  - Use of color in displays
  - Use of color in organization and labeling
  - Color specification
  - Size of colored area
  - Color naming
  - Emergency indicators

- Graphics

  - Symbols
  - Creating or building new symbols
  - Graphics symbols for SMART HOUSE use
  - Additional illustrations

- Auditory displays

  - Informational auditory displays (tone or beep)
  - Informational auditory displays (synthesized speech)
  - Emergency auditory warnings

- Functional allocation and panel layout

  - Functional allocation
  - Principles of arrangement
  - Panel layout
  - Keypads
  - Panel design—continuous controls

- Operating protocol

  - Remote access
  - Response time
  - Computer-based interface guidelines
  - Interaction styles
  - Design of operating procedures
  - Emergency procedures
  - Help features
  - Terminology

Section 2
Population Served

Categories of Functional Disabilities

The human factors guidelines address a wide variety of impairments subdivided under the three principal categories of functional limitations:

Physical Impairment

- Physical impairments
  - Extreme muscle weakness or reduced endurance
  - Paralysis—loss of sensation or voluntary movement
  - Paraplegia—paralysis of both legs and the lower portion of the trunk
  - Quadriplegia—partial or total paralysis of all four extremities, usually from injury to the spinal cord at the sixth cervical vertebra or higher
  - Limited hand/arm reach capability, sometimes due to wheelchair positioning
  - Impairment of dexterity/manipulative skills
  - Tremor—continuous, involuntary quivering
  - Contracture—permanent contraction of a muscle
  - Spasticity—stiff, awkward movements due to involuntary muscle contractions
  - Ataxia—impaired muscle coordination, especially when voluntary muscle control is attempted
  - Apraxia—inability to perform voluntary movements although there is no sensory or motor impairment
  - Rigidity—immovability
  - Use of braces and other prosthetics
  - Extremes of size or maturity
- Speech impairments
  - Dysarthria—slurred speech due to impairment of the tongue or other muscles essential to speech
  - Stuttering
  - Aphasia—impairment of ability to communicate through speech, writing, or signs
  - Complete loss of speech

Perceptual Impairment

- Hearing impairments

  – Partial hearing loss
  – Complete hearing loss
  – Listening impairment

- Vision impairments

  – Legal blindness
  – Color blindness
  – Complete blindness
  – Diplopia—double vision

Cognitive Impairment

- Cognitive Impairments

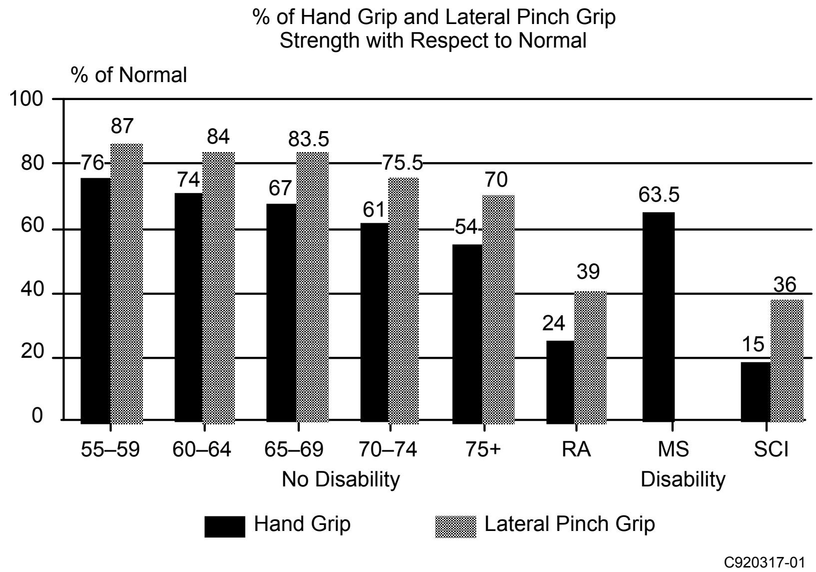
  – Dyslexia—inability to interpret written language
  – Confusion or disorientation
  – Loss of short-term memory
  – Loss of long-term memory
  – Impairment of learning and retention
  – Impairment of perception and attention
  – Impairment of intelligence and thinking
  – Severe mental retardation

Disabling Conditions

The functional limitations listed above are caused by a wide variety of disabling conditions including diseases, accidents, aging and birth defects. The following are some of the more frequently occuring conditions:

- Aging,
- Arthritis,
- Multiple sclerosis,
- Cerebral palsy,
- Stroke and head trauma,
- Spinal cord injury.

Limited strength is common to nearly all disabling conditions and is a common reason for being unable to operate household equipment. Figure 2-1 shows the hand functions (hand grip and lateral pinch) of the elderly and people with rheumatoid arthritis, multiple sclerosis, and spinal cord injuries (levels C4–C7). In this figure, the hand functions for the four groups are normalized as the percentages of normal strength. The data for individuals with spinal cord injury are after any surgical procedures (such as tendon transfers).



Adapted from Stover (1986), Tourtellotte (1965), Helliwell (1987), and Mathiowetz (1985)

Figure 2-1. Hand Grip and Lateral Pinch Strength for Subjects with Various Disabling Conditions (Rheumatoid Arthritis (RA), Multiple Sclerosis (MS), Spinal Cord Injury (SCI))

Aging

The aging process often leads to vision loss, hearing loss, and osteoarthritis, as well as loss of strength.

Age-Related Effects on Hand Strength—It is well documented that muscle strength declines with increasing age for all muscle groups. Here, only the change of hand strength with respect to age will be presented (Mathiowetz, 1985). The actual strengths and percentage losses, as age increases, of hand grip, lateral pinch, tip pinch strength and palmar pinch are illustrated in the following eight figures. The data were gathered from a sample of 310 males and 328 females, ages 20 to 94 years old. The percentage loss is calculated based on the data at the age of 20 to 24. Figures 2-2 to 2-9 show that in most cases the peak of hand strength occurs between 30 and 40 years of age, and no more than 10% decline in strength occurs before age 50 or 55.

Age-Related Effects on Visual Functions—Like other parts of the body, the eyes undergo many changes due to aging. The lens becomes yellowed, thickened, and less elastic, which causes reduced accommodative capacity, reduced light entering the eye, and the scattering of light rays before they reach the retina. Changes in the cornea also lead to increased scattering of light rays. The iris dilator atrophies and becomes more rigid, which reduces the size of the pupil and its ability to adjust its size according to the amount of light available. The reduction in the size of the pupil is known as senile miosis. In addition, there may be deterioration in the visual pathways of the central nervous system (Whitbourne, 1985). These changes in the physical structure of the eye affect several aspects of visual function, including refractive power, accommodation, acuity, dark adaptation, sensitivity to light, color vision, temporal resolution, depth perception, and visual field.

