

Review article

# Optimizing sensation and perception in older adults

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## Abstract

Age-related differences in adult sensory and perceptual function are reviewed for vision, hearing, taste and smell, using laboratory-based research as well as clinical, survey and field studies. In each area, ergonomic interventions aimed at optimizing the performance of older adults are explored. These optimization strategies include modifications to the environment, person and task design. Future research needs are also identified and discussed.

## Relevance to industry

The workforces of many industrialized nations have been growing increasingly older. This trend will continue well into the next century. Yet, ergonomic guidelines and practices are based primarily upon young adult models. This paper describes how the sensory capacities of older adults tend to differ from such models and prescribes ergonomic remediation strategies for optimizing the performance of an aging population.

## Keywords

Ergonomics, aging, sensation and perception, vision, hearing, taste, smell.

## Introduction

The purposes of this article are: to summarize selected information on age-related differences in sensory and perceptual experience in vision, hearing, taste and smell; to review available informa-

tion relative to ergonomic interventions that are possible and necessary to improve sensory functioning when needed; and to suggest new directions for ergonomics research and practice in relation to aging adults. Ergonomic interventions seek to optimize performance in tasks that involve re-

ceiving and providing sensory and perceptual information by: (a) improving the quality and quantity of task relevant information provided to a person; (b) helping a person adapt to or transcend problems associated with situations in which sensory and perceptual information is poor; and (c) redesigning tasks by reassigning functions between machine and human components of a task (Fozard, 1981). While age-related limitations in sensory and perceptual functioning should be taken into account in the assignment of system function to the human or the machine components of a system, the measures taken should not adversely affect the functioning of other (i.e., young) users of the system.

The material in each major section of this report – vision, hearing, taste and smell – is organized in a similar manner. For readers interested in just part of the subject matter, we suggest reading the introduction and the section of interest.

#### *Who are older adults?*

The major demographic change of this century that will continue at least into the middle of the next is the changing age distribution of the population. Figure 1 shows how the relative distribution of age is expected to change through the middle of the twenty-first century. While the projections may be substantially modified by wars, and pandemics that affect the mortality of young adults relatively more than older ones, e.g., new addictive drugs or AIDS, there is little question

that the modal person(s) guiding the practice of ergonomics in the future will be older than the new military enlistee, or college student who have traditionally provided the data for specifications of the human component in man-machine systems.

With respect to age changes in sensory systems there is no single age within or across sensory systems that signals 'old'. Significant biological variability in sensory systems occurs within any age group, young or old. Age changes within a single system are not usually uniform. For example, data to be reviewed indicate that thresholds for pure tones increase steadily throughout adulthood, but those for higher frequencies, e.g. 8 kHz, increase regularly throughout adulthood at a rate of about 1 db per year. Yet, at the same time, auditory thresholds for lower frequencies, e.g. 1 kHz, increase at a rate of about 0.3 db per year from the 20s through the 60s and then at an accelerated rate up to 1.3 db per year thereafter. Until about age 75, variations in visual acuity change very little across age for distant targets, while corrective lenses are typically necessary for good acuity at optical distances less than a meter from about 40 years of age onward. Taste thresholds for the four major taste qualities change little with age, but perception of taste intensity is less reliable in older than in younger adults. Thus the required ergonomic interventions for 'age' will vary depending on the particular sensory/perceptual requirements of the task.

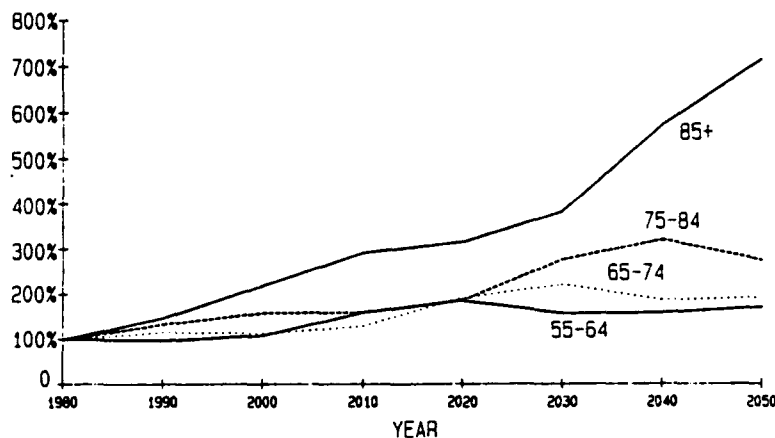


Fig. 1. Projected changes in age distribution of the elderly. Based on United States Bureau of the Census (1983).

