PROJECT REPORT:

Older Consumer Safety: Phase I

A Review and Summary of the Literature on Age-Related Differences in the Adult Consumer Population, and Product-Related Interventions to Compensate for those Differences

December 2005

Timothy P. Smith, Engineering Psychologist
Division of Human Factors
Directorate for Engineering Sciences
U.S. Consumer Product Safety Commission
Washington, DC 20207
301-504-7691, tsmith@cpsc.gov

Contents

Executive Summary

Adults 65 and older are a rapidly growing segment of the U.S. population. Yet the older-adult population is one that is commonly overlooked in consumer product design, and more importantly, in consumer product safety. The successful and safe use of a consumer product is highly dependent on the extent to which the user has the capabilities necessary to meet the demands that the product places on the consumer. Age-related deficits in sensory, cognitive, or physical abilities can, therefore, negatively impact consumer product safety.

The staff of the U.S. Consumer Product Safety Commission (CPSC) initiated a project in 2005 to examine consumer product safety issues associated with older adults. This report is the culmination of the first phase of this project: to develop a comprehensive profile of older adults in terms of attributes relevant to consumer-product interactions. Specifically, the staff performed a literature review to identify changes or differences associated with adult aging that might affect an individual's ability to successfully interact with a product.

As detailed in this report, older adults' sensory systems generally become less sensitive, making them less capable than the young of perceiving information. Age-related declines in muscle strength and motor coordination limit the extent to which older adults are capable of performing actions that may be necessary to use a product or to avoid a hazard. Adult aging is also associated with deficits in cognitive skills that require rapid, flexible thinking about novel or unfamiliar situations. This report also discusses product- or environment-related interventions that are likely to compensate for these age-related differences.

Introduction

Adults 65 and older are a rapidly growing segment of the U.S. population. From 1993 to 2003, the proportion of adults 65 years of age and older rose from 9.5 to 12.4 percent; this percentage is expected to increase to about 20 percent by the year 2030 (U.S. Department of Health and Human Services, 2004). Additionally, people are living longer than ever before, so the oldest adults are increasing in numbers most rapidly. Between the years 2002 and 2030, the number of persons 85 years of age and older is expected to increase from 4.6 million to about 9.6 million (U.S. Department of Health and Human Services, 2004).

Older adults are a potentially vulnerable population, yet one that is commonly overlooked in consumer product design, and more importantly, in consumer product safety. For this reason, the staff of the U.S. Consumer Product Safety Commission (CPSC) initiated a project in 2005 to examine consumer product safety issues associated with older adults. This report is the culmination of the first phase of this project: to develop a comprehensive profile of older adults in terms of attributes relevant to consumer-product interactions. Specifically, the staff performed a literature review to identify changes or differences associated with adult aging that might affect an individual's ability to successfully interact with a product. Understanding these age-related differences was seen as a necessary first step to future work in this area.

Aging and Product Safety

Product-Related Injuries and Deaths[1]

Based on estimates from the CPSC's National Electronic Injury Surveillance System (NEISS), more than 1.4 million people 65 years of age or older were treated in U.S. hospital emergency rooms in 2002 for injuries related to consumer products. About two-thirds of these consumers (955,540) were 75 years of age or older. For the year 2000, the CPSC has received reports of more than 3,300 product-related deaths to consumers 65 years of age and older.

From 1997 through 2002, the rate of product-related injuries treated in U.S. hospital emergency rooms for those 65 years of age and older was higher than for adults 20 to 64 years of age. From 1991 to 2002, the number of consumers between 65 and 74 years of age who were treated in U.S. hospital emergency rooms increased 23 percent, even though the size of the population within that age group showed no increase. Similarly, hospital emergency-room visits for consumers 75 years of age and older increased 73 percent, which is nearly three times the percentage increase in the

[1] The injury data cited in this section, unless otherwise specified, were obtained from the 2005 U.S. Consumer Product Safety Commission special report, *Emergency Room Injuries: Adults 65 and Older*, and from the 2004 *Hazard Screening Report: Injuries to Persons 65 Years of Age and Older: All Products* (Rutherford et al., 2004).

population size of that age group (27 percent) during the same period. This injury rate is approximately twice that of consumers 65 to 74 years of age.

Aging, Human Factors, and Product-Related Safety

Every consumer product places certain demands upon the user. Thus, the successful and safe use of a product is highly dependent on the extent to which the user has the capabilities necessary to meet those demands. Failing to match user capabilities with product-use demands can prevent a person from using the product successfully, and depending on the circumstances, this can prove hazardous. For example, the process of avoiding a hazard may be thought of as a serial sequence of stages, including perceiving the hazard, understanding the hazard or recognizing the danger, deciding to avoid the hazard, and being capable of avoiding the hazard (Cushman & Rosenberg, 1991; Sanders & McCormick, 1993). Successful completion of these stages depends on people's perceptual, cognitive, and physical abilities and characteristics. Therefore, age-related differences in any of these characteristics or capabilities can potentially impact consumer product safety.

Scope and Organization of the Report

Age-Related Differences in Adulthood

A considerable amount of literature details age differences in people's perceptual, cognitive, and physical abilities, and there is general agreement that most capabilities deteriorate at least somewhat with age. This report summarizes primary age-related differences, organized under the general headings of "Sensory and Perceptual Differences," "Cognitive and Psychological Differences," and "Physical and Motor Differences." To some extent, there is overlap among these sections, primarily because a limitation in one area can sometimes affect other abilities. For example, response or reaction times are dependent on the ability to perceive the stimulus, so deficits in vision or hearing can adversely affect response times. This report limits repetition to the extent possible.

Given the substantial literature available, the staff relied primarily on secondary aging-related texts and handbooks written by well-known experts and scholars in the field of aging rather than on primary research-study reports and articles. Although the staff reviewed numerous references, the following six are the primary ones relied upon to identify age-related changes and differences:

- Spirduso, W.W., Francis, K.L., & MacRae, P.G. (2005). *Physical dimensions of aging* (2nd ed.). Champaign, IL: Human Kinetics.

- Shaie, K.W., & Willis, S.L. (2002). *Adult development and aging* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

- Birren, J.E., & Schaie, K.W. (Eds.). (2001). *Handbook of the psychology of aging* (5th ed.). San Diego, CA: Academic Press.

- Craik, F.I.M., & Salthouse, T.A. (Eds.). (2000). *The handbook of aging and cognition* (2nd ed.). Mahwah, NJ: Lawrence Earlbaum Associates.

- Park, D., & Schwarz, N. (Eds.). (2000). *Cognitive aging: A primer*. Philadelphia: Taylor & Francis.

- Fisk, A.D., & Rogers, W.A. (Eds.). (1997). *Handbook of human factors and the older adult*. San Diego, CA: Academic Press.

A full list of references appears at the end of this report. Due to the large number of references reviewed and the substantial agreement among these references on specific age-related differences, the staff decided not to include citations within the discussions of age-related differences. Instead, a list of the most relevant references appears at the end of each sub-section under the heading, "Suggested References." For example, the references that are listed at the end of *Sensory and Perceptual Differences*: *Vision* are the primary ones relied upon to prepare the discussion in that section and are the ones that the reader would likely find most useful if seeking more detailed information related to aging and vision.

Interventions to Compensate for Age-Related Differences

The end of each major section (i.e., *Sensory and Perceptual Differences*, *Cognitive and Psychological Differences*, and *Physical and Motor Differences*) includes a discussion of some interventions that are likely to compensate for the age-related differences discussed in that section. These are based primarily on the preceding discussion of age-related differences, but also reflect the review of literature on aging and human factors. The interventions that are described are intentionally focused on changes to products or the surrounding environment rather than changes to the individual, such as through training or exercise. Additional or more detailed interventions can be found in the following references:

- Fisk, A.D., Rogers, W.A., Charness, N., Czaja, S.J., & Sharit, J. (2004). *Designing for older adults: Principles and creative human factors approaches*. Boca Raton, FL: CRC Press.

- Schieber, F. (2003). Human factors and aging: Identifying and compensating for age-related deficits in sensory and cognitive function. In N. Charness & K.W. Schaie (Eds.), *Impact of technology on successful aging*. (pp. 42–84). New York: Springer Publishing Company.

- Vanderheiden, G.C. (1997). Design for people with functional limitations resulting from disability, aging, or circumstance. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed.). (pp. 2010–2052). New York: John Wiley & Sons.

- Morrell, R.W., & Echt, K.V. (1997). Designing written instructions for older adults: Learning to use computers. In A.D. Fisk & W.A. Rogers (Eds.),

Handbook of human factors and the older adult. (pp. 335–361). San Diego, CA: Academic Press.

Aging Terminology

No firm line separates an "older" adult from a "younger" adult. Generic references to "older" adults often seem to be intended to cover those over the age of 65. However, this is probably done merely out of convenience because it represents the current retirement age. The Age Discrimination Act of 1967 protects individuals aged 40 years and older from employment discrimination based on age (U.S. Equal Employment Opportunity Commission, 1997). Thus, one could interpret this as meaning that a person becomes "older" once he or she has turned 40 years of age. To further complicate matters, the phrases "middle-aged," "young-old," "old-old," "older-old," "elderly," "very-old," and "oldest-old" are sometimes used to distinguish among various adult age groups, and the specific age ranges they represent are not always consistent. Although confusing, distinctions of this kind are often necessary, especially since trying to use specific age cutoffs for changes or differences is often difficult or unrealistic.

This report refers to four groups of adults: "younger," "middle-aged," "older," and "very old" adults. For the purposes of this report, the following definitions are used:

- "Young" or "younger" adults are those in their twenties and thirties.
- "Middle-aged" adults are those between "young" and "old" age, or from about age 40 to 64 years.
- "Old" or "older" adults are those aged 65 years or older.
- "Very old" adults are those aged 75 years or older.

These definitions are based primarily on the literature review performed for this report. The reader should keep in mind, however, that these definitions are somewhat fluid given that age-related change rarely occurs in sudden, abrupt steps. Also, because they are adjectives, "older," "younger," and similar terms may be used in this report in a relative sense, such as when referring to individuals who are "older" than others. To the extent possible, this report avoids potential confusions such as these and relies instead on the above definitions or on specific ages.

This report also frequently uses "age-related changes," "age-related differences," "age differences," and similar phrases to describe the abilities or characteristics of older adults relative to younger adults. The literature sometimes draws distinctions among these terms. For example, some observed differences between the young and the old may be caused by the aging process, whereas other differences may not and may instead reflect generational differences—such as differences in education level. From a practical standpoint, this distinction matters little except when attempting to draw conclusions about future changes or directions in aging. In other words, whether observed age differences are due to aging or to generational differences is likely to be irrelevant unless you want to know whether these differences are likely to lessen, worsen, or remain stable in future generations. Thus, for the purposes of this report, and unless otherwise stated, these terms should be considered synonymous.

Caveat

The age differences that are discussed in this report represent typical or "average" changes during aging; however, like any other population, individual members of the older-adult population will not necessarily show the changes described here. The performance of the older adult population is at least as variable as the younger adult population, and some researchers suggest that variability along these dimensions may actually increase as we age (Kelly and Kroemer, 1990; Rogers, 1997; Vercruyssen, 1997). In fact, it is highly unlikely that any one individual will exhibit all of the changes, in the precise sequence and to the same degree, described in this report.

Sensory and Perceptual Differences

The literature indicates that older consumers have decreased sensory-perceptual abilities relative to younger adults. This appears to affect all senses, though much of the literature and research focuses on vision and hearing.

Vision

Vision generally deteriorates with age, starting as early as one's thirties. About half the population requires some form of visual correction by the mid-forties, while virtually everyone does by the late fifties. In part, this is a consequence of the increased incidence of pathological diseases and conditions of the eye such as cataracts, glaucoma, and macular degeneration, especially as one enters the late sixties. However, vision losses are evident even without these pathologies.

The immediate causes of many age-related declines in vision appear to be changes in the structure of the eye. These changes can begin in middle age, but the greatest losses occur later in life, with significant proportions of older adults exhibiting visual impairments. Changes in some external parts of the eye, such as the lens and the pupil, begin in one's thirties or forties. Changes in the retina and nervous system become noticeable in one's fifties and sixties. Specific changes in visual functioning are described in the sections that follow.

Visual Acuity and Presbyopia

Visual acuity—the ability to resolve fine pattern detail, or the clarity and sharpness of one's vision—tends to decline gradually with increasing age. Age-related declines in acuity may be evident by 30 years of age, but more commonly begin in one's forties and become more pronounced in very old age (i.e., 75 years of age and older). Poor viewing conditions, such as low-light levels or glare, tend to exacerbate age-related deficits in visual acuity. Although many acuity losses are optically correctible—for example, by wearing glasses or contact lenses—losses may persist even after optical correction, especially among those in their seventies. Persistent acuity losses for these very old adults are primarily due to pathological conditions of the retina, such as macular degeneration. Optical correction can also present its own problems; for example, bifocals may be used to correct for age-related deficits in near-vision acuity (see next topic), but the use of bifocals could create acuity problems in the lower portion of one's visual field for distant vision. Acuity for peripheral targets tends to show greater age-related declines than for central targets (also see *Peripheral Vision and Useful Field of View*, below).