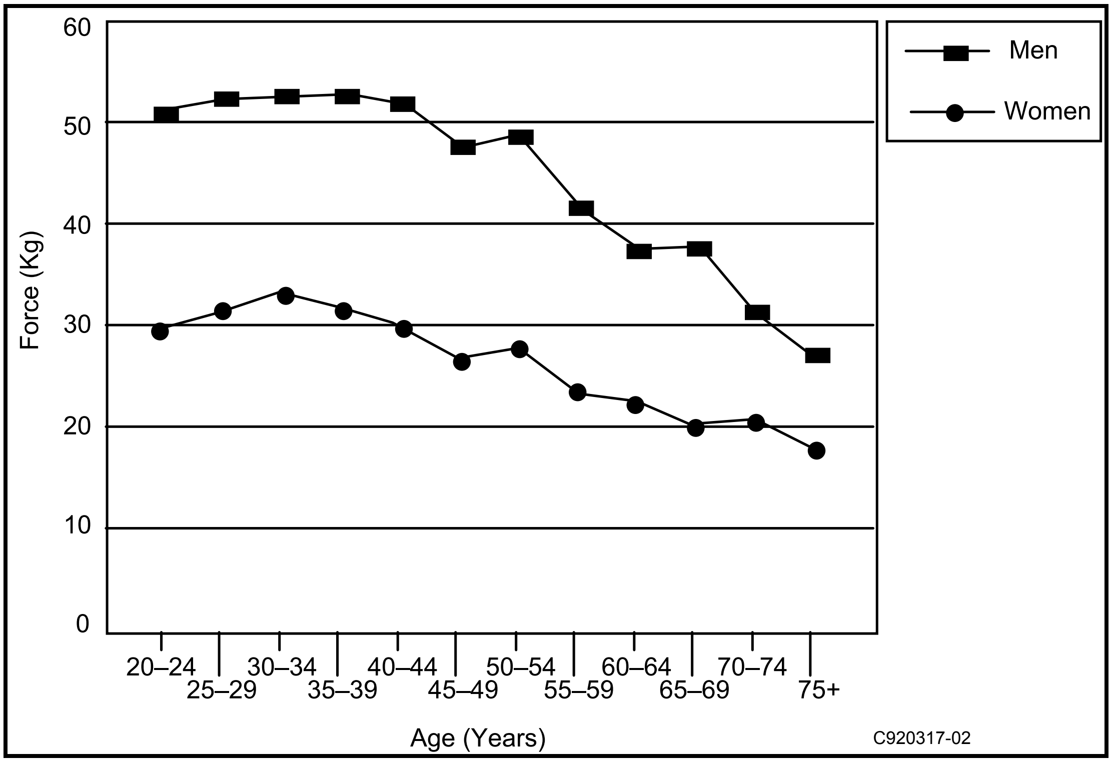


Figure 2-2. Change of Hand Grip Strength with Age

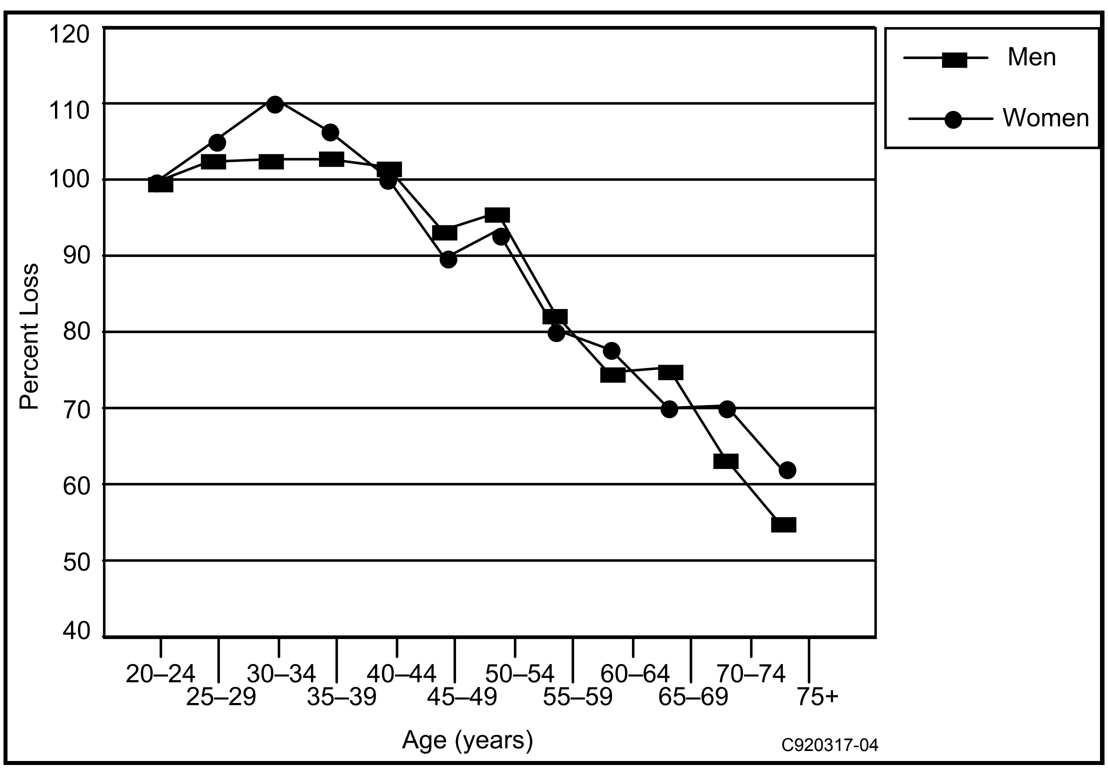


Figure 2-3. Percent Loss of Hand Grip Strength with Age

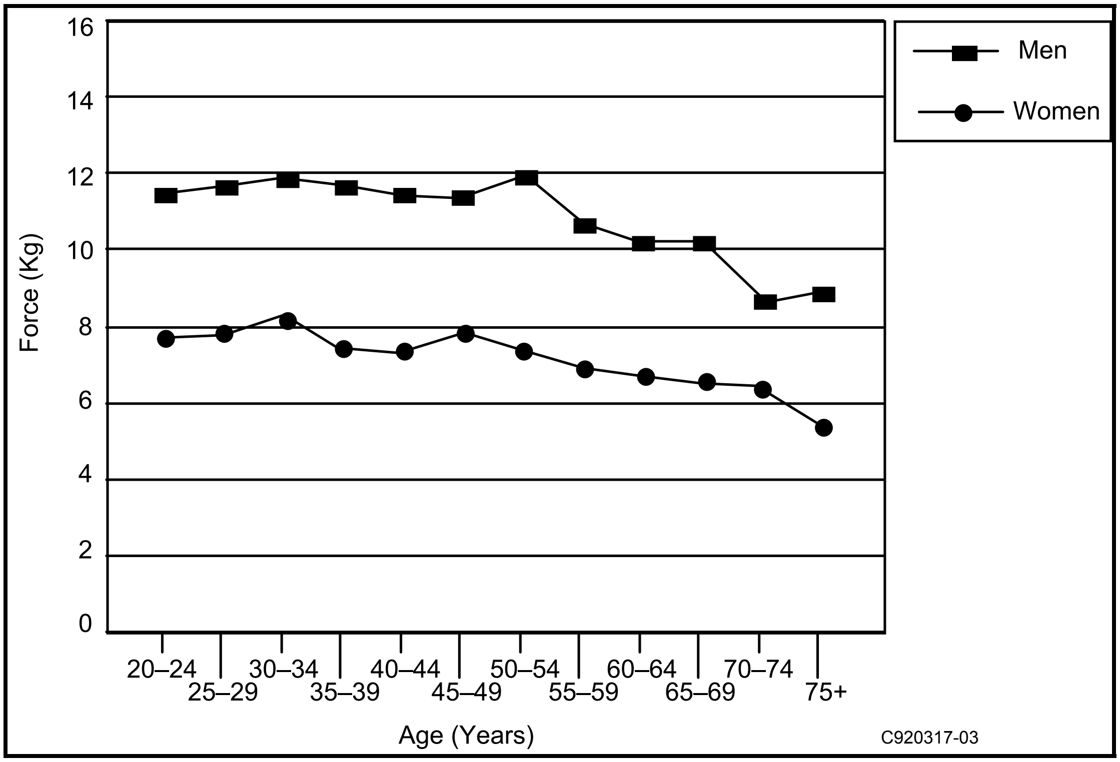


Figure 2-4. Change of Lateral Pinch Grip Strength with Age

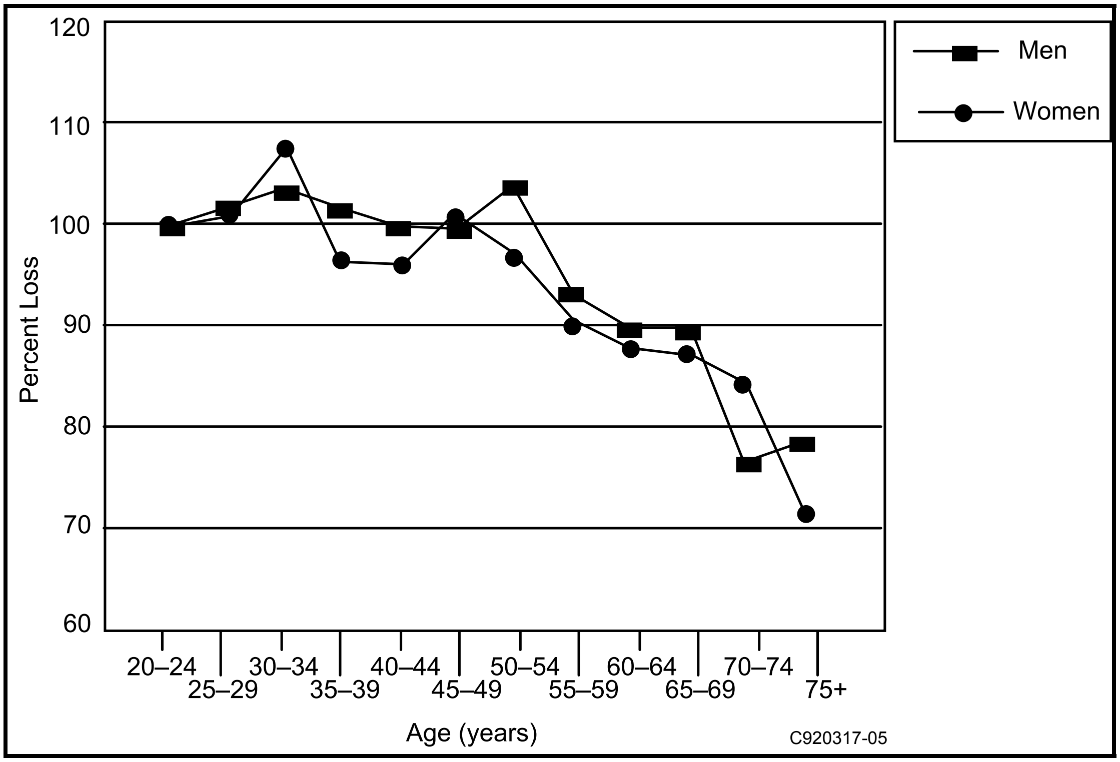


Figure 2-5. Percent Loss of Lateral Pinch with Age

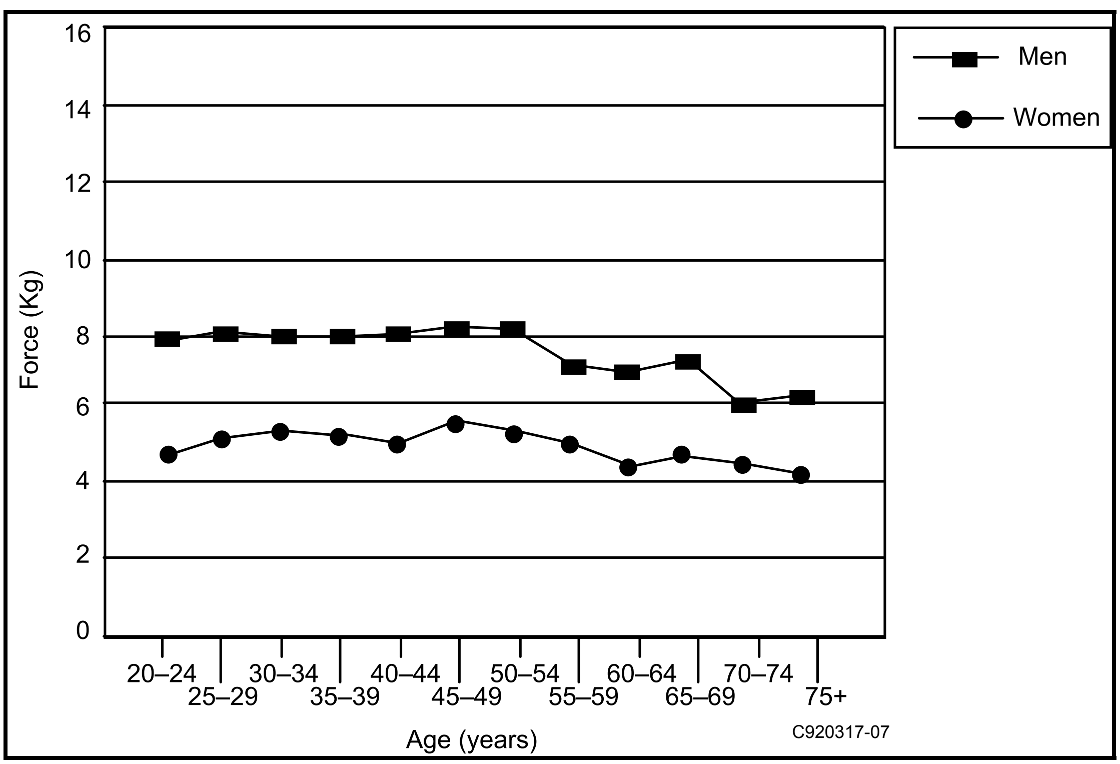


Figure 2-6. Change of Tip Pinch Grip Strength with Age

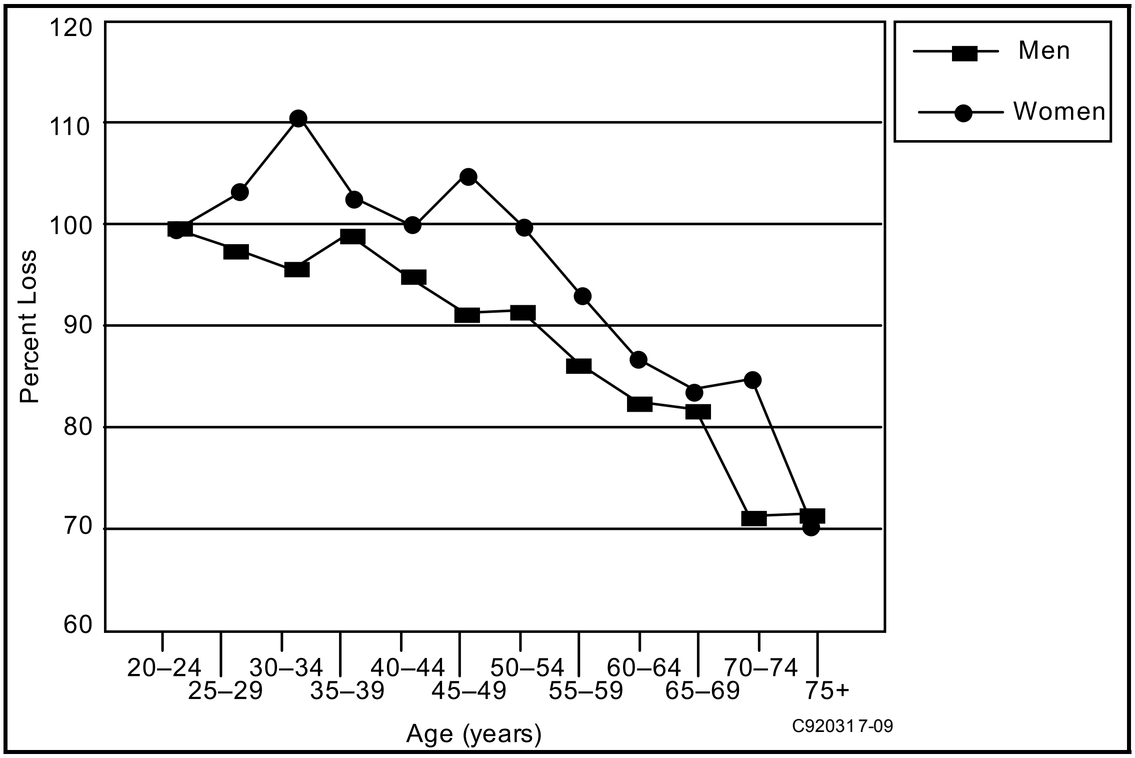


Figure 2-7. Percent Loss of Palmar Pinch with Age

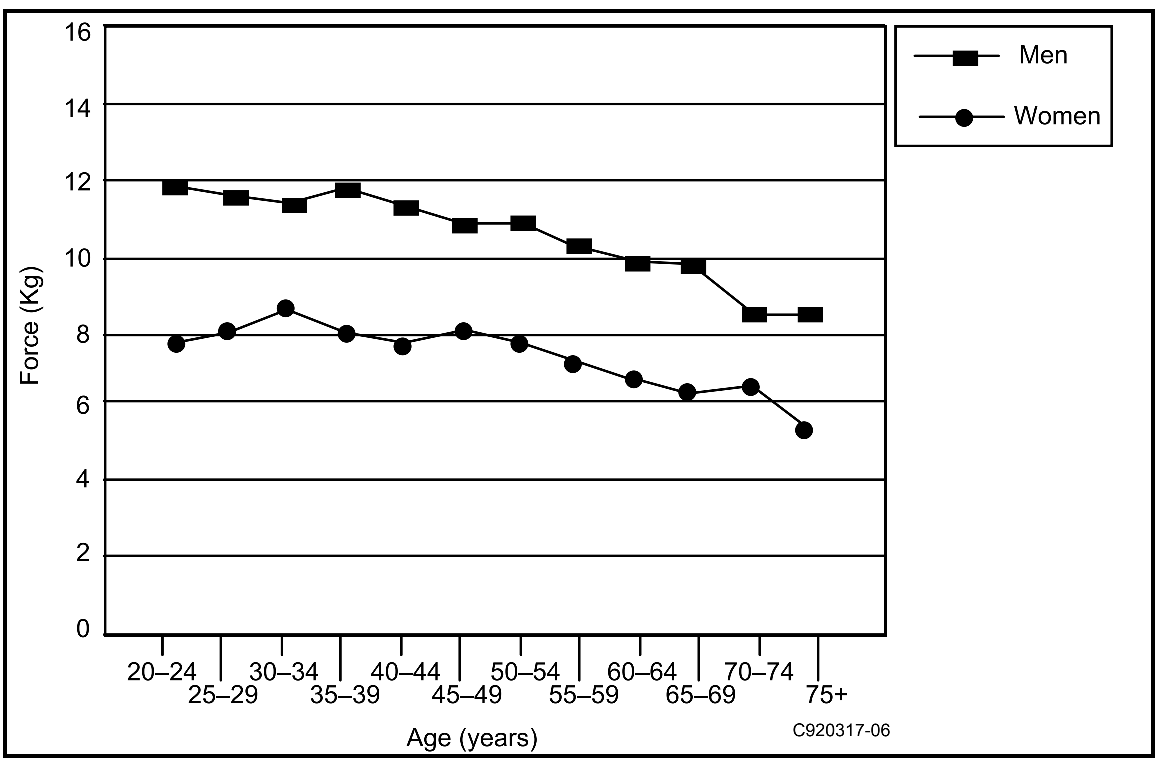


Figure 2-8. Change of Palmar Pinch Strength with Age

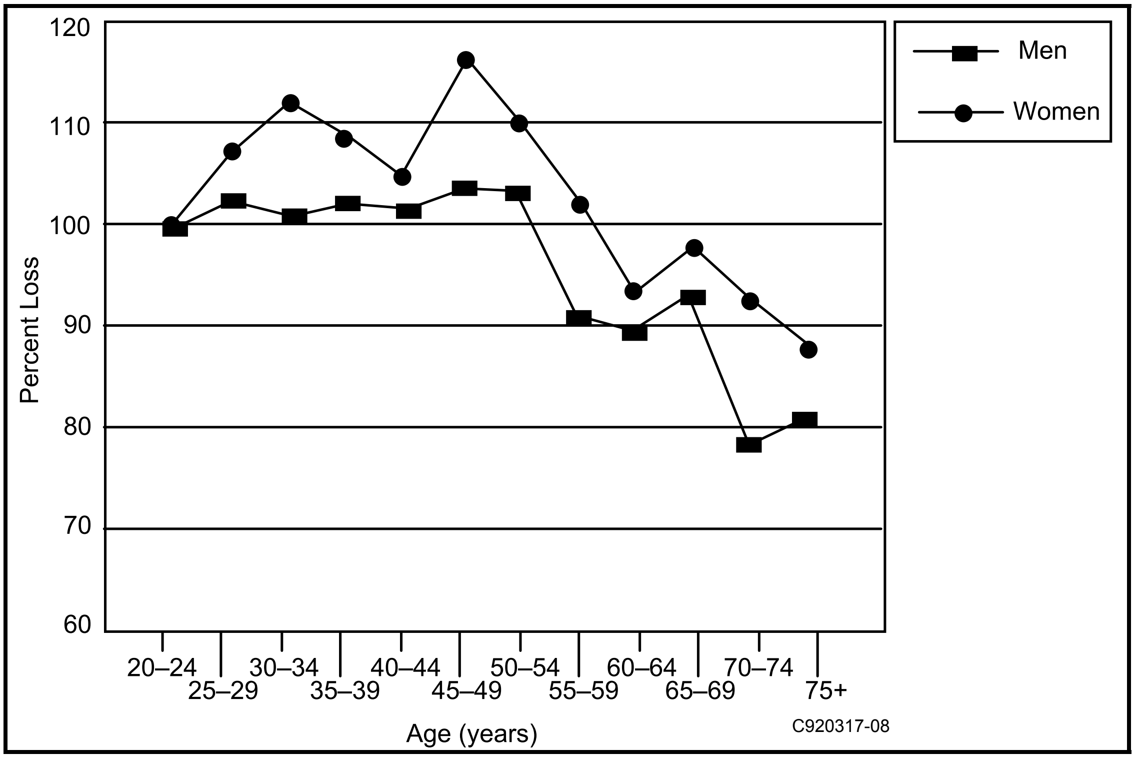
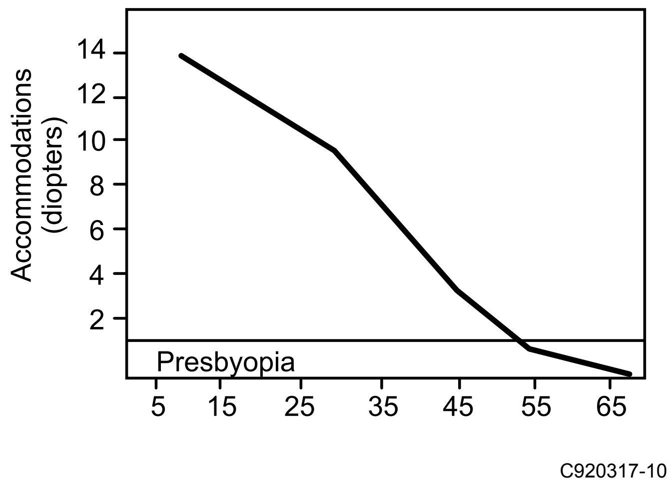


Figure 2-9. Percent Loss of Tip Pinch Grip with Age

Refractive Power—From about age 30 to the mid-60s, the eye gradually becomes more hypermetropic (farsighted) as the lens flattens. After the mid-60s, this reverses and the eye becomes more myopic (nearsighted) (Whitbourne, 1985). Roughly one-third of individuals over age 80 have vision of 20/50 or less (Lewis, 1985).

Accommodation—Adaption is the eye's ability to change its focus from far to near objects. The change in the refractive power of the lens in shifting focus from far to near objects becomes reduced from a peak of 14 diopters at 8 years to less than 2 diopters at age 50. By the age of 60, the lens is completely incapable of accommodating to focus on objects at close distance (Whitbourne, 1985). This is known as presbyopia (Figure 2-10).