### *Optimizing to what target?*

Ergonomics practitioners want to know how unique their interventions need to be with respect to age. There is no simple answer to this question. It is widely believed that most interventions will help performance of young and old adults alike – for example, better contrast in signs, suppression of background noise for speech intelligibility, etc. There are many tasks in which a less than optimal environment can be tolerated better by younger than older persons. Many difficult visual tasks that require rapid adaptation to dim illumination and seeing detail at changing optical distances would not be tolerated by an older adult who has lost the power of visual accommodation and requires greater amounts of target illumination for performance of a task. In this sense designing an adequate environment for the older adult will most likely provide a satisfactory one for the young adult, but not the reverse.

### *Environmental interventions*

Almost all of the material to be discussed in this article concerns age-related limitations in receiving information from the environment. The communication of information by adults of different ages to a man-machine system or to other people in the environment is not dealt with in any depth. One useful classification of person-environment relationships is whether the person, the environment, or both are either static or changing. When both are changing simultaneously, interventions with the environment or task redesign offer the most likely opportunities. Examples of such situations would be driving or walking through an airport where the level and source of information is continuously changing. Environmental interventions would also be relatively powerful where the environment is static. In vision for example, there are many possibilities for changing the amount and configuration of lighting in office, factory and home situations. In hearing, the effectiveness of assistive hearing devices may be greatest when the sources and levels of signal and background noise are most stable. In cases where the auditory environment is changing, the burden of improving performance falls more heavily on the person who can benefit from lip reading and knowledge of how to place oneself in groups to maximize the

information obtained. In the case of taste and smell, the major burden of adaptation is with the environment, partly because of the ephemeral nature of the stimuli and the rapid adaptation of the chemical senses to changes in the environment by adults of all ages.

### *Interventions with people*

Interventions with people independent of changes in the environment or task demands are restricted to the selection of people for a task or training them on the task so that sensory/perceptual limitations are overcome. Well-fitted prosthetic devices, such as spectacles and hearing aids, also can help older adults to better deal with task demands. Traditionally, selection of people on the basis of adequate sensory/perceptual functioning in various tasks has been limited to tasks which are highly specialized, e.g., certain military situations, or to ones in which the screening procedure is very coarse with respect to age, e.g., the visual acuity and binocular depth perception tests used in vision screening for automobile driver's licenses. In the former case, age is not usually the limiting factor; in the latter case, the screen does not identify older people on the basis of many well known age-related problems in vision. At present there is little research or information available on the relationships between individual differences and sensory/perceptual abilities or aptitudes required in various tasks.

In vision and hearing there are a variety of interventions routinely used to train people to improve their ability to understand visual information and speech, and the applications of those techniques to the elderly are reviewed later in this article. Many such interventions were developed for persons with more profound limitations in sensory/perceptual functioning than is typically encountered in the elderly, and therefore are not widely used. Many interventions used do not take into account certain problems that are relatively prominent in the elderly, e.g., slow response speed. As will be seen, there are many opportunities for further development of this area.

The interventions discussed above are targeted toward persons who already have limitations. There is circumstantial evidence that some of the sensory/perceptual problems experienced by many elderly persons might respond to long term

preventive measures. In vision, for example, the development of cataracts is accelerated by excessive exposure to the ultraviolet radiation in sunlight. In the case of hearing, age-related increases in pure tone thresholds are partly due to long term exposure to environmental noise. Similarly, modifiable lifestyle factors such as eating habits and smoking may contribute significantly to age-related changes in gustatory sensitivity. The evidence for such conclusions comes from comparing persons with extreme exposure to the environmental insults to controls, e.g., professional fishermen in the case of cataracts and factory workers in very noisy environments in the case of hearing. Little is known about how much or how long the cumulative insult needs to be in order to produce the sensory impairments.