To focus on objects at varying distances, the lens of the eye "accommodates" by adjusting its thickness so that images transmitted through the lens focus on the retina. Age-related reductions in lens flexibility, and the consequent losses in accommodative capacity, limit one's ability to focus on nearby objects. This is commonly referred to as presbyopia. Losses start to become evident in one's forties, at which time people have difficulty focusing on printed text that is closer than arm's distance. By about 60 to 65 years of age, accommodative ability is essentially lost so that objects are only in sharp focus when at a limited, fixed distance from the eye. This distance may differ between the two eyes.

Light Sensitivity and Dark Adaptation

Age-related reductions in pupil size and changes to the lens, such as yellowing, thickening, and increasing opacity, reduce the amount of light that ultimately reaches an older adult's retina. For example, under identical lighting conditions, the amount of light that reaches the retina of a 60-year-old is estimated to be only one-third of that for a young adult. Evidence also indicates that the rods and cones of the eye become less sensitive with increasing age, further increasing the amount of light needed by older adults. Adaptation to changing light conditions, such as when moving from a brightly lit room to a dark one, also slows with increasing age due to slowed responses of the iris.

Contrast Sensitivity

The literature consistently reports declines in contrast sensitivity, or the ability to distinguish differences in luminance, with increasing age, particularly for higher spatial frequencies (i.e., the number of light/dark cycles per degree of visual angle). These declines appear to be due to the increased scattering of light as it passes through the lens on its way to the retina. However, age-related declines in light sensitivity are also likely to play a role since declines in contrast sensitivity are especially severe in low-light conditions. Contrast sensitivity is believed to be more important to discrimination tasks, such as the ability to detect and recognize common objects, than visual acuity.

Color Sensitivity

Color sensitivity declines modestly with advancing age, and is generally evident at about age 70. Losses are primarily to shorter-wavelength light—that is, greens, blues, and violets—and older adults find it increasingly difficult to distinguish between yellows and blues. The elderly may also have greater difficulty distinguishing among desaturated colors, such as pastels, and among colors of the same hue. Losses in color sensitivity may be caused by the yellowing of the lens and the consequent selective absorption of shorter-wavelength light, the loss of photoreceptors, and the reduction in receptor sensitivity to shorter-wavelength light.

Glare Sensitivity

Adults become increasingly sensitive to glare as they age, and sensitivity increases as the lens becomes more opaque and increasingly scatters the light that enters the eye, reducing visual contrast. Disability glare, therefore, increases with increasing illumination. Glare sensitivity is most pronounced among the very old (i.e., 75 years of age and older). Older adults also require more time than the young to recover from disability glare. Glare negatively affects visual acuity, and has been found to cause losses in color sensitivity outside the range normally affected by age (e.g., reduces red-green sensitivity).

Depth Perception

The literature is mixed about age differences in depth perception; some research indicates differences and some does not. These contrary findings may be because of the redundant methods that one employs to perceive depth. For example, although depth perception is dependent on stereopsis and binocular vision, other cues such as texture discrimination and lens accommodation also play a role. Perceived losses in depth perception may simply be attributable to losses in visual acuity or to the increasing incidence of vision problems. Problems with depth perception, therefore, are likely to be dependent on the specific characteristics of the environment or on the extent to which people suffer deficits in multiple visual abilities. The latter is unlikely to occur until very old age.

Motion Perception and Perception of Change

The literature reports age-related declines in flicker sensitivity, which indicates that older adults would have more difficulty than the young at tasks involving quickly changing stimuli. Similarly, older adults are less sensitive to, and slower to detect, object movement. Although motion-perception impairments affect both foveal (i.e., central) and peripheral vision, impairments appear to be greater for foveal vision. Older adults have also been shown to have difficulty smoothly tracking fast-moving objects with the eyes. This is likely due, in part, to age-related slowing of the oculomotor system.

Peripheral Vision and Useful Field of View

Adult aging is associated with peripheral vision losses and a reduction in the visual field. The size of an individual's visual field appears to remain constant until at least 35 years of age, and reductions are minimal until one's fifties. This field gradually shrinks in one's fifties and sixties, and shows more marked reductions in one's seventies and beyond. For example, the horizontal visual field for young adults is about 180 degrees, while that for a 70-year-old is about 140 degrees. Peripheral vision losses are believed to be due to age-related declines in the density of photoreceptors (i.e., rods) in the periphery of the retina.

A concept related to peripheral vision, and important for visual search and attention tasks, is the useful field of view, which represents the limits of the visual field from which one can accurately locate, identify, and discriminate visual targets when the eye is in a fixed position. Evidence indicates that an older adult's useful field of view is restricted relative to younger adults, and may be only one-third that of a younger adult even among those whose visual acuity appears otherwise normal. Older adults have greater difficulty detecting and discriminating between peripheral targets, and declines in acuity tend to be greater for peripheral targets. Eyeglasses, which may be worn to correct for other age-related declines in vision, are unlikely to compensate for declines in peripheral acuity. Additionally, age-related deficits in flicker sensitivity are most pronounced for targets in the periphery.

Although losses in peripheral vision are likely to affect the useful field of view, age-related reductions in the useful field of view are also likely to be due to age-related deficits in cognitive processing mechanisms (see *Cognitive and Psychological Differences*: *Cognitive Processing Mechanisms*, starting on page 17). For example, the useful field of view decreases as the attentional demands of the task increase and as the number of distractors increases. Reductions in the useful field of view also occur as the target and distractors become more similar, and practice has been found to expand the useful field of view of older adults. Issues related to attention are discussed in more detail in *Cognitive and Psychological Differences: Attention*, which starts on page 19 of this report.

Suggested References

References that discuss age-related changes in vision and visual functioning in greater detail include:

- Fozard, J.L., & Gordon-Salant, S. (2001). Changes in vision and hearing with aging. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 241–266). San Diego, CA: Academic Press.

- Schneider, B.A., & Pichora-Fuller, M.K. (2000). Implications of perceptual deterioration for cognitive aging research. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 155–219). Mahwah, NJ: Lawrence Earlbaum Associates.

- Kline, D.W., & Scialfa, C.T. (1997). Sensory and perceptual functioning. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult*. (pp. 27–54). San Diego, CA: Academic Press.

Hearing

Hearing problems are the most frequent type of impairment reported by individuals aged 65 years and older. The number of people with objectively diagnosed impairments begins to increase at about 30 to 40 years of age, and sharply increases after the age of 60. Hearing loss is the third most prevalent chronic disability among older adults,[2] and hearing loss affects about 30 to 35 percent of people 65 to 75 years of age and 40 to 50 percent of people 75 years of age and older.

The cause of hearing loss varies among individuals, and distinguishing presbycusis, or age-caused hearing loss, from losses caused by lifelong exposure to environmental

[2] First and second are arthritis and hypertension.

noise or to other factors is often impossible. Regardless of the specific cause, the literature identifies the following age-related changes in auditory functioning.

Hearing Sensitivity

Aging is associated with a decline in the ability to perceive noises at all frequencies, but sensitivity or threshold losses are first evident and greatest for higher frequency sounds (e.g., over 8000 Hz). For example, young adults can generally hear sounds at frequencies up to 15,000 Hz, but by about 65 to 70 years of age sounds at frequencies higher than 4000 Hz may be inaudible. Declines in hearing sensitivity are usually apparent at all frequencies by the age of 30 in men and the age of 50 in women. Losses appear to accelerate later in life. Up to half of all adults aged between 75 and 79 years of age have measurable threshold hearing loss. In addition to having an earlier onset of hearing loss, men show greater losses than women; at certain ages the rate of change is more than twice as fast in men as in women. After the age of 70, men also show greater declines in the speech frequency range.

Frequency and Intensity Discrimination

With increasing age, adults become less capable of discriminating among sound frequencies and intensities. Although these declines are evident at all frequencies, they appear to be larger at low frequencies (e.g., 125 to 500 Hz) than at high frequencies. Frequency discrimination is important to many tasks, including speech perception and listening to sounds in noisy environments. Older adults commonly report difficulty hearing in background noise or when several people are speaking simultaneously. These difficulties may be worsened by older adults' increased difficulty in ignoring irrelevant information (see *Cognitive and Psychological Differences*: *Cognitive Processing Mechanisms*: *Inhibitory Control*, which starts on page 18 of this report).

Binaural Processing, Temporal Resolution, and Sound Localization

The binaural processing of sound is associated with how people integrate the sounds received in each ear. The accurate sensing of time differences between ears is commonly referred to as temporal resolution, and there is evidence that older adults have deficits in this ability. For example, older adults have a reduced ability to detect gaps in sounds, and this deficit is independent of hearing loss. Similarly, research points to clear age-related deficits in discriminating differences in the duration of sounds. Temporal resolution is believed to be important for speech perception. Older adults also show declines in the ability to localize sounds, particularly low-frequency sounds. This may be related to deficits in temporal resolution, given that accurate sound localization depends on detecting the sound in each ear and accurately sensing both the interaural time and intensity differences of that sound. Speech recognition also appears to be strongly related to binaural processing.

Speech Perception and Recognition

Age-related deficits in speech recognition are consistently found in the research, and the largest communication complaint of older adults is difficulty understanding speech, particularly in noisy or otherwise degraded listening environments. This is not surprising since older adults are known to experience high-frequency hearing losses, and some of the fine detail of human speech makes use of high-frequency sounds. For example, high-frequency and low-energy sounds such as *f*, *g*, *k*, *p*, *s*, *t*, *z*, *ch*, *sh*, and the voiceless *th* are differentially affected by high-frequency hearing loss. Deficits in temporal resolution and frequency discrimination also appear to play significant roles.

Changes in speech comprehension are minimal between the ages of 20 and 50, but losses are significant by age 80. Improving the signal-to-noise ratio (i.e., increasing the intensity of the target sound, or speech, relative to the background noise) largely eliminates speech-recognition problems. Hearing impairment sufficient to affect speech comprehension has been estimated at between 24 and 30 percent for otherwise healthy adults between the ages of 65 and 75, and between 30 and 48 percent for those over 75 years of age. Older adults also exhibit phonemic regression, a lack of clarity for complex auditory signals such as speech. Speech perception is especially vulnerable to the presence of background noise or distortion. Cognitive aspects of speech perception and comprehension are discussed more thoroughly in *Cognitive and Psychological Differences*: *Language Processing and Comprehension*: *Speech Perception and Comprehension*, which can be found on page 26 of this report.

Suggested References

References that discuss age-related changes in hearing and auditory functioning in greater detail include:

- Fozard, J.L., & Gordon-Salant, S. (2001). Changes in vision and hearing with aging. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 241–266). San Diego, CA: Academic Press.

- Schneider, B.A., & Pichora-Fuller, M.K. (2000). Implications of perceptual deterioration for cognitive aging research. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 155–219). Mahwah, NJ: Lawrence Earlbaum Associates.

- Kline, D.W., & Scialfa, C.T. (1997). Sensory and perceptual functioning. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 27–54). San Diego, CA: Academic Press.

The Other Senses

Somatosensation

The somatosensory system includes all receptors associated with the body's sense of touch, position, and motion. In general, increasing age leads to decreased sensitivity among these senses, meaning that older adults are less likely to detect stimulation. The primary cause is a reduction in the number of sensory receptors for each sense.

Touch, pressure, and vibration are sensed by cutaneous receptors in the skin. Cutaneous sensitivity and discriminability significantly decline with age. Older adults find it increasingly difficult to detect vibrations, with a two to tenfold increase in their vibration threshold. Peripheral neuropathy, a condition that involves a partial to complete loss of sensation, is more common among older adults. Those with severe sensation deficits tend to show greater delays in muscle response and an inability to appropriately scale the response. Sensitivity to pain and to temperature also appears to decline in old age.

The kinesthetic, or proprioceptive, system provides individuals with information about the relative position of the body parts to each other, the position of the body in space, the body's movements, and the nature of objects with which the body comes into contact. These are obtained through receptors in the muscles and joints. The available research indicates that absolute detection thresholds increase with age. Specifically, older adults have less accurate knowledge of limb position, are significantly less capable of detecting slow limb movements, and have difficulty judging the direction of passive limb movements. However, these differences are minimal with fast limb movements, which suggests that joint position sense, although reduced with age, may not have practical significance in many day-to-day activities. Older adults do have reduced sensory feedback, so they rely more on the visual system for postural control.

The vestibular system contributes information regarding the position and movement of the head in space and is critical for maintaining balance when visual or somatosensory information is absent or distorted; it also assists in resolving sensory conflict that arises in complex visual environments. Changes in the vestibular system begin as early as age 30, with a gradual decline that continues progressively through adulthood and results in reduced sensitivity to head movements. By the age of 70, the number of vestibular hair and nerve cells declines by as much as 40 percent. With advancing age, there appears to be a moderate reduction in the speed with which one can stabilize vision when the head moves quickly through space. This reduction adversely affects an older adult's ability to determine whether it is the world or him/herself that is moving in certain situations. Older adults feel increasingly unsteady in complex visual environments and may report sensations of dizziness or vertigo (spinning sensation) that add to their perception of instability.

Smell and Taste

Sensitivity to tastes and smells appears stable until about 60 years of age, after which there are small age-related declines. Declines in smell sensitivity are likely to be related to the shriveling of the olfactory bulbs, but environmental factors may play a more significant role.