Source: Tuniras (1988)

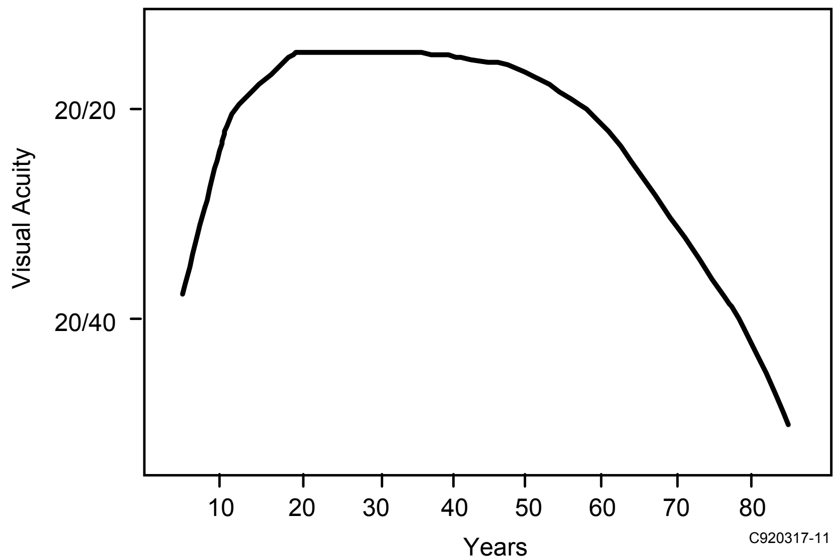
Figure 2-10. Changes in Visual Accommodation with Age

The reduced elasticity of the lens with age makes the lens less able to accommodate for near vision. The minimum distance between an object and the eye for a clear image, the "near point," increases from 9 cm at 10 years to 10 cm at 20 years, 20 cm at 45 years, 84 cm at 60 years (Tuniras, 1988), and 100 cm by age 70 (Kenney, 1989).

Acuity—Visual acuity is the ability to detect details on objects at varying distances. Scatter in the cornea and lens serves to deflect light rays entering the eye and reduce the contrast necessary for detecting details (Tuniras, 1988; Whitbourne, 1985). Senile miosis, the decrease in pupil size, reduces the amount of light entering the eye by as much as one-third (Kenney, 1989; Tuniras, 1988) and therefore also reduces the ability to detect details (Tuniras, 1988; Whitbourne, 1985).

Visual acuity increases during the 20s–30s and remains stable for 10–20 years. It begins to decrease in the 40s, and by age 85, there is an 80% loss of acuity when compared to the acuity at age 40 (Figure 2-11). The loss of acuity is especially severe at low levels of illumination (Whitbourne, 1985) (Figure 2-11).

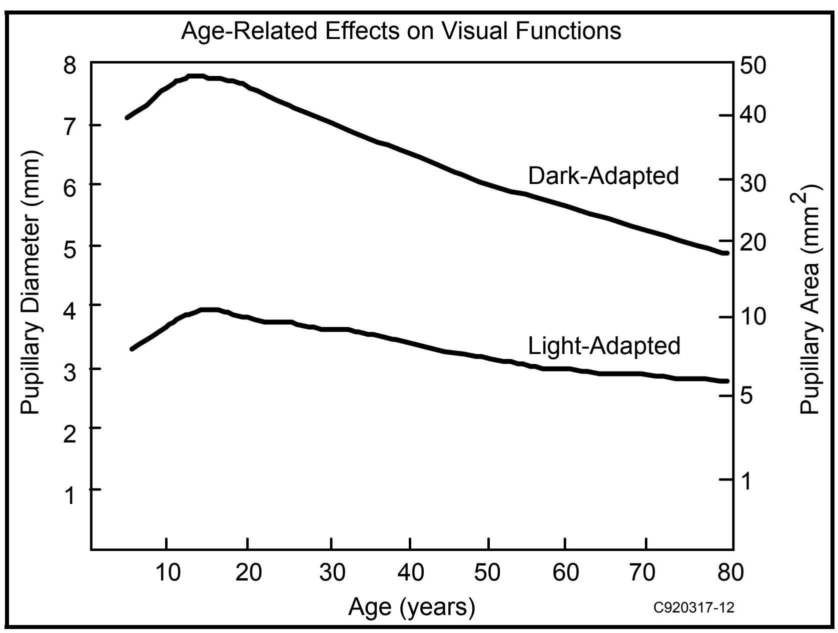
Elimination of glare and improved illumination can help enhance visual acuity substantially in the aged population (Tuniras, 1988).



Source: Pitts (1982)

Figure 2-11. Changes in Visual Acuity Measured in Snellen Index with Age

Dark Adaptation—Dark adaptation occurs when moving from a bright light to a dim environment. Decreased dark adaptation begins in the 20s and is especially pronounced after age 60. This appears to be caused by reduced light transmission through the lens and the reduction in pupil size or senile miosis (Whitbourne, 1985). In a fully dark-adapted eye, the mean diameter of the pupil is 8 mm in the 20s and gradually decreases to a mean of 5 mm in the 90s (Tuniras, 1988) (Figure 2-12).

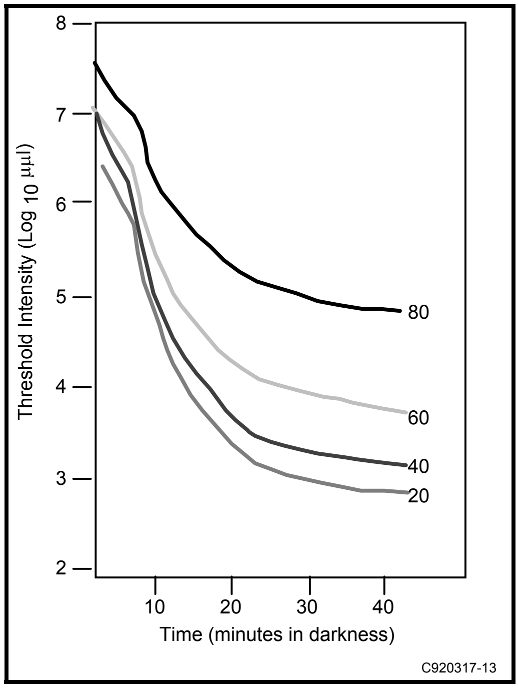


Source: Tuniras (1988); original data from Verriest (1971)

Figure 2-12. Changes with Age in Pupillary Diameter and Area, Measured in Light-Adapted

and Dark-Adapted Individuals

Sensitivity to Light—Older adults are less able to detect low levels of light because the yellowing and increased density of the lens, as well as senile miosis, reduces the amount of light that enters the eye (Whitbourne, 1985) (Figure 2-13). Therefore, the minimum amount of light necessary to see an object increases with age (Tuniras, 1988). Glare may also increase and create visual difficulties (Whitbourne, 1985).



Source: Tuniras (1988); original data from McFarland (1960)

Figure 2-13. Decline in Light Sensitivity with Age; Data Show Changes in Visual Threshold After Dark Adaptation in Different Age Groups

Color Vision—In the 40s and 50s, color perception begins to decline and there is reduced ability to discriminate between colors at the green-blue-violet end of the spectrum. This is due to the thickening and yellowing of the lens with age and is further affected by senile miosis, which restricts light entry to the thickest and most yellow central region of the lens (Tuniras, 1988; Whitbourne, 1985).

Temporal Resolution—The critical fusion frequency is the least frequency of a flashing light that is perceived as an uninterrupted signal. This is also referred to as the critical flicker fusion. With increasing age, there is a decrease in the point at which a flickering stimulus fuses into a continuous light. This is due to changes in the lens that reduce the amount of light entering the eye as well as aging effects in the central nervous system (Whitbourne, 1985).

Depth Perception—Depth perception appears to remain unchanged through the mid-40s, but some changes occur in later life (Whitbourne, 1985).

Visual Field—The size of the visual field is reduced significantly due to loss of receptors, as well as other factors (Kenney, 1989).

Age-Related Effects on Hearing

Hearing impairment is the third most prevalent chronic condition among the elderly population. About half of the population of hearing-impaired people is over 65. The prevalence of hearing impairment is about 12% of all people between ages 45 and 64, about 24% of those between 65 and 74, and about 39% of those age 75 and over (Schow, 1980). In nursing homes, the prevalence of hearing impairment is much higher than in the general population, ranging from 51 to 97% (Schow, 1980).

Hearing loss is classified as conductive, sensorineural, or mixed (Meyerhoff, 1984). A conductive hearing loss is due to a malfunction in the gathering of sound by the external ear, secondary to obstruction of the external auditory canal, or incomplete or inefficient transfer of sound energy to the cochlea by the eardrum or the ossicles of the middle ear. Sensorineural hearing loss may be caused by a lesion of the sensory receptor elements in the cochlea or the auditory nerve or a lesion of the higher processing center. Mixed hearing losses are those that have elements of both disorders (Meyerhoff, 1984).

Presbycusis—The most common cause of sensorineural hearing loss is presbycusis, the gradual reduction in hearing loss with advancing age (Staloff, 1987). It has been shown that hearing loss increases with age and is generally greater in the higher frequencies (Goldstein, 1984; Maurer, 1979). The severity of loss is greater for men than women (Maurer, 1979). Studies have also shown that the elderly can have greater speech discrimination impairment than young adults, although hearing ability is the same for both groups (Kirikae, 1964). Most elements or phonemes of speech fall within the frequency range of 300 to 4000 Hz.

Presbycusis is the most common communicative problem among the aging. It also is the most common auditory disorder in the entire population (Mader, 1984). There are four specific classes of presbycusis, and they have different characteristics in hearing loss (Corso, 1984). Sensory presbycusis produces a high-frequency loss (above 8000 Hz); neural presbycusis affects speech discrimination without a parallel loss in pure tone thresholds; metabolic presbycusis has a nearly uniform threshold loss for all frequencies with loudness recruitment; mechanical presbycusis shows an increase in hearing loss values from low to high frequencies. The most common form is sensorineural presbycusis (Sataloff, 1987).