In the sections that follow, vision, hearing, and the chemical senses – taste and smell – will be discussed in turn. In each area, the basic research on age differences in sensory and perceptual function will be reviewed, the available ergonomic interventions discussed, and the areas for future ergonomics research described.

## Vision

### *Subjective reports of visual problems*

Older adults report greater levels of dissatisfaction with their visual capabilities than do younger adults (Hakkinen, 1984; Kosnik et al., 1988). Recently Babbitt et al. (1989) surveyed 400 participants of the Baltimore Longitudinal Study of Aging ranging in age from 20 to 90 regarding the impact of visual problems on daily tasks of living and specific driving behaviors. For tasks of daily living, self-perceived age-related declines occurred in visual processing speed, dynamic vision, near vision, overall visual quality and seeing under low light conditions. For driving, older respondents reported difficulty with judging speed, instrument panels which were too dim, other vehicles which moved too quickly or entered the peripheral field of vision 'unexpectedly' and merging with traffic. Older drivers also reported more responses that appeared compensatory in nature, such as avoiding 'rush hour' traffic and nighttime driving.

### *Psychophysical reports of visual problems*

Data from laboratory and clinical assessments of visual function are consistent with the self-reports of visual difficulties exhibited by older adults. These data contain the beginnings of the database needed to design visual environments for the elderly. More extensive coverage of this rapidly expanding area is given by Fozard (1990), Kline and Schieber (1985) and Sekuler et al. (1982).

### *Absolute threshold for light and dark adaptation*

The age-related increments in the absolute sensitivity for light reported by Gunkel and Gouras (1963) and McFarland and Fisher (1955) were extended by Eisner et al. (1987), who assessed age differences in absolute light sensitivity under conditions of complete dark adaptation. Between the ages of 60 and 88 years, absolute threshold for light in the dark-adapted eye increased by approximately 0.1 log units per decade. These same subjects were then light adapted and then had their absolute thresholds repeatedly measured across the full period of the photopic and scotopic dark adaptation processes. Eisner et al. concluded that, although final sensitivity for light was diminished with age, the rate of dark adaptation did not change.

### *Acuity*

Visual acuity is most often quantified in terms of the visual angle of the smallest target which can be identified. Since the crystalline lens of the eye must change shape (i.e., accommodate) in order to focus near targets, separate visual acuities for near (40 cm) versus far (6 m) targets are measured. The acuity test has been widely adopted as the basis for correcting optical aberrations of the eye with spectacles (Schieber, 1988).

Gittings and Fozard (1986) reported age-related changes in visual acuity from 577 male participants of the Baltimore Longitudinal Study of Aging (BLSA) as summarized in figure 2. An average of 7 repeated measurements were made on the same individuals, spaced approximately 2 years apart. The linear functions shown represent the best-fit regression lines for each age-stratified subgroup of the sample. Uncorrected far distance acuity declines from age 30 to age 80, but the fall-off in corrected (presenting) far acuity is not

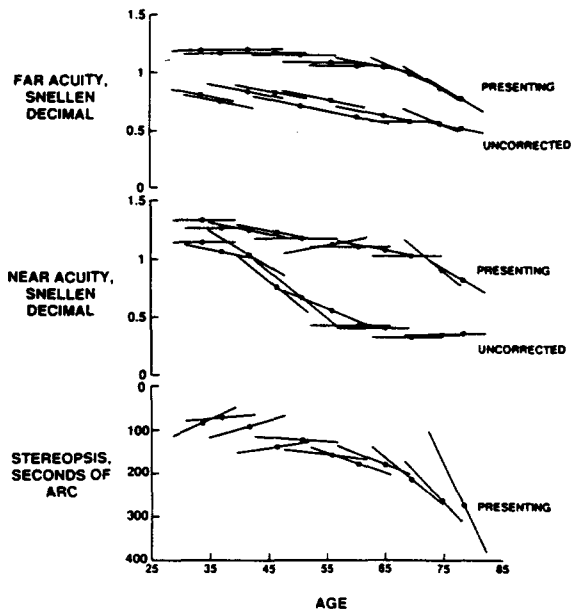


Fig. 2. Longitudinal changes in binocular visual acuity and depth perception in 577 males. The Snellen decimal is the reciprocal of the Snellen fraction (i.e.,  $20/40 = 0.5$ ). Each point is located at the mean age for the men in a particular group; the length of the line represents the number of years each group was followed. The slope of the line represents the best fit linear regression on age. Based upon acuity data by Gittings and Fozard (1986) and stereopsis data by Gittings et al. (1987). Reproduced with permission from Fozard (1990, figure 9.1).