Older adults' reduced taste discrimination is partly due to an age-related decline in the number of taste buds on the tongue; for example, an individual at age 75 has approximately 36 percent the number of taste buds as an individual at age 30. Additionally, older adults' reduced sense of smell tends to reduce taste discrimination. There is evidence that sensitivity to bitter tastes, and possibly sour tastes, lasts longer than sweet or salty tastes.

Suggested References

The literature on age-related changes to sensory functioning other than vision and hearing is sparse, but the following two references include reasonably good discussions of age-related changes in somatosensation:

- Ketcham, C.J., & Stelmach, G.E. (2001). Age-related declines in motor control. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 313–348). San Diego, CA: Academic Press.

- Spirduso, W.W., Francis, K.L., & MacRae, P.G. (2005). *Physical dimensions of aging* (2nd ed.). Champaign, IL: Human Kinetics. (pp. 135–139 & 179–181.)

Interventions to Compensate for Differences

Safe product use and the recognition of hazards depend on the ability of the consumer to perceive the hazard and other important product information. For example, consumers may need to read a warning or printed instructions to avoid a particular hazard. Some hazards may be obvious to those with "normal" vision but missed entirely by those with impaired vision. The inability to read a label may lead a visually impaired consumer to manipulate the wrong control. Similarly, hearing impairments may prevent consumers from hearing important warning signals or may cause consumers to mistake one sound for another. Based on its review of the literature, the staff believes that the following interventions would help compensate for age-related sensory and perceptual differences:

- Provide important information such as warnings and alarms to consumers redundantly through multiple sensory channels. For example, combine auditory alarms with flashing lights.

- Increase illumination levels, especially in situations that require the consumer to read information.

- Use nonreflective, matte or semi-matte finishes to reduce the potential for glare, especially on surfaces that include warnings or other information that consumers must read or focus on.

- Provide high contrast between visual target or focal objects, such as text or graphics, and the background. For example, use very dark lettering (e.g., black, navy blue) on a very light background (e.g., white, yellow), or vice versa.

- Make visual targets large enough to be easily detected and simple enough to be easily discerned. If the consumer must respond to a change in the system or must distinguish among items, make the change or difference that must be detected as large as feasible. Reduce the extent to which consumers must detect small or subtle changes or must rely on fine details to identify or distinguish objects.

- Use at least 12- or 14-point type for information that must be read, but consider using 18-point type to accommodate consumers in their eighties and beyond. Avoid the use of light, decorative, or cursive type. Limit the use of all-uppercase letters to headlines and other situations in which you want to attract attention. Use sentence capitalization for long passages of text. Provide sufficient space between letters and between lines of text.

- Limit the extent to which consumers must perform close-up work. Make those surfaces that require focused vision, such as surfaces that contain warnings or other text, consumer-adjustable for reading distance.

- Limit the extent to which consumers must detect or discriminate between colors. In particular, avoid the need to discriminate among short-wavelength colors (greens, blues, and violets) and desaturated colors such as pastels. When color discriminations are necessary, use large color-contrast differences or steps.

- Limit the extent to which consumers must respond to rapidly changing or moving targets. Avoid the use of scrolling text displays.

- Keep visual targets near the center of the consumer's visual field. Reduce the need to rely on peripheral vision. If consumers must discriminate among objects in the periphery, increase target-distractor and target-background differences.

- Increase the intensity of target sounds or speech relative to background noise and to other distractors by increasing sound intensity, decreasing non-target noise, or both.

- Limit the use of high-frequency sounds for information that must be detected and recognized. Keep important warning or alert sounds below 4,000 Hz, and preferably at about 500 to 1,000 Hz.

- Do not rely solely on sounds to indicate target location. If you must, increase the duration of the sound or repeat the sound until it is acknowledged.

- Consider making illumination, contrast, sound intensity (volume), and sound frequency consumer-adjustable to meet the differing needs of consumers.

Cognitive and Psychological Differences

"Cognition" and related terms are used in this report to describe mental skills and abilities such as memory, learning, attention, language comprehension, judgment, and decision making. Certain cognitive skills and abilities tend to deteriorate with increasing age, while others remain relatively stable. For the average individual, minimal declines in cognitive abilities are evident by the mid- to late-sixties, and more pronounced declines occur beyond 75 years of age. Individual differences, however, are significant. Neurodegenerative diseases, such as Alzheimer's, are also common afflictions of old age, affecting about 5 to 10 percent of individuals over age 65 and 20 to 40 percent of people over the age of 80 years. These diseases can cause progressive declines in cognitive skills and abilities.

Fluid versus Crystallized Intelligence

Cognitive abilities are often divided into two primary types. One, commonly referred to as "cognitive process" or "fluid intelligence," involves the ability to think rapidly and flexibly about relatively unfamiliar and novel problems. Judgment and decision-making skills are believed to be examples of fluid intelligence. The other, commonly referred to as "cognitive product" or "crystallized intelligence," is associated with the ability to draw on the accumulated experience and acquired knowledge and skills that an individual already possesses. Vocabulary and the application of linguistic rules are common examples of crystallized intelligence.

Research consistently finds gradual yet robust age-related declines in fluid intelligence into very old age, possibly starting as early as age 25 or 30. In contrast, crystallized intelligence appears to be relatively stable into late adulthood. Declines in crystallized intelligence may be evident, however, if information must be processed quickly or for individuals who have entered very old age (i.e., 75 or 80 years of age and older).

Some deficits in cognition may be largely attributable to age-related deficits in sensory processes, particularly declines in visual and auditory functioning. Information that is degraded due to deteriorating senses may limit the quality and speed of cognition. For example, language comprehension depends on being capable of accurately hearing the information to be decoded. Thus, while declines in sensory functioning may not represent declines in cognitive functioning per se, the two are strongly related, and sensory functioning is a powerful predictor of cognitive functioning.

Evidence also indicates that many age-related declines in cognition are likely to be due to age-related declines in certain, fundamental cognitive processing mechanisms. These mechanisms are discussed in the following section.

Cognitive Processing Mechanisms

The literature identifies three fundamental cognitive processing mechanisms that deteriorate with increasing age and are believed to be responsible for age-related declines in many cognitive tasks. They are:

- Resource limitations
- Processing speed
- Inhibitory control

None of these mechanisms, independently, accounts for all age-related variance in cognition. Age-related deficits in any cognitive task, however, are likely to be due primarily to some combination of these basic cognitive processing mechanisms.

Resource Limitations

Resource-limitation views posit that individuals have a limited supply of mental resources or capacities that are available to use when performing a cognitive task and that they are allocated based on cognitive needs and task priorities. The processing resources most commonly cited as limiting cognition in older adults are working-memory capacity and, to a lesser extent, attentional capacity. These resources are believed to diminish with increasing age, thereby reducing an older adult's ability to perform resource-demanding cognitive tasks such as dividing attention, reasoning, and problem solving, specifically, tasks that involve effortful, self-initiated processing. Age-related changes in working memory are discussed in greater detail in *Cognitive and Psychological Differences*: *Memory and Learning*: *Short-Term Primary and Working Memory*, starting on page 21 of this report.

Age-related deficits in cognition due to resource limitations may be mitigated through the use of environmental supports, which are external factors or elements of the task that decrease the processing requirements of that task. Environmental supports may include such things as the presence of external cues (e.g., pictures, lists), restructuring the task to allow individuals to rely on relevant prior knowledge, and the use of assistive devices.

Processing Speed

One of the most obvious and commonly recognized changes with increasing age is the slowing of cognitive or mental processing. Evidence indicates that age-related declines in processing speed may account for a substantial amount of the age differences in cognitive processes such as memory, attention, reasoning, and language comprehension. Additionally, age differences in processing speed appear to increase as the cognitive task becomes more complex (also see *Cognitive and Psychological Differences*: *Judgment and Decision Making*, starting on page 27). Cognitive performance in older adults may, in fact, remain quite accurate if they are given sufficient time to complete a task. Generalized slowing, however, does not account for all age-related deficits in cognition.

Inhibitory Control

Inhibitory processes allow individuals to focus information processing and responding tasks on relevant information by (1) preventing irrelevant, off-task information from entering working memory, (2) deleting or suppressing information that is irrelevant, no-longer relevant, or only marginally relevant from working memory, and (3) preventing strong or probable responses until their situational appropriateness can be determined. Inhibitory control, therefore, is associated with processing efficiency rather than processing speed.

Evidence indicates that inhibitory control weakens with age so that older adults have more difficulty focusing on target information and inhibiting attention to distractors and other irrelevant material. Deficits in inhibitory processes are likely to be at least partially responsible for age-related deficits in attention, memory, language comprehension, and other cognitive functions. These deficits can also lead to increased reliance on stereotypes, heuristics, or schemas in decision making (see *Cognitive and Psychological Differences*: *Judgment and Decision Making*, starting on page 27 of this report).

Aging also appears to be associated with a change in the patterns of peak mental alertness or arousal, and therefore cognitive performance, over the course of a day. For example, there is a significant trend toward "morningness" with increasing age, particularly after about 50 years of age. Thus, older adults tend to reach peak mental alertness in the morning and then decline over the day, while younger adults tend to become more alert over the day. Inhibitory processing and control has been found to be impaired at off-peak times, meaning that over the course of the day older adults may be even more susceptible to distracting, irrelevant information; less capable of ignoring well-learned and previously relevant, but currently inappropriate, information; and more likely to rely on stereotypes, heuristics, or schemas in decision making.

Suggested References

References that discuss age-related changes in fundamental cognitive processing mechanisms in greater detail include:

- Park, D.C. (2000). The basic mechanisms accounting for age-related decline in cognitive functioning. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer.* (pp. 3–21). Philadelphia: Taylor & Francis.

- Zacks, R.T., Hasher, L., & Li, K.Z.H. (2000). Human memory. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2^{nd} ed.). (pp. 293–357). Mahwah, NJ: Lawrence Earlbaum Associates.

- McDowd, J.M., & Shaw, R.J. (2000). Attention and aging: A functional perspective. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 221–292). Mahwah, NJ: Lawrence Earlbaum Associates.

Attention

Adequate attention is necessary to be able to successfully encode information so that it can be recalled later. The literature associated with aging and attention is generally organized into the categories of selective attention, switching attention, dividing attention, and sustained attention or vigilance. Each is discussed separately below.

Selective Attention

Selective attention involves the ability to detect and attend to relevant information while simultaneously ignoring irrelevant information; that is, the filtering of information. Overall, evidence indicates that aging is associated with a decline in the ability to selectively attend to information, but the degree of decline is strongly dependent on the specific characteristics of the selective-attention task.

Older adults show greater deficits in selective attention with the presence of distractors. As the attentional draw of irrelevant information becomes stronger, performance of the focal task becomes more impaired. These observed deficits are likely to be caused by age-related deficits in inhibitory control, as described in *Cognitive and Psychological Differences*: *Cognitive Processing Mechanisms* (starting on page 17).

The discriminability of targets and distractors, however, may be more relevant. Older adults show greater deficits in selectively attending to stimuli when the targets are similar to the distractors or to other background objects. This is especially true for conjunction searches, in which the target must be selected on the basis of two or more features (e.g., both color and shape). These findings may point to deficits in sensory functioning as the primary cause of age-related declines in selective attention. For example, age differences in selective attention tend to be minimal when visual acuity is controlled. Age-related declines in working memory capacity may also be relevant since correct discrimination depends on the individual comparing a given stimulus to his or her internal model of a correct target.

Lastly, age differences are apparent when the target location is unknown to the individual or is unpredictable, but cueing can be effective at minimizing these differences. Familiarity and experience tend to reduce age differences by making searches more automatic, so increased opportunities for practice are especially useful for older adults.

Switching Attention

Switching attention involves the refocusing of attention onto a different location or task. Until later old age, older and younger adults are similar in their ability to switch attention for those tasks in which the individual knows where to focus attention. For example, when presented with a valid peripheral cue about the target location, older adults tend to perform as well as younger adults. Age differences do arise, however, when cues require cognitive processing; for example, if the individual must remember to look for the target, or if the cue is central rather than peripheral and the individual must interpret the cue to determine the future target location. This may be due to age-related declines in sensory processing.

Performance differences in attention switching between older and younger adults depend, in part, on the individual tasks involved. For example, age differences tend to increase as the component task demands increase. Also, age differences are evident when distractors or competing information is present. Practice and training tend to reduce these differences.

Dividing Attention

Dividing attention involves splitting attention so that one simultaneously attends to more than one task. The difference between dividing and switching attention can be subtle. Tasks that appear to involve simultaneous performance, such as driving while monitoring one's speed or while reading traffic signs, may, in fact, simply involve rapidly switching attention between tasks. Thus, switching may be involved in divided-attention tasks.

In general, older adults show deficits in the ability to divide attention between tasks. As with attention switching, observed age differences in dividing attention are related to the characteristics of the individual tasks. Relevant task characteristics include the degree to which each task requires attention, task similarity, task novelty, and task difficulty or complexity. Age differences for tasks that are simple and demand little from memory are minimal.

There is some evidence that when older adults must attend to several factors at once, they choose to focus on fewer items and to do so in serial rather than parallel mode. Secondary tasks, therefore, tend to show greater age-related deficits when attention is divided. As with attention switching, practice and training tend to reduce age differences in dividing attention.