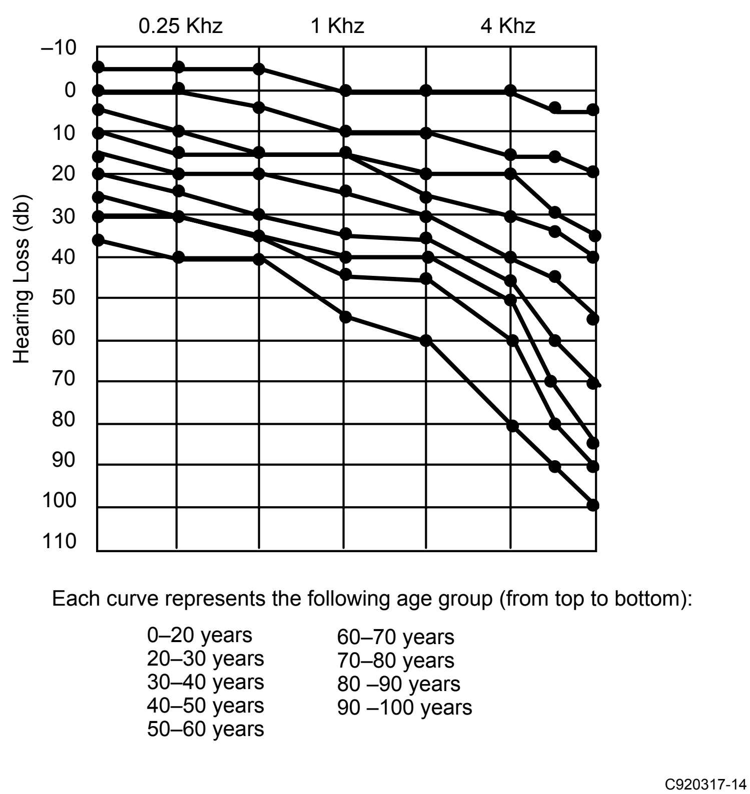
Hearing Thresholds—Hearing tests are usually performed in the frequency range of 500 to 4000 Hz (1000 to 2000 Hz in some cases) (Goldstein,1984), since this range is an estimate of the person's overall functional hearing sensitivity (Schow, 1980). The level of hearing impairment that is considered significant varies from different surveys and research projects and is still being debated.

The level of impairment is reported in terms of the weakest sound an individual can hear as in the following (Office of Technology Assessment, 1986):

Loudness in Decibels (dB)	**Degree of Impairment**
0 to 20	Normal
20 to 40	Mild
40 to 55	Moderate
55 to 70	Moderately severe
70 to 90	Severe
> 90	Profound deafness

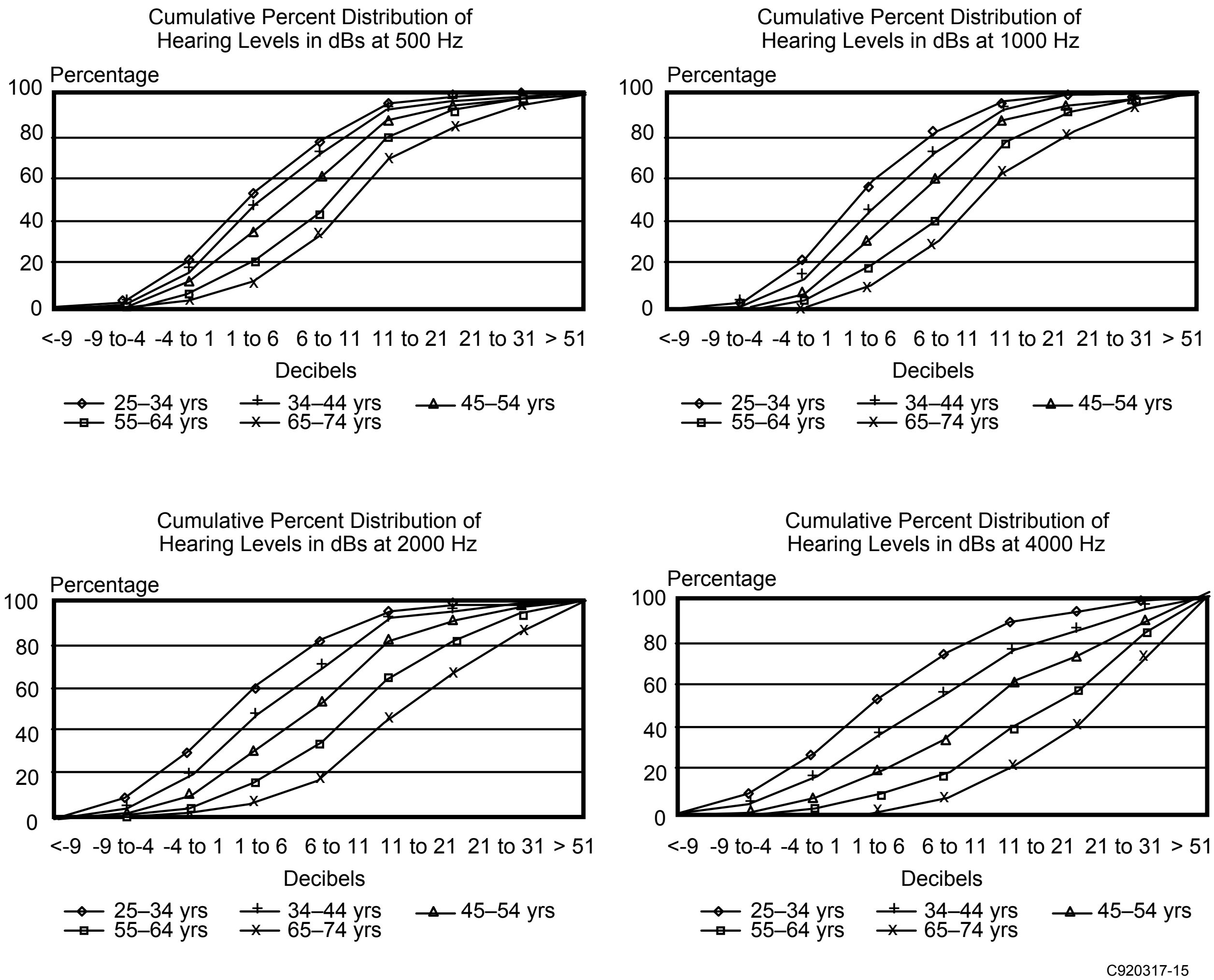
An elevation in hearing thresholds is not necessarily accompanied by a rise in levels that are uncomfortably loud. In other words, shifting the hearing threshold by 40 dB does not mean that the suprathresholds can be shifted as well. This is especially true for hearing loss experienced by the elderly.

The most common means of gathering quantitative hearing data on aging has consisted of pure-tone audiometric surveys (Maurer, 1979). Figure 2-14 shows hearing loss in a population between 0 and 100 years old. Figure 2-15 shows the cumulative percentage distribution of hearing levels at different frequencies. These data are compiled from the Health and Nutrition Examination Survey (1971–1975).



Adapted from Mader (1984)

Figure 2-14. Decade Audiogram Illustrating the Audiometric Patterns of Normal Aging



Adapted from the U.S. Department of Health and Education (1980)

Figure 2-15. Percentage Hearing Loss by Age and Frequency

Arthritis

Arthritis refers to inflammation and destruction of joint linings resulting in swelling, stiffness and pain. Approximately 37 million Americans have one of the many types of arthritis. The two most common forms of arthritis are rheumatoid and osteoarthritis. Impaired joint function as a result of pain and restricted motion is seen in all types of arthritis.

Rheumatoid Arthritis—Rheumatoid arthritis is a disease of the entire body that may affect children as young as two years old. Rheumatoid arthritis is an inflammation of the synovial tissues that line the joints. The synovial tissue increases in size, the joint cartilage wears away, and the joint capsule stiffens and becomes thin. Adjacent bones weaken and deform and tendons and ligaments thin and weaken. Muscle weakness eventually results. During a flareup of the disease, an individual experiences considerable pain during movement. If the inflammation continues or returns frequently, the individual eventually loses range of motion in the joints and becomes weaker. This limited range of motion, joint deformity and weakness in the feet, knees and/or hips makes walking difficult or impossible. Hands are often severely affected—hand grip and lateral pinch strength is greatly diminished and the hand may not fully open and/or close.

In one study (Helliwell, 1987), 20 controls (most of them women, aged 18–30) and 46 subjects with rheumatoid arthritis (33 women and 13 men, aged 33–77 with a mean of 57) were tested for maximum grip and lateral pinch strength. The data are summarized as follows:

	Normal Mean (SD)	**Patients with Rheumatoid Arthritis Mean (SD)**	**Percent of Normal**
Grip strength (kg)	26.1 (1.6)	6.1 (0.5)	24
Lateral pinch (kg)	8.5 (0.3)	3.3 (0.2)	39

These data compare favorably with others (Jones, 1987), although the literature indicates some variation (Walker, 1978). For people with rheumatoid arthritis, lateral pinch strength is often stronger than hand grip strength, and patients frequently rely on this motion in their everyday activities.

In a study of operation of rotary types of equipment controls among 50 individuals with arthritis, 74% of them reported that the most difficult task was that of turning, while 24% reported that grasping was the most difficult. Difficulty in pushing and pulling were reported by about 16% and 14%, respectively; 16% of subjects reported no difficulty (Voelz, 1987).

Osteoarthritis in the Elderly—Osteoarthritis is a degenerative joint disease, affecting people as they age. Joint degeneration affects half the population by the age of 40 or 50, but most people do not experience symptoms until 10 to 20 years later. In osteoarthritis the surface cartilage of the joint roughens, the bones develop spurs, and eventually the cartilage wears away and the bones in the joint rub against one another. The pain caused by the bones rubbing together leads to decreased use, which in turn leads to limited range of motion and weakness. Usually only a few joints in the hands, knees or hips are affected.

Multiple Sclerosis

In multiple sclerosis (MS), the myelin sheath surrounding the nerve axons is destroyed in areas of the brain and spinal cord, thus interrupting and distorting the flow of nerve impulses. The cause is unknown. The location of the lesions determines the symptoms an individual experiences. Symptoms may include cognitive deterioration, spastic paralysis of the extremities, diminished touch sensation and numbness, visual disturbances, ataxia (loss of coordination), loss of balance, tremors, and speech and language disturbances.

The most common vision problems for individuals with multiple sclerosis are diplopia (double vision) and blurring. Lesions in the cerebellum and brainstem may result in nystagmus (rapid involuntary movement of the eyeball). Dysarthia—slurred and imprecise speech due to incoordination of the muscles involved in speech—is common. Aphasia also can affect speech, and confusion may affect language performance. Memory and the ability to process information may be mildly or significantly impaired. It may take longer or be impossible to learn new procedures.