readily noticeable until age 65–70. This latter finding supports the conclusions of cross-sectional studies (see Pitts, 1982). However, previous studies have found that only 69 percent of those ages 75–85 are capable of being corrected to 20/25 (1.25 minarc) acuity levels (Kahn et al., 1977). Gittings and Fozard's uncorrected near visual acuity showed a marked decrement between the ages of 40 and 55 consistent with the well-known age-related loss in the accommodative capacity of the lens (presbyopia) which occurs during the fifth decade of life. The age-related change in presenting (bifocal corrected) near acuity parallels the pattern of age-related loss reported for far acuity. Much of the longitudinal decline in acuity across increasing age was observed in persons who initially presented with good visual acuity, a finding that underscores the importance of more frequent assessment of visual acuity in older persons.

#### Contrast sensitivity

Visual acuity does not fully describe the spatial

visual capabilities of an individual. Visual sensitivity varies with target size, contrast and spatial orientation (Braddick et al., 1978; Olzak and Thomas, 1986). The ability to see small high contrast targets (i.e., acuity) does not predict the ability to detect large objects or those viewed under diminished contrast (Ginsburg et al., 1982; Watson et al., 1983). At the cost of more complex and time-consuming procedures, contrast sensitivity measures yield information about an individual's ability to see low contrast targets over an extended range of target size (and orientation). They use sine-wave gratings ranging from 0.5 to 32 cycles/degree as targets instead of the letter and checkerboard optotypes used in acuity tests, partly because they have useful mathematical properties (Ginsburg, 1977) and because early stages of visual processing are optimally sensitive to a family of sine-wave grating targets (Maffei, 1978; Watson et al., 1983). Because high levels of visual sensitivity are associated with low contrast thresholds, a reciprocal measure ( $1/\text{threshold}$ ), termed the contrast sensitivity score, is computed. These scores are determined for the spatial frequencies examined and constitute an individual's contrast sensitivity function (CSF).

In the BLSA age-related differences in the contrast sensitivity function (Schieber et al., 1989) are being determined using rigorous psychophysical procedures suitable for determining longitudinal changes. The data from over 200 BLSA participants in this study are presented in figure 3, which shows that older persons experience losses in visual sensitivity for large objects as well as smaller ones relative to younger adults. These findings replicate and extend the results of previous studies of aging and contrast sensitivity (Kline et al., 1983; Owsley et al., 1983).

Owsley et al. (1983) found that such age-differences in contrast sensitivity were not eliminated when young subjects viewed the stimuli under conditions of simulated ocular aging (viz., markedly reduced retinal illumination and refractive error induced via 'plus' spherical defocusing lenses). The results indicated that the residual age differences in contrast sensitivity represented an age-related change in the visual nervous system. Such a neurally mediated change in visual sensitivity would mandate that engineering-based compensation strategies for losses in contrast sensitiv-