Sustained Attention or Vigilance

Sustained attention, also known as vigilance, involves the ability to maintain focus or concentration over an extended period. The evidence for age differences in vigilance is mixed. Although age differences in the performance of vigilance tasks have been observed, these differences often can be attributed to other aspects of the task rather than deficits in sustained attention per se. For example, when signal or target detectability is taken into account, older and younger adults perform essentially the same. Age-related deficits are also greater when the tasks require some cognitive component, such as having to discriminate among stimuli, having to decide how to respond to a particular stimuli, having to scan rapidly and continuously, or increasing the uncertainty associated with the event rate or target location.

Suggested References

References that discuss age-related changes in attention in greater detail include:

- Rogers, W.A. (2000). Attention and aging. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 57–73). Philadelphia: Taylor & Francis.

- McDowd, J.M., & Shaw, R.J. (2000). Attention and aging: A functional perspective. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 221–292). Mahwah, NJ: Lawrence Earlbaum Associates.

- Rogers, W.A., & Fisk, A.D. (2001). Understanding the role of attention in cognitive aging research. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 267–287). San Diego, CA: Academic Press.

Memory and Learning

Age-related declines in memory are commonly reported both anecdotally and in research. As a general rule, aging is associated with declines in memory tasks that require self-initiated, effortful processing; tasks that require less effortful processing generally show little to no change with increasing age. The literature on aging and memory typically distinguishes between short-term memory, which includes primary and working memory, and long-term memory, which includes episodic, semantic, and implicit memory. Long-term memory, particularly implicit memory, is closely tied to learning because an individual must encode the information into memory, or "learn" the information, to be capable of retrieving that information later when it is needed.

Short-Term Primary and Working Memory

The literature on short-term memory typically distinguishes between primary memory and working memory. Primary memory involves the ability to briefly and passively retain recently presented information such as a telephone number in one's consciousness. Research indicates that primary short-term memory, in terms of memory capacity, shows little to no change with age. Thus, both older and younger adults can hold similar amounts of information in primary memory. There is some evidence, however, that deficits might arise in one's seventies and beyond.

Working memory involves the ability to retain information in one's consciousness, or within primary memory, while mentally processing and manipulating that or other information; for example, mentally calculating a 15-percent gratuity. Research consistently finds large age-related deficits in working memory. These deficits strongly affect the ability to perform other cognitive tasks (see *Cognitive and*

Psychological Differences: *Cognitive Processing Mechanisms*, starting on page 17), and tend to become more pronounced as the task grows increasingly complex and places greater cognitive demands upon the individual. Deficits also tend to accelerate in very old age. Working memory deficits may also account for age differences in the ability to recall information that is presented auditorily since the individual cannot refer back to the item visually (see *Cognitive and Psychological Differences*: *Language Processing and Comprehension*, starting on page 25). The underlying cause of age deficits in working memory is unclear. However, given the cognitive-processing component of working memory, age-related declines are believed to be associated with reduced processing speed or the reduced ability to inhibit unwanted information.

Episodic Memory

Episodic memory is a form of long-term "explicit" memory in that it involves the deliberate and conscious recall of personally experienced events or life experiences associated with a specific time and place. Research has consistently shown large age-related declines in episodic memory after peaking in early adulthood. There is some evidence that declines accelerate in very old age (i.e., age 75 and older). Age-related deficits also seem to be significantly larger for recall than recognition, which tends to show little or no age deficits.

Source memory—a specific aspect of episodic memory that involves the ability to recall the specific context of an event, or how and from whom information was originally obtained—appears to be especially affected by deteriorating episodic memory. Examples of contextual cues that are likely to be negatively affected include perceptual details (e.g., color), location, temporal sequence (i.e., the order of events), who did or said something, whether the individual personally did something or simply said it, and whether something was seen, heard, or simply inferred from other information. Age-related declines in source memory mean that older adults tend to have more false or distorted memories than do younger adults and may not accurately recall whether something actually happened or was simply imagined. Similarly, older adults appear to be more susceptible to the "truth effect" in which the perceived validity of a statement, whether accurate or not, tends to increase with increased repetition.

Episodic memory has been found to be better for information that was originally learned or encoded earlier in life, typically between the ages of 10 and 30 years. Thus, older adults may be better able to recall events that occurred when they were between 10 to 30 years of age than events that occurred when they were 40 years of age or older. This may be associated with age-related changes in the encoding of information. Research indicates that older adults tend to encode information in a more general or prototypical manner than—that is, not as deeply as—younger adults. Older adults focus on the main idea (general) rather than on the details and minor points or features (specific) of the information to be remembered. This may account for age-related declines in the ability to recall specific details and source information.

Prospective memory, or remembering to perform a certain action in the future, shows similar age-related deficits as episodic memory. This is likely to be because it requires that the individual remember the specific, required action. The degree of loss, however, appears to depend on whether the prospective memory is time- or event-based. Time-based prospective-memory tasks, in which one must perform an action at a specific time, are particularly difficult for older adults to remember and tend to show greater age deficits than event-based prospective-memory tasks, in which one must perform an action concurrent with an event (e.g., taking medication with breakfast).

Semantic Memory

Semantic memory is long-term memory for factual information and general world knowledge dissociated from the specific time and place where the information was learned; examples include the meanings of words, the names of people, places, and objects, and relationships among concepts. The content and organization of information in semantic memory generally show little to no age-related deterioration. However, significant declines start to become evident in one's mid-seventies and beyond.

Although semantic information tends to be maintained in memory, older adults do appear to have a reduced ability to quickly recall words and names and have more "tip-of-the-tongue" experiences—in which there is a feeling that the word is known but elusive—than the young, especially in very old age. These deficits may not be associated with deterioration in the information per se but with deficits in processing speed; that is, older adults simply require more time to retrieve or access this information. Problems associated with naming may also indicate that age-related declines in memory tend to be greater for specific or detailed information than for general information. This would be consistent with the often greater losses observed in episodic memory, which typically involves more detailed information than semantic memory. As with episodic memory, older adults are better able to remember factual information learned earlier rather than later in life and show greater age differences in the ability to recall than to recognize factual information.

Implicit Memory and Skill Acquisition

Implicit memory differs from more explicit forms of long-term memory, like episodic memory, in that it does not involve deliberate or conscious recall. Rather, it represents, and is commonly measured indirectly by, the extent to which earlier experiences unconsciously influence subsequent performance in terms of speed, accuracy, or bias. Implicit memory allows for the gradual acquisition or learning of motor, perceptual, or cognitive operations and skills, such as walking, skating, and driving, through practice.

Although some age-related deficits have been reported in procedural tasks, the general consensus is that implicit memory is largely unaffected by age. Memory for previously acquired skills, in particular, generally shows little to no decline with increasing age, even in very old age. Evidence does indicate, however, that the speed with which older adults can acquire new skills is sometimes slowed relative to younger adults, particularly for tasks that are complex or that require the individual to inhibit or "unlearn" a previously acquired skill. Also, age-related declines in sensory functioning (e.g., somatosensation) and in motor control and coordination will likely have a negative effect on the quality of motor-skill performance, even if the memory of that skill is intact.

Age differences in new-skill acquisition can be reduced or eliminated with practice, which eventually transfers skill performance into implicit memory. Older adults require more practice time than younger adults to show equivalent performance improvements and especially benefit from specific external feedback about the movement process or outcome. Thus, opportunities for practice and training are even more important for older adults. Training that focuses on procedural information is more important for older-adult understanding than is conceptual information; hence, hands-on action training tends to be superior to training that simply involves presenting factual information and descriptions. Research also suggests that older adults are less likely to prefer trial-and-error type learning than do younger adults, so relying solely on instructional materials or self-discovery is unlikely to be effective for older adults.

Suggested References

References that discuss age-related changes in memory and learning in greater detail include:

- Bäckman, L., Small, B.J., & Wahlin, Å. (2001). Aging and memory: Cognitive and biological perspectives. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 349–377). San Diego, CA: Academic Press.

- Zacks, R.T., Hasher, L., & Li, K.Z.H. (2000). Human memory. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 293–357). Mahwah, NJ: Lawrence Earlbaum Associates.

- Prull, M.W., Gabrieli, J.D.E., & Bunge, S.A. (2000). Age-related changes in memory: A cognitive neuroscience perspective. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 91–153). Mahwah, NJ: Lawrence Earlbaum Associates.

- Craik, F.I.M. (2000). Age-related changes in human memory. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 75–92). Philadelphia: Taylor & Francis.

- Howard, Jr., J.H., & Howard, D.V. (1997). Learning and memory. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult*. (pp. 7–26). San Diego, CA: Academic Press.

Language Processing and Comprehension

To comprehend language or discourse, whether it be in the form of speech or text, an individual must perceptually encode the auditory or visual input, identify and recognize the individual words, determine the relations among those words by parsing the words into phrases and clauses, and determine the full meaning of the message by integrating the literal content of the message with unstated but implied information based on the linguistic context and the individual's real-world knowledge. Although individual differences can vary widely, older adults generally exhibit age-related deficits in sensory functioning, working memory capacity, cognitive processing, and inhibitory control, all of which can negatively affect language processing and comprehension.

Despite the above, certain aspects of language processing are well preserved into old age. For example, linguistic knowledge such as lexical (vocabulary) access and semantic memory appear to be relatively age invariant. Thus, to compensate for deteriorated sensory input, older adults tend to spontaneously employ top-down processing of language by drawing information from their linguistic knowledge and the supporting linguistic context.

Reading Comprehension

Reading comprehension, because it requires the visual processing of text or other printed material, is negatively affected by age-related declines in visual functioning, including deficits in visual acuity and contrast sensitivity, and increases in glare sensitivity. These effects are exacerbated in low-luminance and low-contrast situations.

Working memory limitations affect the ability of an older adult to retain information that was read for later recall or use, particularly if the text is syntactically complex. Older adults find it increasingly difficult to retrieve relevant information from memory and to recall the main ideas from text as the number (density) of propositions, or ideas, within the text increases. Also, the ability to identify pronominal referents (e.g., to what the term "it" refers in the phrase "turn it counter-clockwise") and to generate inferences from text declines with increasing age. Older adults appear to rely more on context to interpret the meanings of the individual words and sentences in the text that is read; thus, contextual constraints, such as the use of titles and headings, may be particularly beneficial to older adults. Older adults tend to allocate less reading time than younger adults to processing new concepts, even though overall reading times between older and younger readers are similar.

Age-related weakening of inhibitory mechanisms allows older adults to be more easily distracted by irrelevant or unimportant words and phrases that are embedded within the text, and this impairs older adults' comprehension and recall of relevant text. Their increased distractibility also means that older adults have more difficulty than younger adults identifying or inhibiting less important propositions from text in which there is reduced organizational support within the text (e.g., no headings or titles). Semantically related or meaningful distractors have been found to slow reading times even more than unrelated or nonlinguistic ones.

Speech Perception and Comprehension

The ability to process and understand speech declines with age. Age-related declines in auditory functioning, particularly high-frequency hearing losses, are especially relevant to speech perception and comprehension. These hearing losses differentially affect the ability of an older adult to discern high-frequency and low-energy consonants such as *f*, *g*, *k*, *p*, *s*, *t*, *z*, *ch*, *sh*, and the voiceless *th*. However, age-related losses in peripheral, auditory functioning, which were discussed in greater detail in the *Sensory and Perceptual Differences*: *Hearing* section of this report (starting on page 9), do not account for all observed age differences in speech perception and comprehension.

Older adults are generally able to understand and recall short, simple sentences that are common to everyday discourse. Speech comprehension, however, imposes a greater memory and processing burden than does reading comprehension. For example, unlike reading, in which an individual can look back and reread a sentence that was previously misunderstood, ambiguous, or confusing, speech must be retained in working memory for any retrospective analysis of the meaning. Also, age-related slowing of cognitive processing reduces the rate at which older adults can process incoming speech. Older adults, therefore, have greater difficulty comprehending rapid speech and speech with sentences that are very long, require inferential processing and rapid gist extraction (e.g., those that require the reader to remember to whom "he" refers after several sentences), are propositionally dense (i.e., those that try to convey many ideas), or are syntactically complex. To some extent, older adults can compensate for these losses by relying on linguistic knowledge and contextual cues. However, contextual cues that follow rather than precede the information that requires clarification still rely upon working memory and may show age differences. Providing pauses at natural speech processing units, such as the ends of sentences and clauses, also seems to help with rapid speech.

The ability to understand speech in the presence of background noise appears to be especially difficult for older adults. Other forms of distorted speech, such as reverberant and filtered speech, also show age differences. These problems are likely due to age-related deficits in both hearing and inhibitory control.

In communications with older adults, young adults typically employ "elderspeak," a simplified speech register with exaggerated prosody (e.g., intonation pattern, word stress, loudness, speech timing), simplified grammar, limited vocabulary, and a slow rate of delivery that is similar to the speech directed toward young children. The spontaneous use of elderspeak may be triggered by real communicative deficits or by imagined ones that are based on negative stereotypes about older adults. Evidence indicates that elderspeak may improve older adults' comprehension. However, elderspeak may contribute to the development of an "old" identity, reinforce negative stereotypes about older adults, lower older adults' self-esteem, and be viewed as patronizing, conveying a sense of disrespect and that they are cognitively and communicatively impaired.