Motor impairments include spasticity, ataxia, loss of balance, tremors, and contractures. Spasticity is spontaneous, involuntary muscle contractions that result when corticospinal tracts in the cerebrum, brain stem, or spinal cord are involved. Spasticity in the upper or lower extremities can make controlled movement extremely difficult. Contractures are due to weakness or spasticity and result in limited range of motion for joints. Ataxia (loss of coordination), loss of balance, and tremors result from lesions in the cerebellum. Along with weakness, these symptoms make ambulation and controlled, precise and/or repetitive movements difficult or impossible. Fingers as well as other body parts may tingle or become numb and limit the amount of tactile information an individual can receive from the environment.

The hand grip and leg strength of people with multiple sclerosis as compared to those with no disability can be seen in the following table. In one study (Tourtellotte, 1965), eight subjects with no disability and an average age of 26 and 50 subjects with multiple sclerosis (32 females with an average age of 37.5; 18 males with an average age of 39.5) were tested for maximum isometric grip strength. In another study (Chen, 1987) with 17 individuals with no disability (eight males with an average age of 37.6; nine females with an average age of 36.1) and 15 people with multiple sclerosis (six men with an average age of 45.5 years; nine women with an average age of 33.6 years), the peak isometric torque for both quadriceps and hamstring was tested at 45 degrees of knee flexion.

	No Disability		**Multiple Sclerosis**		**Percent of Individuals with No Disability**	
	Male Mean (SD)	**Female Mean (SD)**	**Male Mean (SD)**	**Female Mean (SD)**	**Male**	**Female**
Grip (lb)	45.4 (11.8)		28.8 (13.7)		63.5	
Quadriceps (kg ∞ m)	17.8	11.4	11.0	8.9	62	78
Hamstring (kg ∞ m)	9.8	6.2	6.7	5.0	68	81

As expected, variations can be found in the literature for the strength of individuals with multiple sclerosis (Gehlsen,1984).

Cerebral Palsy

Cerebral palsy is a motor disorder resulting from damage to the brain before or during birth or in early childhood. Approximately 700,000 Americans have some degree of cerebral palsy. Symptoms of cerebral palsy include spasticity, athetosis, dystonia, atonia, rigidity, ataxia and tremor. One, two, three, or four extremities may be affected, as well as the neck and trunk. Vision,

hearing, and cognitive impairments are also possible, and some people with cerebral palsy have mental retardation. Individuals with cerebral palsy find it difficult or impossible to control various central nervous system reflexes, leading to involuntary muscle contractions, inability to control accuracy of movement, and involuntary movement. The combination of symptoms makes walking difficult or impossible if the lower limbs are affected. Purposeful, fine motor movements of the hands and arms are difficult or impossible with an affected upper extremity.

Stroke and Head Trauma

Stroke refers to brain damage resulting from a damaged blood vessel in the brain. Head trauma is damage to the brain from direct trauma. The effects are the same regardless of the type of trauma and are determined by the location of the damage. There may be motor, sensory, and cognitive impairments. Motor impairments may include poor balance, a wide-based gait, or hemiplegia (paralysis of one side of the body), making walking and fine motor control difficult or impossible. Sensory disorders may include impaired tactile sensation, visual-motor integration or perception of temperature, making it difficult to manipulate small, smooth controls. Visual impairments may include diplopia (double vision) and visual field impairments. Dysarthria and dyspraxia may be present, resulting in difficulty in language communication. Attention and concentration, memory, and information processing may also be impaired, making it difficult to learn and remember complex operations.

Spinal Cord Injury

There are approximately 150,000 persons with spinal cord injuries living in the United States. Spinal cord injuries are classified by the location of the injury along the spinal cord and whether the lesion is complete or incomplete. In a complete lesion, no nerve impulses pass through the region. In an incomplete injury, impulses pass through some areas of the cord and not through others. The term paraplegia refers to injuries in the thoracic or lumbar region of the spinal column, and quadraplegia refers to injuries in the cervical region. People with a complete or incomplete lesion in the thoracic or lumbar region will have impairment in the lower limbs only; they likely will need a wheelchair or other device to assist with mobility but will have normal strength and control in their arms. The higher the injury, the greater the disability. Lesions in the cervical region of the spine affect the upper extremities. Depending on the location and completeness of the injury, an individual may experience impaired ability to manipulate fingers and thumbs, wrists, elbows and shoulders. An individual with a complete spinal cord injury at the fourth cervical vertebra has no motor or sensory function from the shoulders down. Vision, hearing, and cognitive functions are not affected.

Of all people with spinal cord injury, 36% have injuries between cervical vertebrae C5 and C8 (Stover, 1986). Little quantitative information is available regarding the strength of these individuals. Several experts have indicated that practically no force will be registered when measuring strength of people with this type of injury. However, there are several articles describing surgical operations (e.g., tendon transfer) to restore grasp and lateral pinch. Wide variations among patients were observed. Following is a summary of published data:

Force After Surgery Mean/SD (range)(kg)			
Grip	**Key Pinch**	**Palmar Pinch**	**Notes, Source**
5.7/3.0	3.2/2.0		House, 1976
7.1/2.2	3.5/1.8		House, 1985
	4.6/3.5		Hentz, 1983
	0.94/1.0 (0.0,3.3)		1.0 cm object, Rieser, 1986
	1.30/1.1 (0.0,3.5)		2.5 cm object, Rieser, 1986
	2.03/2.4 (0.0,8.0)		3.5 cm object, Rieser, 1986
2.81/2.89 (trace,10)	1.47/1.29 (0.13, 4.7)	1.04/1.02 (0.2,3.0)	Kelly, 1985

Section 3
Controls

The guidelines in this section specify the design of controls. The types of controls included here are the conventional set of pushbutton, rotary, and other discrete controls, keyboards, and the more recent membrane keypads. The topics for each type of control include:

- Application,
- Design,
- Size,
- Force,
- Travel (movement),
- Spacing,
- Direction of activation.

Finger-Operated Pushbutton

Application—Single, sequential, finger-operated pushbuttons are appropriate for many applications. Multiple-finger simultaneous operations should be avoided. Autorepeat activation (as the pushbutton is held down) should be avoided.

Design—Pushbuttons should have a matte, nonslip surface. The edges should be raised above the surrounding panel surface. It is preferred that the center of the pushbutton be slightly dished.

Size—From 0.5- to 1.0-in. diameter or from 0.5- to 1.0-in. square.

Force—From 10 to 20 oz of force.

Travel—From 0.125 to 1.5 in. of travel. A positive click should be felt to indicate actuation.

Spacing—For single-finger, sequential operation, from 0.5- to 2.0-in. separation between pushbuttons.

Direction—Pressing the pushbutton should turn on, start, or engage the device. If the pushbutton is a momentary-action type with spring return, some other indication of whether the device is on should be provided, such as an indicator light and tone.

Palm-Activated Pushbutton

Application—Single, sequential, palm-operated pushbuttons are quite effective for many applications. Multiple simultaneous operations should be avoided. Autorepeat activation (as the pushbutton is held down) should be avoided.

Design—Pushbuttons should have a matte, nonslip surface. The edges should be raised above the surrounding panel surface. It is preferred that the center of the pushbutton be dished or that the rim be raised.

Size—From 1.0- to 3.0-in. diameter or from 1.5- to 3.0-in. square.

Force—From 10 to 80 oz of force.

Travel—From 0.125 to 1.5 in. of travel. A positive click should be felt to indicate actuation.

Spacing—Separation between pushbuttons of at least 6 in. is preferred.

Direction—Pressing the pushbutton should turn on, start, or engage the device. Simultaneous push-and-turn or pull-and-turn operation should be avoided. If the pushbutton is a momentary-action type with spring return, some other indication of whether the device is on should be provided, such as an indicator light and tone.

Push-Pull Controls

Application—Push-pull-type controls are not recommended. For activation, they require simultaneous grasping and pulling. The position setting of the control is not apparent without visual reference, and is sometimes ambiguous even with vision.

Membrane Touch Keys—Pushbuttons

Application—Membrane touch keys are not recommended unless they have certain design features listed below. Multiple simultaneous keypresses should be avoided. Autorepeat activation (as the key is held down) should be avoided.

Design—Keys should have a matte, nonslip surface. The edges should be raised above the surrounding panel surface, and color-coding or other visual demarcation of the edges should be provided. Definitive tactile feedback and audible feedback of key actuation should both be provided, and it is preferred that the audible feedback can be disabled if desired.

Size—From 0.5- to 1.0-in. square or rectangular.

Force—From 10 to 20 oz of force, consistent for all keys. Each key should have a snap dome and permit activation with equivalent pressure anywhere within the area demarcated with the raised edges.

Travel—A positive click should be felt to indicate actuation.

Spacing—From 0.5 to 2.0 in. separation between keys.

Direction—Pressing the key should turn on, start, or engage the device. An associated display mechanism should be provided to indicate the state of the controls.

Keypad Keys

Application—Keypad keys like those found on a telephone or calculator are usually used in sequence by multiple fingers, so they can be smaller than usual single-finger pushbuttons. Multiple simultaneous keypresses should be avoided. Auto-repeat activation (as the key is held down) should be avoided.

Design—Keys should have a matte, nonslip surface. The tops of the keys should be concave to prevent the finger from slipping off. Definitive tactile feedback of key actuation should be provided.

Size—From 0.375 to 0.75 in. diameter, square, or rectangular.

Force—From 1 to 10 oz of force for alphanumeric keys; from 3.5 to 15 oz for numeric keys. Smaller keys should use forces in the lower range; larger keys in the higher range.

Travel—Minimum travel of 0.05 in. for small keys and 0.25 in. for larger keys. A positive click should be felt to indicate actuation.

Spacing—Minimum spacing of 0.25 in. between keys measured at the keytops.

Direction—Pressing the key should turn on, start, or engage the device. An associated display mechanism should be provided to indicate the state of the controls.

Toggle Switches

Application—Toggle switches are effective as two-position or three-position controls. It is easy to verify those with discrete settings. Toggle switches are inappropriate for continuous controls.

Design—Definitive tactile feedback of toggle switch actuation should be provided. If momentary action with spring return is provided, auxiliary feedback regarding the setting of the switch must be provided.

Size—Stand from 0.5 to 2.0 in. from the surrounding surface; from 0.25 to 1.0 in. wide or thick.

Force—From 10 to 40 oz of force.

Travel—From 30° to 120° of travel; 40° to 60° is preferred. A detent or click should be felt to indicate actuation.

Spacing—From 0.75 to 2.0 in. of separation between switches.

Direction—The up, away, or right position of the switch should turn on, start, or engage the device.