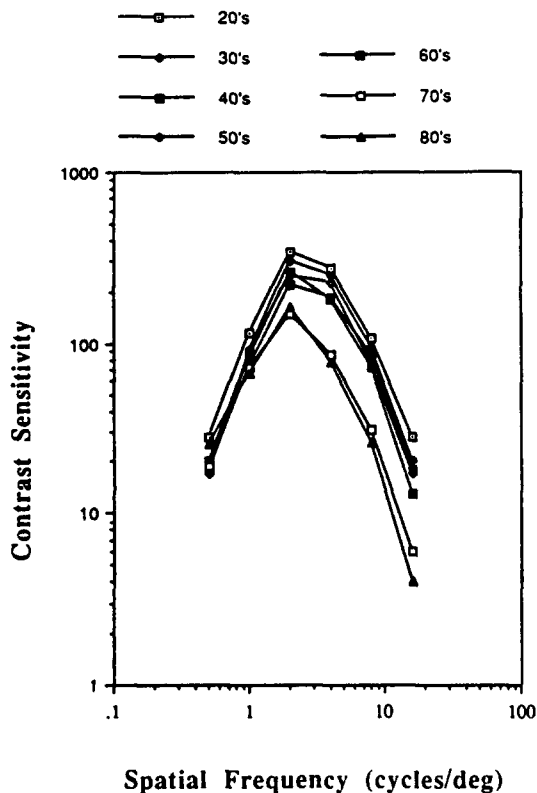


Fig. 3. Contrast sensitivity as a function of age. Based upon data by Schieber et al. (1989).

ity focus upon remediations in the environment rather than the individual observer.

### Stereopsis

The ability of the visual system to detect and utilize changes in binocular retinal disparity to make inferences about depth is known as binocular depth perception, or stereopsis. Stereopsis is only one of many visual cues used to make judgments of depth or distance. Gittings et al. (1987) examined age changes in stereopsis over a period of 10 years in 577 male participants of the BLSA. As shown in the bottom panel of figure 2, threshold stereopsis increases from a minimum of 100 sec of arc in the 30-year-olds to a maximum of approximately 300 sec in the 80-year-olds. This age-related loss in stereopsis ability did not correlate with age-changes in acuity collected from these same individuals. Similar reductions in binocular depth perception with increasing adult age have been reported using cross-sectional techniques

(Bell et al., 1972; Greene and Madden, 1987; Jani, 1966).

### Color discrimination

The ability to discriminate subtle differences in hue under standard lighting conditions has been repeatedly demonstrated to decline with age (Dalderup and Fredericks, 1969; Knoblauch et al., 1987). Gilbert (1957) found that in subjects ranging in age from 10 to 93 years, all experienced greater difficulty discriminating among blues and greens (short wavelengths) as opposed to reds and yellows (long wavelengths). This blue-green confusability became especially pronounced among the older observers.

### Eye movements

Saccadic eye movements maintain visual contact with the central area of the retina specialized for fine detail and color vision. Pursuit eye movements, in conjunction with saccades, allow the visual system to track moving targets.

Older adults are capable of maintaining accurate levels of fixation over extended periods of observation (e.g., Kosnik et al., 1987), but there is evidence that the time needed to initiate a saccadic eye movement following the onset of a visual stimulus increases with adult age. Whitaker et al. (1986) found mean saccadic latencies of 255 ms in 18–32 year olds vs. 284 ms in 57–72 year olds. Pitts and Rawles (1988) reported that between the ages of 20–68 saccadic latency increased by 0.76 percent per year while saccadic velocity decreased by about 0.25 percent per year.

Sharpe and Sylvester (1978) reported that young adults could accurately track targets at velocities up to 30 degrees/sec; the corresponding figure for older observers was about 10 degrees/sec. Relatedly, Kaufman and Abel (1986) demonstrated that age differences in pursuit accuracy are exacerbated in the presence of competing or distracting stimulus backgrounds. Although classic texts on ophthalmology place the restriction on upward gaze in older adults between 40 and 45 degrees (Adler, 1933; Duke-Elder, 1949), Chamberlain's (1971) assessment of 367 persons ages 5–94 revealed that the limit of upward gaze declines linearly across the lifespan for a high of 40 degrees at ages 5–14 to a low of 16 degrees at ages 75–84. Little or no age-related limitation in the extent of lateral or downward gaze was noted.

### *Motion sensitivity*

Buckingham et al. (1987) measured threshold sensitivity for the detection of horizontal oscillatory motion in a 2 cycle/degree sine-wave grating target as a function of age and temporal frequency (1–20 Hz). At all temporal frequencies, older (mean age = 69.7) observers were less sensitive to motion than middle aged (mean age = 48.0) observers who, in turn, were less sensitive than the young (mean age = 20.7). When the grating oscillated at a frequency of 8 Hz, young, middle-aged and older observers required oscillation amplitudes of approximately 39, 52 and 97 sec of arc, respectively, to detect the occurrence of motion. In another study demonstrating loss of motion sensitivity with age, Owsley et al. (1983) reported that older adults exhibited markedly attenuated sensitivity for the detection of a 1.0 cycle/degree sine-wave grating which drifted at a velocity of 4.3 degrees/sec despite the fact that no age differences in sensitivity were observed for a stationary grating of the same spatial frequency.