Suggested References

References that discuss age-related changes in language, speech, and message comprehension in greater detail include:

- Wingfield, A. (2000). Speech perception and the comprehension of spoken language in adult aging. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 175–195). Philadelphia: Taylor & Francis.

- Wingfield, A., & Stine-Morrow, E.A.L. (2000). Language and speech. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 359–416). Mahwah, NJ: Lawrence Earlbaum Associates.

- Kemper, S., & Kemtes, K. (2000). Aging and message production and comprehension. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 197–213). Philadelphia: Taylor & Francis.

- Kemper, S., & Mitzner, T.L. (2001). Language production and comprehension. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 378–398). San Diego, CA: Academic Press.

- Tun, P.A.., & Wingfield, A. (1997). Language and communication: Fundamentals of speech communication and language processing in old age. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult*. (pp. 125–149). San Diego, CA: Academic Press.

Judgment and Decision Making

Judgment and decision-making processes include the ability to judge, estimate, or predict a magnitude, quantity, or condition based on an evaluation of information from several sources, as well as the ability to choose one item among several alternatives, each with multiple relevant attributes or characteristics. Judgments and decisions are typically used by people to solve problems, and successful judgments and decisions depend on one's ability to gather, consider, properly integrate, and remember relevant information.

Problem-Solving Strategies

In response to age-related declines in sensory functioning and in cognitive processing mechanisms (e.g., deficits in processing speed, working memory capacity, and inhibitory control; see *Cognitive and Psychological Differences*: *Cognitive Processing Mechanisms*, starting on page 17), older adults tend to employ judgment and decision-making strategies that reduce the cognitive demands of the task. For example, older adults tend to seek out less information, consider fewer alternatives, and make fewer comparisons among alternatives before arriving at a final decision.

Efforts to reduce the cognitive demands of the task also lead older adults to rely on top-down, or schematic, processing strategies in which judgments and decisions are based more on their accumulated knowledge and experience, and on the application of heuristics (i.e., mental shortcuts such as stereotypes) that have worked well in the past, rather than on intensive information gathering and analysis. Older adults, therefore, are more likely to interpret information in the context of their pre-existing knowledge, beliefs, attitudes, and experiences. Information that is relevant to an individual's integrated world view, or schema, is noticed, remembered better, and is more influential in the final judgment or decision, while information that is irrelevant to, or inconsistent with, the schema is not. For this reason, older adults are less likely to recognize, consider, or remember new information that contradicts their previously held beliefs or expectations. The ability to revise one's beliefs in response to new information is essential to making accurate judgments. For example, older adults may falsely remember information that was never presented if that information is implied by or consistent with information that was presented and is consistent with their pre-existing beliefs. Older adults also have greater difficulty remembering and processing complex stimulus-response, control-display, or similar relationships.

Because of their increased reliance on accumulated knowledge, the quality of an older adult's final judgment or decision is likely to be strongly dependent on the individual's degree of familiarity with the task or subject matter. Judgments and decisions that depend on experience and a large knowledge base may show smaller age differences for older adults who have the required knowledge and experience. These individuals may not need to consider as much information and may be better able than younger adults to identify important information and to reject inferior options. On the other hand, novel, unfamiliar, or complex tasks are likely to be more cognitively demanding and would be more likely to show age deficits.

Decision-Making Speed

Evidence is somewhat mixed regarding the speed with which older adults make decisions. Because they consider less relevant information before making a decision, older adults may make decisions more quickly than younger adults. However, some research shows that older adults are slower to make decisions. These apparently contradictory findings could be due to the individual's background knowledge. For example, an older individual who is highly familiar with the subject of the decision-making task, or who is a subject-matter expert, may make decisions more quickly. Older adults also may be more likely to defer to a subject-matter expert (e.g., a medical doctor in the case of a treatment decision) than would a younger adult, which would presumably reduce their decision-making times. In contrast, decisions that are unfamiliar or novel, and for which a subject-matter expert is not available, would likely show age deficits in speed.

Age-related deficits in decision-making time are strongly evident in reaction-time research. Age-related differences associated with simple reaction-time tasks, in which the individual must perform a single predetermined response to a single stimulus, are relatively small (see *Physical and Motor Differences*: *Movement Speed and Motor Coordination*: *Movement Speed*, starting on page 39, for more on this). However, choice reaction-time tasks, which require the processing of stimuli and decisions about the appropriate response, show robust declines with age. These differences are amplified as the number of stimuli and responses increases (i.e., as the number of possible choices or decisions to make increases), as the stimuli become increasingly difficult to discriminate, as the required responses become more complex or difficult, and if the relationships or mapping among the stimuli and responses are arbitrary, not apparent, or incompatible. These differences can be largely offset with precues, which reduce the uncertainty associated with the stimulus. Thus, the difference in performance between older and younger adults will be greater for tasks that require cognitive processing and decision making than for tasks that require single, discrete actions that can be planned in advance, or for simple, continuous, and repetitive actions. If they are allowed sufficient time, however, older adults often respond very accurately.

Risky Decision Making

Risky decision making is a form of decision making in which the ultimate consequences of the decision are uncertain and at least some of those consequences are negative. Overall, research findings associated with aging and risky decision making are consistent with the findings described above in terms of the amount of information considered and the speed of decision making.

Although the literature is somewhat mixed, research generally indicates that people become more cautious or risk averse with increasing age. For example, older adults have been found to favor accuracy over speed and will generally err on the side of performing a fewer number of tasks "better." Although people naturally slow down following an error, older adults tend to slow down more than do the young. Older adults also appear to be motivated by a desire to avoid mistakes. For example, in uncertain situations, older adults may choose to not respond at all rather than to guess at a correct response. They also may refuse to endorse a risky course of action, regardless of the possibility for success. These findings may be associated with age-related shifts in focus to health and to preventing illness. In some cases, increased cautiousness can be a strength. However, these findings suggest that older adults may be less likely to take any action if they are uncertain about the proper one to take. This could also place older consumers in greater danger in situations that require fast responses.

Control beliefs—specifically, self-efficacy and locus of control—strongly influence decisions about how to respond to or manage a threat and how long one should persist in his or her efforts to this end. Locus of control is associated with the perceived causes of events and can be defined as the degree to which people believe that one's behavior determines the course of events or that forces beyond their control—for example, chance or powerful others—determines the outcome. Those who believe the former are classified as "internals" and those who believe the latter are "externals," though most people are not exclusively one or the other. These beliefs may also differ across domains; for example, an individual may believe he has considerable influence over his health but little influence over his finances. Evidence indicates that internal locus of control beliefs tend to remain stable or to decline slightly with age. External locus of control beliefs, particularly those about the power of others, show marked increases with increasing age, especially in the domains of health and intellectual functioning. Thus, older adults may be less confident in their ability to control the events of their lives and increasingly believe that others are better able to do things; this could make older adults more dependent on others to solve problems.

Self-efficacy is associated with one's beliefs about the degree to which he or she has the ability to achieve a specific, desired outcome. The extent to which a person performs health-related behaviors is highly dependent on the individual's perceived self-efficacy. For example, if an individual is told to perform a certain task or procedure for improved health (e.g., exercise) or to avoid a health threat (e.g., respond to a product recall), that person is unlikely to perform the necessary behavior unless he or she believes that the task will be effective and that he or she has the knowledge and ability to perform the task well enough to accomplish the goal.

Older adults are aware that intellectual and memory abilities decline with increasing age and perceive that their own abilities have declined. Evidence suggests that older adults may react to salient age-related stereotypes by behaving in stereotypical ways, creating a self-fulfilling prophecy through decreased effort, decreased use of adaptive strategies, or reduced exposure to challenging situations. Also, those who experience painful or threatening symptoms when active are more likely to avoid activity. Since older adults, as a whole, are more likely to include individuals who experience these symptoms, they are less likely to attempt tasks and behaviors that require significant physical exertion. Thus, although older adults may be more motivated to perform tasks that promote health or reduce threats to health, as discussed above, they are less likely than young adults to believe that they are capable of performing the required tasks. Furthermore, training does not appear to eliminate perceptions of reduced efficacy, even if it results in objective improvements in performance.

Suggested References

References that discuss age-related changes in judgment and decision making in more detail include:

- Sanfey, A.G., & Hastie, R. (2000). Judgment and decision making across the adult life span: A tutorial review of psychological research. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer.* (pp. 253–273). Philadelphia: Taylor & Francis.

- Peters, E., Finucane, M.L., MacGregor, D.G., & Slovic, P. (2000). The bearable lightness of aging: Judgment and decision processes in older adults. In P.C. Stern & L.L. Carstensen (Eds.), *The aging mind: Opportunities in cognitive research* (pp. 144–165). Washington, DC: National Academy Press.

- Davis, D., & Loftus, E.F. (2005). Age and functioning in the legal system: Victims, witnesses, and jurors. In Y.I. Noy & W. Karwowski (Eds.), *Handbook of human factors in litigation* (pp. 11-1–11-53). Boca Raton, FL: CRC Press.

Other Forms of Nonverbal Intelligence

Numeric Ability

Numeric ability refers to the ability to understand numeric relationships, work with figures, and solve simple arithmetic problems, such as addition, subtraction, and multiplication, rapidly and accurately. Research has found that numeric ability tends to peak in one's late thirties, begins to decline in one's fifties, and becomes significant by about 60 years of age. Declines in late life (e.g., by one's late eighties) are severe.

Numeric ability appears to have peaked among those born roughly 80 to 90 years ago, and it has declined since that time; the cause of this decline is unclear. Thus, studies that directly compare older adults to younger adults are likely to underestimate the declines that occur with aging. This suggests that age differences in numeric ability may actually worsen in the coming years.

Spatial Ability

Spatial ability refers to the ability to reason and to make judgments about mental visual images, forms, and patterns; that is, the ability to mentally construct, maintain (i.e., remember), and manipulate these images. Spatial ability generally peaks and remains stable during the middle-age years, from one's forties into the early sixties. Starting in one's sixties, spatial ability starts to decline.

Specifically, age differences have been found for tasks that involve the mental manipulation of spatial information. Memory for spatial location, which includes the ability to locate an object or to locate oneself with respect to other spatial objects, also shows age deficits. This finding is consistent with age-related declines in the ability to recall contextual information (i.e., source memory) (see *Cognitive and Psychological Differences*: *Memory and Learning*: *Episodic Memory*, starting on page 22). Spatial ability is important for object-identification tasks because one must remember the visual-spatial characteristics of an object, and these also show age deficits. Some evidence indicates that older adults have difficulty on simple conservation problems.

Declines in spatial ability tend to be greater in situations that place high demands on working memory, such as complex visual environments, or on ongoing information processing. Expertise appears to compensate somewhat for age-related losses. Spatial abilities show a positive generational trend, suggesting that age differences in comparison studies between older and younger adults overestimate age-related change. Thus, age differences in spatial ability may be smaller in the future.

Suggested References

References that include substantial, detailed discussions of age-related changes in numeric and spatial ability are rare. The following references, however, provide additional detail on these topics, particularly spatial ability:

- Schaie, K.W. (2005). *Developmental influences on adult intelligence: The Seattle longitudinal study*. New York: Oxford University Press.

- Fisk, A.D., Rogers, W.A., Charness, N., Czaja, S.J., & Sharit, J. (2004). *Designing for older adults: Principles and creative human factors approaches*. Boca Raton, FL: CRC Press.

- Davis, D., & Loftus, E.F. (2005). Age and functioning in the legal system: Victims, witnesses, and jurors. In Y.I. Noy & W. Karwowski (Eds.), *Handbook of human factors in litigation* (pp. 11-1–11-53). Boca Raton, FL: CRC Press.

Interventions to Compensate for Differences

To avoid product hazards, consumers must attend to and understand important information. Even if this information is understood, consumers may be placed at risk if they are unable to remember this information at the appropriate time. Based on its review of the literature, the staff has identified three general interventions that are likely to help compensate for age-related differences in cognition. First, to the extent possible, one should extend or entirely avoid time constraints on consumer responses. Consumers should be provided with enough time to think, to respond, and to complete the required task. Second, clutter, background noise, and other task-irrelevant information should be eliminated from product interfaces, instructions, and the environment of use. Lastly, products and product-related materials should be designed to reduce the demands placed upon consumers' memories or other mental resources. Some specific interventions that would likely achieve these goals include the following:

- Maximize the extent to which products, their instructions, and the tasks that must be performed rely on and are consistent with older adults' accumulated knowledge, experience, skills, pre-existing beliefs, and expectations. Rely on affordances, stereotypes, and patterns that are likely to be familiar to older adults. Control-display, stimulus-response, and cue-criterion relationships should be obvious and compatible from the perspective of an older adult.

- Provide older adults with plenty of opportunities for hands-on practice and training when they are required to use novel and unfamiliar products. Avoid tasks or responses that require consumers to "unlearn" a previously acquired skill.

- Limit the extent to which consumers must retain or manipulate information, especially specific details, values, sequences, or locations, in memory while performing a task. Provide memory aids such as pictures, samples, charts, or checklists to which consumers can refer. Provide a way for consumers to confirm that a task, or a step in a task, has been completed or still needs to be performed without relying on memory. Avoid the need for mental calculations, even seemingly simple ones. Reduce the extent to which the individual must mentally construct, manipulate, and remember visual/spatial images and patterns. Reduce the need to remember the location of objects, parts, etc., especially if other information must also be processed.