Rocker Switches

Design—Definitive tactile feedback of rocker switch actuation should be provided. If momentary action with spring return is provided, auxiliary feedback about the setting of the switch must be provided.

Size—From 0.5 in. long and 0.25 in. wide to 2.5 in. long and 1.5 in. wide.

Force—From 10 to 40 oz of force.

Travel—30° of angular travel is recommended. A detent or click should be felt to indicate actuation.

Spacing—Minimum of 0.75-in. separation between switches.

Direction—The upper, away, or right part of the switch should turn on, start, or engage the device.

Slide Switches

Application—Slide switches are generally not recommended for discrete-position controls, especially for more than two positions. They require precision in placement of the finger and precision in movement. For discrete-position controls, pushbuttons are preferable. Slide switches are acceptable for continuous-position controls.

Design—Top of the slide switch should be serrated to develop friction with the finger. Momentary action with spring return should be avoided.

Size—Stand a minimum of 0.5 in. above the surrounding surface; from 0.25 to 1.0 in. wide.

Force—From 10 to 16 oz of force for continuous positioning.

Travel—No minimum or maximum requirements.

Spacing—Minimum of 1.0-in. separation between switches.

Direction—Movement up, away, or right should increase the level of the associated function.

Detented Rotary Selectors

Application—Detented rotary selectors are effective for multiple position settings of a control and provide easy verification of position setting. However, rotary selectors are difficult to operate because they require simultaneous grasping and turning actions.

Design—Definitive tactile feedback of rotary selector positioning should be provided. From 3 to 12 discrete positions is acceptable. If a blade handle is used, the pointing end of the handle should be shaped unambiguously and different from the opposite end. A good design for a detented rotary selector has a blade handle that can be extended with a clip or tube for more leverage. Momentary action with spring return should be avoided.

Size—From 0.625 in. high and 1.0 in. long to 3.0 in. high, 4.0 in. long, and 1.0 in. wide.

Force—From 12 to 48 oz of force, with forces in the higher range for larger controls.

Travel—From 15° to 40° angular travel between detented positions; 30° is recommended. Stops should be provided at the limits of the control range to prevent placing the rotary selector in an unused position.

Spacing—Minimum of 2.0 in. of separation between selectors.

Direction—The rotary selector should turn to the right or clockwise to turn on, start, or engage the device. Increasing positions should continue clockwise.

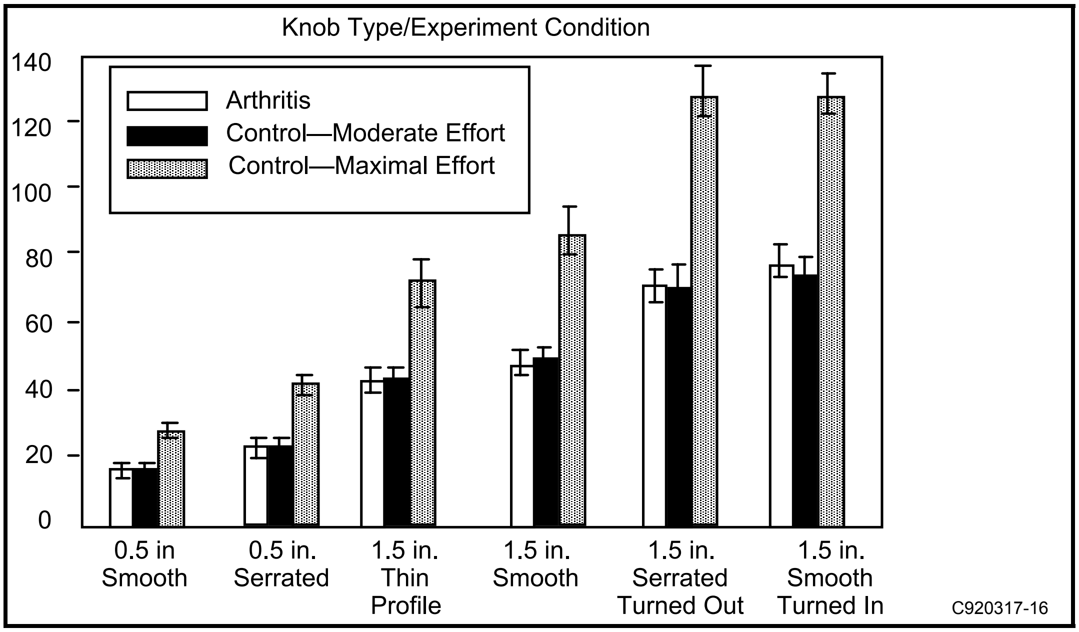
Continuous Rotary Controls

Application—Continuous rotary controls are effective for selecting fine gradations. However, continuous rotary controls require movement precision and can be difficult to operate.

Design—A knob with a blade handle accommodates most people. If a blade handle is used, the pointing end of the handle should be shaped unambiguously and different from the opposite end. If a round knob is used, the sides should be serrated to develop friction with the user's fingers or hand. In all cases, the pointer should be distinctly shape-coded and color-coded.

Size—From 0.5 to 1.0 in. high and from 1.0 to 1.5 in. in diameter. Knobs cannot be too small or too large because some individuals with disabilities cannot bring their thumbs and fingers very close together and others cannot separate them very far.

Force—The maximum amount of torque that can be required to turn a knob is a function of the size, shape, and surface texture of the knob. In general, the fewer the sides, the greater the amount of torque that can be applied. If possible, the torque necessary to turn a knob should be no more than the average of the maximum effort available for individuals with limited hand strength.



Source: Metz (1990)

Figure 3-1. Torque Applied to Rotary Control by Subjects with Arthritis and Control Groups

Travel—For coarse settings, 180° of knob rotation should produce about 6 in. of movement on a corresponding linear scale or other display. For fine settings, 180° of rotation should produce 1 to 2 in. of linear scale movement. Stops should be provided at the limits of the control range.

Spacing—Minimum of 2.0 in. of separation between controls.

Direction—The rotary selector should turn clockwise to increase the level of the associated function.

Section 4
Visual Displays

The guidelines in this section specify the design of displays, including alphanumeric text displays, and light indicators.

The topics for visual displays include:

- Application,
- Design,
- Brightness,
- Angle of view,
- Distance,
- Readability,
- Labels,
- Color,

Alphanumeric Text Displays

Application—(TBD)

Design—(TBD)

Brightness—As a minimum, the average brightness of a text display should be twice the brightness of its surround. On-pixels should be 10 times as bright as off-pixels.

Angle of View—Characters on a text display should be readable from any location within 45° of a line perpendicular to the surface of the display.

Size—From 16 to 45 min of arc subtended at the eye for height of alphanumeric characters. Preferred height is 20 to 22 min of arc. A reading distance of no less than 12 in. should be used to determine visual angle.

Character Design—Height-to-width ratio of characters in fixed-column presentation should be 1:0.7 to 1:0.9. Height-to-width ratio for proportionally spaced characters should be 1:0.5 to 1:1. Stroke width should be 1/12 of the character height or 1 min of arc, whichever is greater. Neither the height nor width of a character should vary by more than 10%, regardless of its display location within the image area.

Character Spacing—Between-character spacing should be the width of one stroke or one pixel, whichever is greater.

Line Spacing—Between-line spacing should be the width of two strokes or two pixels, whichever is greater. Preferred spacing is from one-half to one character height. Between-line spacing is measured from the lowest descender on one line to the highest uppercase letter on the next line.

Word Spacing—Between-word spacing should be the width of one character. For proportional typefaces, the width of the capital letter "N" should be used for spacing.

Typeface—Helvetica typeface (without serifs) is preferred.

Display Flicker—The alphanumeric text display should not flicker noticeably.

Display Luminance—Display luminance should vary by not more than 50% between the center of the display and any point along the edge of the display.

Display Jitter—Geometric location of characters should vary by no more than 0.0002 times the viewing distance over a period of 1 sec.

Light Indicators

(TBD)

Labels

This section contains guidelines for the design of labels—textual and numerical information placed on a product to link controls and displays with their intended functions. Guidelines for labels are intended to enhance their readability, and include characteristics similar to text displays such as character size, standard font style, sufficient spacing between characters and words, and foreground-background contrast.

Label layout guidelines are included in this section. Labels are understood better when they are organized well on the control panel and placed adjacent to the control or display they describe.

Color

(TBD)

Emergency Indicators

Frequency—Visual warning signs should flash at a frequency of less than 5 Hz.

Section 5
Auditory Displays

The guidelines in this section specify the design of auditory displays.

The auditory display guidelines cover:

- Application,
- Frequency,
- Amplitude,
- Coding,
- Tone quality,
- Synthesized speech,
- Informational auditory displays,
- Emergency auditory warnings,
- Alarms.

Informational Auditory Displays (tone or beep)

Application—Tones or beeps are effective means of indicating the successful input to touch-type controls (e.g., membrane switches). Tones or beeps may be used to indicate to the user that additional input is needed; however, repetitive beeping is considered annoying.

Frequency—Adjustable frequency would serve the most people; otherwise the best range is 300-–750 Hz.

Amplitude—(TBD)

Coding—(TBD)

Tone Quality—(TBD)

Informational Auditory Displays (synthesized speech)

Application—(TBD)

Frequency—(TBD)

Amplitude—(TBD)

Coding—(TBD)

Tone Quality (Gender)—Either male or female voice is acceptable. In most applications, voice style should be either friendly or neutral, except for serious situations in which a reserved style is preferred.

Emergency Auditory Warnings

Amplitude—Alarms shall produce a sound level that exceeds the normal prevailing equivalent sound level at the ears of the intended listeners by at least 15 dB or any maximum sound level with a duration of 30 sec by 5 dB, whichever is louder, and not exceed 120 dB.

Section 6
Functional Allocation and Panel Layout

The design and selection of controls, displays, and labels is addressed in the previous sections. This section addresses the task of matching the function to the type of control and display. In the design process, selection is followed by organizing the design of the control panel. Principles are provided for arrangement and panel layout in terms of:

- Sequential operation,
- Functional layout,
- Importance.

Functional Allocation

(TBD)

Principles of Arrangement

(TBD)

Panel Layout

(TBD)

Keypads

(TBD)

Panel Design—Continuous Controls

(TBD)

Section 7
Operating Protocol

This section includes data on how to design the interaction sequence or protocol of control and information display. The guidelines here supplement the data in all the other sections. The following topics are included:

- Remote access,
- Response time,
- Sequence control,
- Error messages,
- Interaction styles,
- Operating procedures,
- Emergency procedures,
- Help features.