Dynamic visual acuity refers to the ability to resolve fine spatial detail for objects in motion relative to the observer. Burg (1966) examined both conventional and dynamic visual acuity in a sample of 17,000 drivers ages 16 through 92. Acuity for moving targets declined more rapidly with age than did conventional measures of acuity. Other investigators have reported similar findings (Farimond, 1967; Reading, 1972). Unlike static visual acuity measures, dynamic visual acuity assessment appears to have some predictive power as regards the driving performance of older adults (Henderson and Burg, 1974). Relatedly, Scialfa et al. (1987) have reported age-related decrements in the accuracy of vehicular speed estimations on a video simulation of a driving task.

### *Visual search*

The ability to detect and orient to events which occur in the parafoveal and peripheral fields of vision is essential for many daily tasks. However, very little is known about non-foveal visual functioning in the older adult. Wolf (1967) assessed the limits of far peripheral visual sensitivity for individuals ages 16 through 91 using a dim, 1 mm<sup>2</sup> target. The maximum extent of peripheral vision remained relatively stable through age 55, followed by a progressive decrease in the width of

the visual field through age 91. However, recent evidence suggests that perimetric measures such as those obtained by Wolf may severely underestimate age-related declines in the ability to utilize information presented to the non-central areas of the retina. Sekuler and Ball (1986) measured age differences on a task that assessed how well a simple target could be localized when randomly positioned anywhere within the central 30 degrees of the visual field. This localization task was also performed both with and without visual distracter stimuli as well as under conditions of divided attention where the observer had to perform a concurrent central visual task. In the absence of the distracter stimuli observers of all ages did equally well at localizing the peripherally presented target. However, the presentation of the peripheral distracters resulted in a significant performance decrement for the old group (mean age = 68.8) but not the young group (mean age = 25.1). In a follow-up study, Ball et al. (1988) determined the range of parafoveal vision over which accurate localization performance could be maintained under conditions of divided attention with peripheral distracters. They determined that the 'useful field of view' (UFOV), the visual area over which information can be acquired within a single eye fixation under complex conditions, contracted significantly in size as age increased from 22 to 75 years.

### *Night vision*

When available light is decreased to low levels, visual functions such as acuity and contrast sensitivity become impaired (Lit, 1968; Van Meeteren and Vos, 1972). Applied night vision research has tended to focus upon military applications where scotopic levels of visual adaptation are required. Hence, much data is available regarding the relationship between absolute threshold and dark adaptation measures and performance (National Research Council, 1987). However, few night vision tasks involving the civilian elderly population must be carried out under scotopic conditions. Instead, vision in the mesopic and low photopic range is more characteristic of common night vision tasks such as driving (Byrnes, 1962). Although limited, there is a database regarding age differences in visual function under mesopic and low photopic levels of adaptation. These studies

have revealed that age-related declines in visual function become exacerbated under low light conditions.

Richards (1977) measured acuity for charts ranging in luminance from 0.3 to 34 cd/m<sup>2</sup> for individuals ranging in age for 16–90 years. Although the acuity of all individuals decreased as available light was diminished, the magnitude of this effect was much stronger for those individuals in their 70's and 80's. Relatedly, Rice and Jones (1984) examined corrected visual acuity under normal and reduced (i.e., nighttime) illumination conditions. Of 4,038 drivers who passed the test (20/40 or better) under standard levels of illuminance, 267 (6.6%) were unable to pass the night vision version of the test. Older persons were disproportionately represented in this group as 36% of those ages 61–70 and 68% of those ages 81+ failed the nighttime version of the visual screening test. Similar findings have been reported by Waller et al. (1980).