- Avoid situations that require the consumer to infer an appropriate response or action or the intended meaning of an instruction. Reduce the need for on-the-spot judgments and decisions about how to proceed. Explicitly describe what must be done. Provide step-by-step instructions written in the active voice and in list format, and avoid ambiguous words, phrases, sentences, and graphics. Include text-relevant examples and graphics to clarify the message and facilitate mental modeling. Reduce the number of pronominal referents (e.g., the term "it" in the phrase "turn it counter-clockwise") presented in text and speech, and keep pronouns and referents close together.

- Limit the amount of information consumers must process. Design the product to reduce the number of steps that are necessary to perform a task or to achieve the consumer's goal. Reduce the number of stimuli to which the consumer must respond and the number of possible responses to those stimuli.

- Call attention to important task-relevant information, including visual warnings, headings, and keywords, through the use of well-established cues and perceptual aids such as changes in size, contrast, or motion (e.g., blinking or flashing). Locate target objects and information near the center of where consumers are expected to be looking.

- Clearly distinguish target objects and information from the background or other task-irrelevant information. Limit the extent to which consumers must perform conjunction searches, in which one must rely on two features to identify the object as the target.

- Avoid unnecessary graphics, colors, patterns, words, phrases, and similar information, especially if that information once was but no longer is relevant, or is semantically related or meaningful but is not relevant to the task at hand.

- Provide salient external cues, prompts, or reminders that allow consumers to rely on recognition rather than recall. For example, associate prospective tasks, such as taking medication or changing a smoke-detector battery, with other events, such as eating breakfast or changing the clock due to daylight savings time.

- Use cueing when possible to indicate the future location of a sought target. Ideally, use the location of the cue to indicate target location rather than having individuals process and interpret a centrally located cue.

- Limit the extent to which consumers must switch or divide their attention among tasks. Design products and tasks so that consumers can perform tasks consecutively rather than concurrently.

- Limit the amount of rapidly arriving detail in a message. Reduce the rate at which language must be processed.

- Avoid very long sentences, especially for speech. However, do not arbitrarily chop long sentences into several short ones.

- Provide adequate pauses at the ends of sentences and clauses, especially for rapid speech.

- Reduce the propositional density and syntactic complexity of text and speech. Limit the number of propositions or ideas conveyed in each sentence, as well as the number of subordinate and embedded clauses.

- Provide semantic elaborations and important, comprehension-relevant context in instructions. Repeat important information. Clarify and expound upon instructions or requests. Provide contextual cues such as titles and headings in text. In speech, provide important context before the information that requires it.

- Avoid the exaggerated "baby talk" version of elderspeak. Maintain normal prosody (e.g., intonation pattern, word stress, loudness, speech timing).

- Consider phrasing warnings and instructions positively rather than negatively—that is, describe what the person should do rather than what the person should not do—to reduce the likelihood that consumers will incorrectly remember the negative action as the correct one.

- When instructing or warning consumers about the importance of performing a task, make it clear that the task will achieve the desired objective and that the individual can perform the necessary action. Make sure, however, that this is truly the case.

Physical and Motor Differences

Anthropometry

Little anthropometric data has been collected on the elderly or on anthropometric changes associated with aging, particularly for the U.S. civilian population. Furthermore, most data that are available tend to group people within larger age brackets than for younger cohorts—for example, within 10-year age brackets rather than 5-year brackets—or to simply group everyone over 65 together as a single age cohort. The available data do, however, suggest certain age-related patterns of change.

After reaching adulthood, at approximately 20 years of age, body dimensions change very little. During one's sixties and beyond, however, changes become more evident and dramatic. Still, these changes show extreme variance, with some people changing dimensions rapidly within a few years and others showing little change over longer time periods.

Stature or Height

Maximum height is generally reached in one's twenties, with women achieving peak height slightly earlier than men. Starting in one's thirties, stature slowly declines with advancing age. Height losses average about 1 cm per decade from age 40 to age 60. After age 60, height losses for women may accelerate relative to men, with losses of about 1.5 cm in their sixties and 2.0 cm in their seventies. By about 65 to 79 years of age, adults have lost about 3 to 6 percent of their peak height.

The primary causes of age-related declines in height are likely to be the compression or flattening of the vertebrae and of the body's weight-carrying connective tissues—especially the cartilaginous disks between the vertebrae—and postural change or "slump," some cases of which may be related to the increased incidence of osteoporosis in old age. Osteoporosis, a degenerative bone disease, is more prevalent among older women relative to older men, and could account for their greater declines in height in their sixties and beyond.

Weight

Males and females show similar patterns of weight gain, stabilization, and weight loss during adulthood. Although the literature is mixed regarding the specific timing of these changes, bodyweight typically increases during early adulthood and into middle age, and then declines in old age. Despite sharing similar patterns of weight gain and loss, men and women tend to differ in the timing of these changes. For example, male bodyweight generally increases until roughly age 30 to 40, remains stable to about age 50 or 55, and then gradually declines. Weight loss among very old men (i.e., those in their eighties and beyond) may accelerate relative to earlier losses. Women, in contrast, tend to continue gaining weight for about 10 years after men have stabilized, resulting in greater overall weight gains. Weight losses among women generally start at about age 70.

Weight gains in early adulthood and into middle age are generally attributable to changes in lifestyle—specifically, reduced activity levels combined with changes in diet—which leads to increases in body fat. Weight losses in old age are believed to be largely the result of decreases in muscle mass from inactivity. Age differences in weight might, however, simply reflect the shortened life span of those who are obese.

Other Body Dimensions

- *Head and face*. The nose and ears increase in both width and length with age. There is also some evidence that head circumference, length, and breadth increase with age.

- *Arms*. Upper arm circumference appears to decrease with increasing age, a finding that is consistent with decreases in subcutaneous fat in the limbs. Arm span shows significant declines with age even though shoulder-to-elbow and elbow-to middle finger lengths do not. Declines in functional reach have also been reported.

- *Trunk breadths, depths, and circumferences*. Adult aging appears to be associated with a general increase in trunk dimensions. For example, trunk breadths such as hip and chest breadths generally increase with increasing age. Similarly, although reported changes in chest circumference are somewhat mixed, chest depth and abdominal depth and circumference appear to increase with age. These increases in trunk dimensions with increasing age are consistent with age-related increases in fat deposits on the trunk.

Suggested References

References that discuss age-related anthropometric changes, particularly changes in height and weight, in greater detail include:

- Spirduso, W.W., Francis, K.L., & MacRae, P.G. (2005). *Physical dimensions of aging* (2^{nd} ed.). Champaign, IL: Human Kinetics.

- Kroemer, K.H.E. (1997). Anthropometry and biomechanics. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 87–124). San Diego, CA: Academic Press.

- Kelly, P.L., & Kroemer, K.H.E. (1990). Anthropometry of the elderly: Status and recommendations. *Human Factors, 32*(5), 571–595.

The following references include anthropometric data specific to older adults:

- Henry Dreyfuss Associates, & Tilly, A.R. (2002). *The measure of man and woman: Human factors in design* (Revised ed.). New York: John Wiley & Sons.

- Smith, S., Norris, B., & Peebles, L. (2000). *OLDER ADULTDATA: The handbook of measurements and capabilities of the older adult* (DTI/Pub 4445/3k/01/00/NP URN 00/500). London, UK: Department of Trade and Industry.

- Kelly, P.L., & Kroemer, K.H.E. (1990). Anthropometry of the elderly: Status and recommendations. *Human Factors, 32*(5), 571–595.

Physical Work Capacity

Cardiovascular and Respiratory Functioning

The capacity to perform physical work is highly dependent on the proper functioning of the cardiovascular and respiratory systems. Various structural changes occur in these systems with age, though it is unclear how much is attributable to environmental factors, lifestyle (e.g., smoking, physical inactivity), or the physical aging of these structures. Pathological processes, such as heart disease, are also likely to play a significant role. Some of the practical effects of these changes include the following:

- Reduced cardiac output, during exhaustive exercise, relative to body size

- Increased systolic and diastolic blood pressures

- Reduced maximum heart rate levels—from peak efficiency at about 25 years of age—and slower recovery after exertion

- Reduced elastic recoil of the lungs

- Reduced maximum breathing, or vital, capacity

The general conclusion that can be drawn is that increased age is associated with declining physical work capacity. Maintaining a physically active lifestyle is the key to maintaining cardiovascular health, as declines are much less in chronic or habitual exercisers.

Flexibility and Range of Motion

Upper body flexibility is important to many daily activities, including simple reaching and grasping. With age, the connective tissues and joints gradually become less flexible and mobile, and the muscles become less elastic. Between the ages of 30 and 70, one's maximum range of motion typically decreases by about 20 to 30 percent, with the most significant declines occuring after the age of 50. Declines in flexibility and joint mobility are likely to differ among the various parts of the body. Spinal flexibility shows the greatest declines with age, but the ankle joint also shows significant losses; females lose about 50 percent of their range of motion in their ankle joint from age 55 to 85, and males lose about 35 percent over the same age span. Women tend to remain more flexible than men throughout life.

The gradual loss of flexibility with age appears to have two primary causes: Disuse and degenerative diseases. Flexibility is maintained in a joint through use and by participating in physical activities that move the joint through its complete range of motion. Among healthy individuals, the greatest losses in flexibility involve those movements that the individual does not perform habitually or are not required in everyday life. Those not involved in sport, dance, or regular exercise rarely move a joint through its full range of motion, and the literature indicates that older adults who are engaged in flexibility training usually maintain or improve their range of motion as they age. Hence, among healthy individuals, disuse seems to be the primary cause. Arthritis (osteoarthritis), a degenerative, chronic disease of the joints, is likely to be another significant cause of reduced joint mobility.

Muscular Strength and Power

People generally reach their peak muscle strength in their twenties or thirties, after which strength begins to decline. Strength declines are gradual at first, decreasing by about 1 percent per year. Typical muscle strength levels cited in the literature, relative to peak strength levels in one's twenties and thirties, include the following:

Age or Age Range (years)	Relative Muscle Strength
45	90%
50s	75 to 85%
60s	50 to 85%

Muscle strength losses appear to accelerate with age, particularly after the age of 70. Older adults are also unable to produce forces smoothly and, instead, tend to produce forces in multiple bursts.

The three types of muscle strength typically cited in the literature are isometric or static strength, concentric strength, and eccentric strength. Isometric strength involves the application of muscular force without a change in muscle length; for example, pushing on an immovable object. Isometric strength initially changes little, but then decreases 1 to 1.5 percent per year from age 50 to 70, and 3 percent per year after that. Concentric strength involves the application of muscular force with a shortening of muscle length, or contraction of the muscle; for example, lifting an object by bending the arm. Losses in concentric strength are similar to those for isometric strength, with the most dramatic losses after the age of 70 years. Eccentric strength is associated with the lengthening of a muscle; for example, lowering an object. Eccentric strength losses are consistently less than for other strength types.

Research indicates that the muscles of the lower extremities may show greater declines than those of the upper extremities. For example, knee flexion strength values for people aged 70 to 86 years of age may be as little as 56 percent of the value for people aged 20 to 35 years. Despite this, significant losses of arm and shoulder strength after 65 years of age have been reported. Men show greater declines in upper body strength than do women, and hand and grip strength show clear declines with age, particularly once one enters his or her fifties.

Although older adults cannot generate the same grip forces as younger adults, at times they may actually exert more force than the young. For example, in a precision grip task, older adults may apply much more grip force than is necessary to maintain a grip while lifting an object. This may be overcompensation for known age-related losses in strength or reduced somatosensory feedback. In either case, older adults appear less capable of calibrating appropriate levels of force than are younger adults.

Muscular power, defined as the product of the force produced and the movement speed, involves the rapid generation of force such as that involved in grabbing a handrail, recovering from a stumble, and otherwise correcting for an unexpected loss of balance. Age-related declines in muscular power are greater than declines in strength, with losses of about 6 to 11 percent per decade for absolute power and 6 to 8 percent per decade for relative power (scaled to body mass).

Despite the general patterns of loss described above, the degree of age-related losses in muscle strength and power is highly variable among individuals. The principle causes of age-related decreases in muscle strength and power are reduced physical activity levels and disuse of the muscles, with consequent losses in muscle mass. For example, muscle strength is better maintained in the muscles used in daily activities; however, muscles that are used infrequently or for specialized activities tend to show greater declines.

Suggested References

References that discuss age-related changes in physical work capacity in greater detail include:

- Spirduso, W.W., Francis, K.L., & MacRae, P.G. (2005). *Physical dimensions of aging* (2nd ed.). Champaign, IL: Human Kinetics.

- Haywood, K.M., & Getchell, N. (2001). *Life span motor development* (3rd ed.). Champaign, IL: Human Kinetics.

Movement Speed and Motor Coordination

Movement Speed

One of the most obvious and reliable changes with increasing age is the slowing of voluntary physical movements and behavior. On average, older adults are approximately 1 ½ to 2 times slower than their younger counterparts. This slowing first becomes apparent as early as the late thirties and early forties, with linear declines in speed until about 80 years of age, at which time declines tend to accelerate. Men, however, tend to respond faster than women. Deficits in movement speed with advanced age may be attributable to the loss of muscle mass, especially since a large portion of muscle fiber loss occurs in the type II, or fast twitch, fibers. Declines in force production and regulation may also play a role.