Matrix of Categories of Functional Disabilities vs. Design Principles

(TBD)

Functional Performance Specifications (details TBD)

- Input devices
  - Modified standard keyboard controls
    - Multiple keystroke control
    - Keyboard repeat rate
    - Input redundancy
    - Toggle keystroke control
  - Alternative input devices
  - Keyboard orientation aids

- Output devices
  - Auditory output capability
  - Information redundancy
  - Characteristics of monitor display
    - Large character size
    - Access to screen memory for text
    - Access to screen memory for graphics
    - Cursor presentation blink rate
    - Color presentation

- Accessibility
  - Walking disabilities
    - Thresholds and door mats
  - Wheelchair users
    - Space requirements for maneuvering
    - Space requirements for reaching
    - Space requirements for passing
  - Chronic impairment of the upper limbs and shoulders
  - Extremes of size and maturity
  - Chronic restrictive conditions affecting agility, stamina, reaction time
  - Severe auditory impairment
  - Severe visual impairment
    - Long cane technique
    - Cueing aids
    - Color blindness
  - Confusion and disorientation
  - Difficulty bending, sitting, kneeling, and rising
  - Incontinence

- Equipment Design
  - Door hardware
  - Thresholds and door mats
  - Automatic openers/closers
  - Aids for existing doors
  - Windows
  - Floor coverings
  - Signs and signage systems
  - Elevators
  - Mechanical lifts
  - Ramps
  - Furnishings
  - Special construction
  - Toilet and bathing facilities
    - Faucets and controls
    - Grab bars and accessories
  - Listening systems

Appendix A
Types of Grips

There are several types of grips commonly used to manipulate controls (Steinfeld, 1990)

- **Lateral pinch grip**—The lateral pinch grip is also known as a key grip because this is the method used by most people to grasp a key. The pad of the thumb opposes the side of the index finger. The pinch grip is used for precise manipulation of small objects and requires a moderate amount of force.

- **Tip pinch or disc grip**—With this grip, all finger tips are in contact with the device at one time. This grip is usually used for precise, rotational control of objects and requires very little force.

- **Hand grip or power grip**—The entire hand is used to grasp the object. This grip produces maximum force for most individuals with minimal precision.

- **Palmar pinch**—The palmar pinch is a type of pinch grip where the palm opposes the fingertips. This type of grip is most often used by individuals who are unable to use their thumb in a pinch grip.

- **Span grip**—In a span grip, the edge of the hand along the thumb and index finger encloses an object. This grip is used for rotational movement when strength is required, such as turning a door knob.

- **Finger push**—One finger is used to push, or just touch, a specific area.

- **Flat-hand push**—In a flat-hand push, several fingers, the thumb and/or the palm are used to push against or touch a surface. The control with a flat-hand push is less precise than a finger push, but more force can be generated.

From Steinfeld, 1990

Figure A-1. Types of Grips

Lateral pinch grip

Hand or power grip

Tip pinch or disc grip

Span grip

Flat-hand push

Finger push

References

General References

Department of Education and General Services Administration (1980). *Initial Guidelines for Electronic Equipment Accessibility*, September.

Capital Development Board, State of Illinois (1978). *Accessibility Standards Illustrated*.

ANSI A117.1 (1980). *Specifications for Making Buildings and Facilities Accessible to and Usable by Physically Handicapped People*.

United States Government (1984). *Uniform Federal Accessibility Standards*, August.

Paralyzed Veterans of America (19--). *Construction Specifier*.

Honeywell Corporate Systems Development Division (1988). *SMART HOUSE Human Factors Guidelines*, March.

Department of Education, National Institute on Disability and Rehabilitation Research and General Services Administration, Information Resources Management Service (1987). *Access to Information Technology by Users with Disabilities—Initial Guidelines*, October.

References: Hearing

Corso, J.F. (1984). Auditory processes and aging: Significant problems for research, *Experimental Aging Research*; Vol. 10, pp. 171–174.

Dunkle, R.E., Haug, M.R., and Rosenberg, M. (1984). *Communications Technology and the Elderly: Issues and Forecasts*. New York: Springer Publishing Company.

Glickman, D.S. (1978). *Accessibility Standards - Illustrated*. State of Illinois: Capital Development Board.

Goldstein, D.P. (1984). Hearing impairment, hearing aids and audiology, *ASHA*, pp. 24–38.

Hopf, P.S., and Raeber, J.A. (1984). *Access for the Handicapped*, New York: Van Nostrand Reinhold Company.

Kirikae, I., Sato, T., and Shitara, T. (1964). A study of hearing in advanced age. *Laryngoscope*, Vol. 74, pp. 205–221.

Mader, S. (1984). Hearing impairment in elderly persons, *Journal of American Geriatrics Society*, Vol. 32, No. 7, pp. 584–553.

Maurer, J. F., and Rupp, R.R. (1979). *Hearing and Aging: Tactics for Intervention*. London: Grune and Stratton, Inc.

Meyerhoff, W.L., Liston, S., and Anderson, R.G. (1984). *Diagnosis and Management of Hearing Loss*. Philadelphia: W.B. Saunders Company.

Office of Technology Assessment, Congress of the United States (1986). *Hearing Impairment and Elderly People* (Background Paper).

Popelka, G.R. (1984). Improving the hearing of the elderly, *Communications Technology and the Elderly*, Dunkle, R.E. (ed.). New York: Springer Publishing Company.

Sataloff, R.T., and Sataloff, J. (1987). *Occupational Hearing Loss*. New York: Marcel Dekker, Inc.

Schow, R.L., and Nerbonne, M.A. (1980). Hearing levels among elderly nursing home residents, *Journal of Speech and Hearing Disorders*, Vol. XLV, pp. 124–132, February.

U.S. Department of Health and Education (1980). *U.S. Vital and Health Statistics* (Series 11).

References: Vision

Kenney, R.S. (1989). *Physiology of Aging*. Chicago: Yearbook Medical Publishers.

Boyce, P.R., *Human Factors in Lighting*. New York: Macmillan Publishing Co.

Lewis, C.B. (1990). *Aging: The Health Care Challenge*. Philadelphia: F.A. Davis.

Milne, J.S. (1985). *Clinical Effects of Aging: A Longitudinal Study*. London, Dover, N.H.: Croom Helm.

Tuniras, P.S. (1988). *Physiological Basis of Geriatrics*. New York: Macmillan Publishing Co.

Whitbourne, S.K. (1985). *The Aging Body, Physiological Changes and Psychological Consequences*. New York: Springer-Verlag.

References: Disabling Conditions

Chen, W.Y., Pierson, F.M., and Burnett, C.N. (1987). Force-time measurements of knee muscle function of subjects with multiple sclerosis, *Physical Therapy*, Vol. 67, pp. 934–940.

Gehlsen, G.M., Grigsby, S.A., and Winant, D.M. (1984). Effects of an aquatic fitness program on the muscular strength and endurance of patients with multiple sclerosis, *Physical Therapy*, Vol. 64, No. 5, pp. 653–657

Helliwell, P., Howe, A., and Wright, V. (1987). Functional assessment of the hand: Reproducibility, acceptability, and utility of a new system for measuring strength, *Annals of the Rheumatic Diseases*, Vol. 46, pp. 203–208.

Hentz, V.R., Brown, M., and Keoshian, L.A. (1983). Upper limb reconstruction in quadriplegia: functional assessment and proposed treatment modifications, *Journal of Hand Surgery*,Vol. 8, No. 2, pp. 119–131.

House, J.H., Gwathwey, F.W., and Lundsgaard, D.K. (1976). Restoration of strong grasp and lateral pinch in tetraplegia due to spinal cord injury, *Journal of Hand Surgery*, Vol. 1, No. 2, pp. 152–159.

House, J.H., and Shannon, M.A. (1985). Restoration of strong grasp and lateral pinch in tetraplegia: A comparison of two methods of thumb control in each patient, *Journal of Hand Surgery*, Vol. 10(A): 21–29.

Jones, R.A., Unsworth, A., and Haslock, I. (1987). Functional measurements in the hands of patients with rheumatoid arthritis, *International Rehabilitation Research*, pp. 62–72.

Kelly, C.M., Freehafer, A.A., Pechnam, P.H., and Stroh, K. (1985). Postoperative results of opponensplasty and flexor tendon transfer in patients with spinal cord injuries, *Journal of Hand Surgery*, Vol. 10, pp. 890–894.

Mathiowetz, V., Kashman, N., Volland, G., Weber, K., and Dowe, M. (1985). Grip and pinch strength: Nomative data for adults, *Archives of Physical Medicine and Rehabilitation*, Vol. 66, pp. 69–74.

Scheer, Steven J. (ed.) (1991). *Medical Perspectives in Vocational Assessment of Impaired Workers*. Gaithersburg, MD: Aspen Publishers, Inc.

Rieser, T.V., and Waters, R.L. (1986). Long-term follow-up of the Moberg key grip procedure, *Journal of Hand Surgery*, Vol. 11.

Steinfeld, E., and Mullick, A. (1990). Universal design: The case of the hand, *Journal of Industrial Design Society of America*, Vol. 9, No. 3, pp. 27–30.

Stolov, Walter C. (1981). *Handbook of Severe Disability: A Text for Rehabilitation Counselors, Other Vocational Practitioners, and Allied Health Profesionals*. Washington, D.C.: U.S. Department of Education, Rehabilitation Services Administration.

Stover, S.L., and Fine, P.R. (1986). *Spinal Cord Injury: The Facts and Figures*. Birmingham, AL: University of Alabama–Birmingham.

Thomas, Clayton L. (ed.) (1985). *Taber's Cyclopedic Medical Dictionary*, Edition 15. Philadelphia: F. A. Davis Company.

Tourtellotte, W. W., Haerer, A. F., Simpson, J. F., Kuzma, J. W., and Sikorski, J. (1965). Quantitative clinical neurological testing. Part I. A study of a battery of tests designed to evaluate the neurological function of patients with multiple sclerosis and its use in a therapeutic trial, *Annals of the New York Academy of Sciences*, Vol. 122, No. 1, pp. 480–505.

Voelz, S.L., and Hunt, F.E. (1987). Measurement of hand strength in arthritic women and design of appliance control knobs, *Home Economics Research Journal*, Vol. 16, No. 1, pp. 65–69.

Walker, P.S., Rutherford, R.J., Davidson, W., and Erkman, M.J. (1978). An apparatus to assess function of the hand, *Journal of Hand Surgery*, Vol. 3, pp. 189–93.