Age-related deficits in movement speed are most evident with fast, repetitive, or complex movements. This is most commonly seen in tests of simple reaction time, in which an individual must respond in a single predetermined way to a single stimulus. A generalized slowing of movements has also been found in everyday tasks, such as reaching and grasping, point-to-point movement tasks, and continuous movements.

Any movement can be divided into the primary submovement, which is the initial ballistic portion of the movement in which the limb is propelled toward the target, and the secondary submovements, which are corrective feedback-oriented movements associated with the position of the limb with respect to the target. Research indicates that older adults cover proportionally less distance with their primary submovement than do younger adults. Consequently, older adults perform more secondary, corrective submovements, a finding that is consistent with the finding that older adults show lengthened mid-flight and deceleration phases of movements relative to younger adults. Thus, tasks that require greater accuracy show greater age-related deficits in speed than those that do not.

Age-related deficits in response time also increase as the number and complexity of stimuli and responses increase; but, as described in *Cognitive and Psychological Differences: Cognitive Processing Mechanisms* (starting on page 17) and in *Cognitive and Psychological Differences: Judgment and Decision Making* (starting on page 27), this is due more to declines in cognition (e.g., deficits in decision-making time) than in movement speed per se. Some declines may also be due to increasing cautiousness and the consequent tradeoff of speed for accuracy in movements.

Motor Control and Coordination

Research indicates that movement variability increases with age and that motor coordination consequently deteriorates. Older adults appear to be less accurate in independently controlling the forces applied by the index finger and thumb, and find it more difficult than the young to coordinate asymmetrical movements than symmetrical ones. Fine-motor skills such as precision grip are limited in old age, and older adults are less able to effectively stop a movement once it has begun.

Age-related deficits in motor coordination and control are likely to be due, in part, to age-related deteriorations in the sensorimotor system, as the information obtained through the various senses must be integrated to perform even simple movements. For example, the visual system contributes information about the location, direction, and speed of movement, and research indicates that older adults tend to rely on vision much more than younger adults to guide and control movement. The somatosensory system provides information related to body contact (e.g., touch and vibration sensitivity), limb and joint position, and other similar information. The loss of muscle mass with age may also contribute to motor coordination deficits, as does the increasing incidence of arthritis. Continuous and complex movements, such as simple tracking tasks, are also affected by age-related reductions in processing speed, because these movements require individuals to continuously monitor their progress in an attempt to minimize the distance between the target and some object (e.g., a cursor).

Suggested References

References that discuss age-related changes in movement speed, control, and coordination in greater detail include:

- Ketcham, C.J., & Stelmach, G.E. (2001). Age-related declines in motor control. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 313–348). San Diego, CA: Academic Press.

- Vercruyssen, M. (1997). Movement control and speed of behavior. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 55–86). San Diego, CA: Academic Press.

- Spirduso, W.W., Francis, K.L., & MacRae, P.G. (2005). *Physical dimensions of aging* (2nd ed.). Champaign, IL: Human Kinetics.

Balance and Falls

Balance can be defined as the process of controlling the body's center of mass or gravity relative to the base of support, typically one's feet. Failing to maintain balance ultimately leads to a fall. Balance is often separated into two types: static balance, which involves the maintenance of balance while in a stationary position, and dynamic balance, which involves the maintenance of balance during locomotion or while otherwise moving.

Static Balance and Postural Stability

Static balance is commonly measured in two ways: postural sway during quiet standing and response to an outside perturbation of balance. Testing consistently finds that older adults (i.e., those over age 60) have poorer static balance than do younger adults. For example, older adults show more body sway, in terms of both speed and range, than do younger adults.

In response to postural sway and outside perturbations, people maintain balance through the use of ankle, hip, and step postural strategies. The ankle strategy is typically used for small perturbations and is also used to control body sway during quiet standing. When employing the ankle strategy, the upper and lower body moves as a single unit around the ankles as the muscles surrounding the ankles apply force to the standing surface to bring one's center of gravity back over the base of support. The hip strategy is employed after a larger or faster perturbation, in which the center of gravity must be brought over the base of support more quickly to avoid a loss of balance, and involves the use of the muscles surrounding the knee and hip as the upper and lower body move in directions opposite one another. The step strategy involves taking one or more steps to establish a new base of support. Although this strategy is used when the perturbation is so large that the hip strategy would likely be ineffective, it also appears to be a naturally preferred balance strategy.

The ability to maintain balance depends on the sensory, cognitive, and motor control systems. The visual, prioreceptive or somatosensory, and vestibular sensory systems provide a visual layout of the surrounding environment, information about body position with respect to the environment, body limb positions with respect to each other, and head position and movement. The cognitive system then processes and integrates this sensory information and may plan the appropriate response. Finally, the motor control system makes the necessary adjustments to maintain balance.

Age-related declines in some or all of these systems are likely to be responsible for observed age-related deficits in balance. For example, age-related declines in the visual, prioreceptive/somatosensory, and vestibular senses can result in reduced or distorted sensory information and in the slower integration of this information, which may limit one's ability to quickly and accurately perceive where the body is in space. Furthermore, the evidence indicates that older adults rely more on vision and visual feedback than do younger adults, even when that information may be inaccurate or when vision is declining. Age-related cognitive impairments associated with working memory and attention are also likely to affect balance, since older adults tend to allocate more attention to maintaining balance than do younger adults but are less capable of dividing attention. Thus, older adults are likely to have greater difficulty maintaining balance while simultaneously focusing on another task. Lastly, declines in muscular strength, power, and coordination are likely to limit the extent to which older adults can produce rapid and accurate adjustment forces or steps to maintain balance after an unexpected perturbation.

Advancing age is associated with deteriorations in the integration of movement senses and vestibular cues. Losses in these senses reduce the ability to control body positions and movements, which leaves older adults vulnerable to instability and falls. The senses of movement, touch, and position are due to receptors in the joints, muscles, and skin, and are more variable in old age.

Dynamic Balance, Locomotion, and Gait

Dynamic balance is typically assessed by changes in the walking cycle, or gait. In a sense, walking can be seen as a series of continuous losses and recoveries of balance during a forward translation of one's center of gravity. The normal gait cycle for each limb consists of stance and swing phases. The stance phase is that time when the foot is in contact with the ground and makes up about 60 percent of the gait cycle for that limb. This phase includes initial foot-ground contact, or heel-strike, the flattening of the foot during single limb support, and push-off. The swing phase is that time when the foot is off the ground and moving through the air and makes up the remaining 40 percent of the gait cycle. This phase, between push-off and subsequent foot-ground contact, involves the forward advancement of the limb. Most slip and fall incidents occur at the moment when weight is transferred from one foot to the other—that is, when only the toes of the back foot and the heel of the front foot are in contact with the ground—because of the small contact area between the person and the ground, the angle created between the limbs and the ground, and the forces that the foot must apply to the ground during push-off and foot-ground contact. Reduced friction between the foot and the ground, therefore, may lead to a slip and fall.

As in the case of static balance, the sensory, cognitive, and motor systems play important roles in maintaining gait pattern and mobility. For example, vision is important for signaling the need to adjust the gait pattern in response to obstacles or changes in elevation, and somatosensation provides important information about limb position and foot contact during the gait cycle. Age-related deficits in attentional control and information processing speed likely affect the extent to which older adults can successfully plan avoidance maneuvers. Reductions in flexibility, joint range of motion (e.g., ankle extension, pelvic rotation), and muscle strength, power, and coordination are also likely to be important in the maintenance of gait timing and stability.

The most significant and observable age-related change in gait is slowed, self-selected (preferred) walking speed, with reductions of about 10 to 20 percent per decade after the age of 60 years. This appears to be primarily due to age-related reductions in step or stride length. Other reported changes in gait with increasing age include a wider and out-toed stance, more flat-footed contact with the ground, and longer stance or support times relative to swing times. However, women over age 75 reportedly manifest some degree of bow-leggedness and have narrower walking stances.

Older adults tend to not lift their feet as high as younger adults during the swing phase of stride and are, therefore, less able to clear obstructions or changes in elevation, potentially resulting in a trip. Similarly, older adults tend to clear obstacles using a slower, shorter step that often results in the foot contacting the opposite side of the obstacle before contacting the ground. Evidence indicates that most falls during locomotion among older adults are initiated by a trip.

Suggested References

References that discuss age-related changes in balance, postural stability, locomotion, and gait in greater detail include:

- Spirduso, W.W., Francis, K.L., & MacRae, P.G. (2005). *Physical dimensions of aging* (2nd ed.). Champaign, IL: Human Kinetics.

- Cohen, H.H., & LaRue, C.A. (2005). Perceptual-Cognitive and Biomechanical Factors in Pedestrian Falls. In Y.I. Noy & W. Karwowski (Eds.), *Handbook of human factors in litigation* (Chapter 19). Boca Raton, FL: CRC Press.

- Haywood, K.M., & Getchell, N. (2001). *Life span motor development* (3rd ed.). Champaign, IL: Human Kinetics.

Interventions to Compensate for Differences

Avoiding product hazards ultimately requires that individuals be physically capable of carrying out the appropriate avoidance behavior. Controls that require substantial strength or dexterity can exceed the abilities of the individual, making that control inoperable to that individual. Based on its review of the literature, the staff believes that the following general interventions would help compensate for age-related physical and motor differences:

- Seek out and consider older-adult anthropometric, strength, and similar data when designing a product to be used by the population as a whole, especially when the design must accommodate the smallest and weakest adults.

- Reduce the amount of fine-motor coordination or precision that is required to use a product or to perform a task. Minimize the number of smooth or precise movements that are necessary to use the product. Design or position controls and other product components so they are forgiving of imprecise movements; for example, make controls large and distant from one another. Avoid controls that require twisting or complex motions. Do not require consumers to operate two controls simultaneously unless doing so prevents unsafe, inadvertent operation.

- Minimize the strength required to operate controls and other product features. Design products that must be handled and manipulated so they are lightweight and have a large, high-friction gripping surface.

- Minimize the need for rapid movements, especially if the required movements must also be forceful, precise, or complex.

- Reduce the flexibility demands of the product or task. Design the product to minimize joint deviations from neutral.

- Limit the extent to which consumers must assemble or install the product before use.

- Make products sturdy and impact-resistant to account for reduced physical dexterity.

Based on estimates from the CPSC's National Electronic Injury Surveillance System (NEISS), 59 percent of product-related emergency-room visits for adults 65 to 74 years of age involve falls, and 77 percent of those for adults aged 75 and older involve falls. Typical fall scenarios include falling down stairs while descending or ascending; tripping over loose carpets, cords, or other obstacles on the floor; and falling off ladders and step stools. Based on its review of the literature, the staff believes that the following general interventions may reduce the likelihood of falls:

- Use uniform high-traction tread surfaces on steps or other walking surfaces. Avoid sudden or unexpected changes in surface friction.

- Limit the need for older adults to adjust their gait to compensate for obstructions or changes in elevation. Reduce the number of obstructions, obstacles, and other loose objects on the floor, ground, or other walking surface. Eliminate changes in elevation when possible, particularly those that are unexpected or inconspicuous. If elevation changes are necessary, highlight this change in some way; for example, use a contrasting color on the step edge.

- Increase illumination levels, particularly in stairways and around other changes in elevation. Highlight the edges of steps to increase conspicuity.

- Provide and properly locate balance assists such as handrails and grab bars. Make sure these assists can be easily grasped and are firmly attached.

- Provide conspicuous, high-contrast visual cues or anchors to assist in balance and postural control. Reduce the visual complexity of one's environment. Eliminate visual distractions.

- Maintain consistent riser heights and tread depths from one step to the next.

Conclusions

As detailed in this report, adult aging is associated with declines in many perceptual, cognitive, and physical abilities. Generally, older adults' sensory systems become less sensitive, making them less capable than the young of perceiving information. Age-related deficits in vision and hearing, in particular, are commonly reported, meaning that older adults are less likely to see or hear important information. Age-related declines in muscle strength and motor coordination limit the extent to which older adults are capable of performing actions that may be necessary to use a product or to avoid a hazard.

Age-related deficits in cognitive skills are widely reported as well. However, at least until very old age, these deficits are generally restricted to those skills that require rapid, flexible thinking about novel or unfamiliar situations. These observed age differences are likely to be due to age-related cognitive resource limitations (e.g., deficits in working memory), reductions in cognitive processing speed, and deficits in inhibitory control. In contrast, cognitive tasks that rely on the individual's accumulated knowledge or experience tend to be age invariant.

As the U.S. population grows older, involving older adults in the product-design process becomes increasingly important to make sure the demands of the product and other product-related materials do not exceed the capabilities of consumers. Making products more usable by older adults will likely increase the safety of those products for both younger and older adults.

References

Bäckman, L., Small, B.J., Wahlin, Å, & Larsson, M. (2000). Cognitive functioning in very old age. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 499–558). Mahwah, NJ: Lawrence Earlbaum Associates.

Bäckman, L., Small, B.J., & Wahlin, Å. (2001). Aging and memory: Cognitive and biological perspectives. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 349–377). San Diego, CA: Academic Press.

Burdick, D.C., & Kwon, S. (2004). *Gerotechnology: Research and practice in technology and aging*. New York: Springer Publishing Company.

Charness, N. (2001). Aging and communication: Human factors issues. In N. Charness, D.C. Parks, & B.A. Sabel (Eds.), *Communication, technology and aging: Opportunities and challenges for the future*. (pp. 1–29). New York: Springer Publishing Company.

Clark, M., Jackson, P.L., & Cohen, H.H. (1996, July). What you don't see can hurt you. *Ergonomics in design, 4*(3), 16–21.

Cohen, H.H., & LaRue, C.A. (2005). Perceptual-Cognitive and Biomechanical Factors in Pedestrian Falls. In Y.I. Noy & W. Karwowski (Eds.), *Handbook of human factors in litigation* (Chapter 19). Boca Raton, FL: CRC Press.

Cohen, J., & Cohen, H.H. (2001, Summer). Human factors in stairway fall litigation. *Ergonomics in design, 9*(3), 19–24.

Craik, F.I.M. (2000). Age-related changes in human memory. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 75–92). Philadelphia: Taylor & Francis.

Cushman, W.H., & Rosenberg, D.J. (1991). Human factors in product design (Volume 14). In G. Salvendy (Series Ed.), *Advances in human factors/ergonomics*. Amsterdam: Elsevier.

Czaja, S.J. (1997). Using technologies to aid the performance of home tasks. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult*. (pp. 311–334). San Diego, CA: Academic Press.

Czaja, S.J. (2001). Technological change and the older worker. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 547–568). San Diego, CA: Academic Press.

Davis, D., & Loftus, E.F. (2005). Age and functioning in the legal system: Victims, witnesses, and jurors. In Y.I. Noy & W. Karwowski (Eds.), *Handbook of human factors in litigation* (Chapter 11). Boca Raton, FL: CRC Press.

Dixon, R.A. (2000). Concepts and mechanisms of gains in cognitive aging. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer.* (pp. 23–41). Philadelphia: Taylor & Francis.

Feldman, R.S. (2000). *Development across the life span* (2nd ed.). Upper Saddle River, NJ: Prentice Hall.

Fisk, A.D., Rogers, W.A., Charness, N., Czaja, S.J., & Sharit, J. (2004). *Designing for older adults: Principles and creative human factors approaches*. Boca Raton, FL: CRC Press.

Fozard, J.L. (2003). Commentary: Using technology to lower the perceptual and cognitive hurdles of aging. In N. Charness & K.W. Schaie (Eds.), *Impact of technology on successful aging.* (pp. 100–112). New York: Springer Publishing Company.

Fozard, J.L., & Gordon-Salant, S. (2001). Changes in vision and hearing with aging. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 241–266). San Diego, CA: Academic Press.

Gutman, G.M. (2003). Commentary: Gerotechnology and the home environment. In N. Charness & K.W. Schaie (Eds.), *Impact of technology on successful aging.* (pp. 251–261). New York: Springer Publishing Company.

Haywood, K.M., & Getchell, N. (2001). *Life span motor development* (3rd ed.). Champaign, IL: Human Kinetics.

Henry Dreyfuss Associates, & Tilly, A.R. (2002). *The measure of man and woman: Human factors in design* (Revised ed.). New York: John Wiley & Sons.

Hertzog, C., & Hultsch, D.F. (2000). Language and speech. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 417–466). Mahwah, NJ: Lawrence Earlbaum Associates.

Howard, Jr., J.H., & Howard, D.V. (1997). Learning and memory. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 7–26). San Diego, CA: Academic Press.

Kelly, P.L., & Kroemer, K.H.E. (1990). Anthropometry of the elderly: Status and recommendations. *Human Factors, 32*(5), 571–595.

Kemper, S. (2001). Over-accommodations and under-accommodations to aging. In N. Charness, D.C. Parks, & B.A. Sabel (Eds.), *Communication, technology and aging: Opportunities and challenges for the future.* (pp. 30–46). New York: Springer Publishing Company.

Kemper, S., & Kemtes, K. (2000). Aging and message production and comprehension. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer.* (pp. 197–213). Philadelphia: Taylor & Francis.

Kemper, S., & Mitzner, T.L. (2001). Language production and comprehension. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 378–398). San Diego, CA: Academic Press.

Ketcham, C.J., & Stelmach, G.E. (2001). Age-related declines in motor control. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 313–348). San Diego, CA: Academic Press.

Kline, D.W., & Scialfa, C.T. (1997). Sensory and perceptual functioning. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 27–54). San Diego, CA: Academic Press.

Kroemer, K.H.E. (1997). Anthropometry and biomechanics. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 87–124). San Diego, CA: Academic Press.

Kroemer, K.H.E., Kroemer, H.J., & Kroemer-Elbert, K.E. (1997). *Engineering physiology: Bases of human factors/ergonomics* (3rd ed.). New York: Van Nostrand Reinhold. 23, 78, 286.

Laux, L.F. (2001). Aging, communication, and interface design. In N. Charness, D.C. Parks, & B.A. Sabel (Eds.), *Communication, technology and aging: Opportunities and challenges for the future.* (pp. 153–168). New York: Springer Publishing Company.

Leventhal, H., Rabin, C., Leventhal, E.A., & Burns, E. (2001). Health risk behaviors and aging. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 186–214). San Diego, CA: Academic Press.

Liu, L.L, & Park, D.C. (2003). Technology and the promise of independent living for adults: A cognitive perspective. In N. Charness & K.W. Schaie (Eds.), *Impact of technology on successful aging.* (pp. 262–289). New York: Springer Publishing Company.

Madden, D.J. (2001). Speed and timing of behavioral processes. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 288–312). San Diego, CA: Academic Press.

McDowd, J.M., & Shaw, R.J. (2000). Attention and aging: A functional perspective. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 221–292). Mahwah, NJ: Lawrence Earlbaum Associates.

Morrell, R.W., Dailey, S.R., & Rousseau, G.K. (2003). Commentary: Applying research: The NIHSeniorHealth.gov project. In N. Charness & K.W. Schaie (Eds.), *Impact of technology on successful aging.* (pp. 134–161). New York: Springer Publishing Company.

Morrell, R.W., & Echt, K.V. (1997). Designing written instructions for older adults: Learning to use computers. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of* *human factors and the older adult*. (pp. 335–361). San Diego, CA: Academic Press.

Morrow, D., & Leirer, V. (1997). Aging, pilot performance, and expertise. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult*. (pp. 199–230). San Diego, CA: Academic Press.

National Institute on Deafness and Other Communication Disorders (NIDCD). (February 23, 2005). *Presbycusis* [On-line]. Available: http://www.nidcd.nih.gov/health/hearing/presbycusis.asp.

National Research Council. (2000). *The aging mind: Opportunities in cognitive research*. Washington, DC: National Academy Press.

Panek, P.E. (1997). The older worker. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult*. (pp. 363–394). San Diego, CA: Academic Press.

Park, D.C. (2000). The basic mechanisms accounting for age-related decline in cognitive functioning. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 3–21). Philadelphia: Taylor & Francis.

Park, D.C, & Gutchess, A.H. (2000). Cognitive aging and everyday life. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 217–232). Philadelphia: Taylor & Francis.

Park, D.C., & Jones, T.R. (1997). Medication adherence and aging. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult*. (pp. 257–287). San Diego, CA: Academic Press.

Peters, E., Finucane, M.L., MacGregor, D.G., & Slovic, P. (2000). The bearable lightness of aging: Judgment and decision processes in older adults. In P.C. Stern & L.L. Carstensen (Eds.), *The aging mind: Opportunities in cognitive research* (pp. 144–165). Washington, DC: National Academy Press.

Prull, M.W., Gabrieli, J.D.E., & Bunge, S.A. (2000). Age-related changes in memory: A cognitive neuroscience perspective. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 91–153). Mahwah, NJ: Lawrence Earlbaum Associates.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 1–90). Mahwah, NJ: Lawrence Earlbaum Associates.

Reuter-Lorenz, P.A. (2000). Cognitive neuropsychology of the aging brain. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 93–114). Philadelphia: Taylor & Francis.

Rogers, W. (1997). Individual differences, aging, and human factors: An overview. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 151–170). San Diego, CA: Academic Press.

Rogers, W.A. (2000). Attention and aging. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer.* (pp. 57–73). Philadelphia: Taylor & Francis.

Rogers, W.A., & Fisk, A.D. (2000). Human factors, applied cognition, and aging. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 559–591). Mahwah, NJ: Lawrence Earlbaum Associates.

Rogers, W.A., & Fisk, A.D. (2001). Understanding the role of attention in cognitive aging research. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 267–287). San Diego, CA: Academic Press.

Rubin, D.C. (2000). Autobiographical memory and aging. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer.* (pp. 131–149). Philadelphia: Taylor & Francis.

Rutherford, Jr., G.W., Marcy, N., & Mills, A. (2004). *Hazard screening report: Injuries to persons 65 years of age and older: All products.* [On-line]. Available: http://www.cpsc.gov/LIBRARY/hazard_older.pdf

Salthouse, T.A. (2000). Pressing issues in cognitive aging. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer.* (pp. 43–54). Philadelphia: Taylor & Francis.

Sanders, M.S., & McCormick, E.J. (1993). *Human factors in engineering and design* (7th ed.). New York: McGraw-Hill. 77, 669–671.

Sanfey, A.G., & Hastie, R. (2000). Judgment and decision making across the adult life span: A tutorial review of psychological research. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer.* (pp. 253–273). Philadelphia: Taylor & Francis.

Schaie, K.W. (2004). Cognitive aging. In National Research Council, *Technology for adaptive aging.* (pp. 43–63). Washington, DC: The National Academies Press.

Schaie, K.W. (2005). *Developmental influences on adult intelligence: The Seattle longitudinal study*. New York: Oxford University Press.

Schaie, K.W., & Willis, S.L. (2002). *Adult development and aging* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

Schieber, F. (2003). Human factors and aging: Identifying and compensating for age-related deficits in sensory and cognitive function. In N. Charness & K.W. Schaie (Eds.), *Impact of technology on successful aging.* (pp. 42–84). New York: Springer Publishing Company.

Schneider, B.A., & Pichora-Fuller, M.K. (2000). Implications of perceptual deterioration for cognitive aging research. In F.I.M. Craik & T.A. Salthouse

(Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 155–219). Mahwah, NJ: Lawrence Earlbaum Associates.

Smith, S., Norris, B., & Peebles, L. (2000). *OLDER ADULTDATA: The handbook of measurements and capabilities of the older adult* (DTI/Pub 4445/3k/01/00/NP URN 00/500). London: Department of Trade and Industry.

Spirduso, W.W., Francis, K.L., & MacRae, P.G. (2005). *Physical dimensions of aging* (2nd ed.). Champaign, IL: Human Kinetics.

Staudinger, U.M., & Pasupathi, M. (2000). Life-span perspectives on self, personality, and social cognition. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed.). (pp. 633–688). Mahwah, NJ: Lawrence Earlbaum Associates.

Sternberg, R.J., & Lubart, T.I. (2001). Wisdom and creativity. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 500–522). San Diego, CA: Academic Press.

Tun, P.A.., & Wingfield, A. (1997). Language and communication: Fundamentals of speech communication and language processing in old age. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 125–149). San Diego, CA: Academic Press.

U.S. Consumer Product Safety Commission (CPSC). (2005). *Special report: Emergency room injuries: Adults 65 and older* [On-line]. Available: http://www.cpsc.gov/library/foia/foia05/os/older.pdf

U.S. Department of Health and Human Services. (2004). *A profile of older Americans* [On-line]. Available: http://www.aoa.gov/prof/Statistics/profile/2004/profiles2004.asp

U.S. Equal Employment Opportunity Commission. (1997). *Facts about age discrimination* [On-line]. Available: http://www.eeoc.gov/policy/adea.html

Vanderheiden, G.C. (1997). Design for people with functional limitations resulting from disability, aging, or circumstance. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed.). (pp. 2010–2052). New York: John Wiley & Sons.

Vercruyssen, M. (1997). Movement control and speed of behavior. In A.D. Fisk & W.A. Rogers (Eds.), *Handbook of human factors and the older adult.* (pp. 55–86). San Diego, CA: Academic Press.

Vinters, H.V. (2001). Aging and the human nervous system. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed.). (pp. 135–160). San Diego, CA: Academic Press.

Wingfield, A. (2000). Speech perception and the comprehension of spoken language in adult aging. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 175–195). Philadelphia: Taylor & Francis.

Wingfield, A., & Stine-Morrow, E.A.L. (2000). Language and speech. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2^{nd} ed.). (pp. 359–416). Mahwah, NJ: Lawrence Earlbaum Associates.

Yoon, C., May, C.P., & Hasher, L. (2000). Aging, circadian arousal patterns, and cognition. In D. Park & N. Schwarz (Eds.), *Cognitive aging: A primer*. (pp. 151–171). Philadelphia: Taylor & Francis.

Zackowitz, I.B., & Vredenburgh, A.G. (2005). Preschoolers, adolescents, and seniors: Age-related factors pertaining to forensic human factors analyses. In Y.I. Noy & W. Karwowski (Eds.), *Handbook of human factors in litigation* (Chapter 35). Boca Raton, FL: CRC Press.

Zacks, R.T., Hasher, L., & Li, K.Z.H. (2000). Human memory. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2^{nd} ed.). (pp. 293–357). Mahwah, NJ: Lawrence Earlbaum Associates.