Sloane et al. (1988) reported that age differences in contrast sensitivity increased as target luminance was decreased from 107 to 0.107 cd/m<sup>2</sup>. At the lowest luminance level, over 50% of the older subjects failed to detect targets having a spatial frequency of 4 cycles/degree or higher at the maximum available level of contrast (70%). Applied research initiatives have also demonstrated that the performance of older adults suffers disproportionately under low luminance conditions. Sivak and Olson (1982) found that older adults demonstrated nighttime legibility distances for highway signs that were only 65–77% of those obtained by their young counterparts. This age difference could be accounted for by low luminance acuity scores but not acuity scores collected under traditional high luminance conditions.

#### *Glare sensitivity*

Bennett (1977) reported a 3-fold decrease in the aged for the amount of glare which could be tolerated before significant levels of psychological discomfort were encountered. This decreased threshold for discomfort glare among the elderly was especially problematic at levels of background illumination resembling nighttime driving conditions. Similarly, Pulling et al. (1980) observed a significant decline with age in headlight glare resistance when observers were tested in a driving

simulator. Wolf (1960) examined the effects of a central glare source on the luminance required to identify a target (orientation of a Landolt-ring) in persons ages 5 through 85. The luminance increment required to overcome the glare mediated reduction in acuity significantly increased with age, especially after age 45. Burg (1967) repeated Wolf's (1960) observations on a sample of 17,000+ drivers ages 16–92. In addition, he assessed the time needed to recover visual sensitivity which was lost following exposure to a glare source. The amount of luminance required to identify the acuity targets in the presence of the glare source increased with age. Glare recovery was also slower in older adults: 3.9, 5.6 and 6.8 sec for drivers ages 20–24, 40–44 and 75–79, respectively. Other studies have also reported an age-related increase in the time required to recover lost visual sensitivity following exposure to a transient glare source (Reading, 1966; Olson and Sivak, 1989). Recent studies of disability glare suggest that contrast sensitivity may be more sensitive than acuity measures for assessing the magnitude of glare effects (e.g., Abrahamsson and Sjostrand, 1986; Elliot, 1987; Finlay and Wilkinson, 1984).

#### *Ocular mechanisms of age-related visual changes*

Age-related changes in the diameter of the pupil and the optical quality of the crystalline lens appear to significantly alter the image formed upon the retina of the typical older adult. Birren et al. (1950) measured the pupil sizes of 222 observers ages 20 to 89 and reported that pupillary diameter decreased significantly with age. Pupillary diameter declined linearly from an average of 4.7 mm at age 20 to 2.3 mm at age 80 under light adapted conditions. Under dark adapted conditions, the age difference in pupil size becomes magnified – average diameter decreasing from 8 mm to 2.5 mm from age 20 through 80 (Kornzweig, 1954; Weale, 1961). This means that under low light levels the pupil permits much less light to enter the older eye. However, this phenomenon may not always have deleterious effects since smaller pupil sizes also tend to minimize the effects of optical aberrations (at the cost of reducing total light flux reaching the retina). In fact, Sloane et al. (1988) recently reported that increasing the pupil size of older adults did not reduce age-related differences



in contrast sensitivity under low luminance conditions.

Increasing adult age is also accompanied by an increase in the thickness and optical density of the crystalline lens, which causes increased light absorption and intraocular light scatter (Weale, 1963). The transmittance of the lens decreases systematically with age, especially for short wavelength (blue) light (Said and Weale, 1959; Wyzecki and Stiles, 1967). Wide individual differences in lens transmittance exist at every age across the lifespan (Sample et al., 1988). The light which manages to pass through the aging lens also suffers from greater levels of off-axis scatter which serves to reduce the effective contrast of the retinal image (Mellerio, 1971; Pokorny et al., 1986). Wolf and Gardiner (1965) measured age differences in light back-scatter of the optic media using a modified slit-lamp. They found that the lens of the 80-year-old suffered from 16 and 30-fold increases in scatter relative to the 40-year-old and adolescent eye, respectively. Unlike the transmittance of light, lenticular scatter does not appear to be wavelength dependent (DeMott and Davis, 1960). Blackwell and Blackwell (1980) have produced a general formula for estimating the combined effects of decreased pupillary diameter and increased optical density of the lens as a function of age. This index of 'relative effective overall transmittance' (p. 225) relates the transmittance of the human ocular media to chronological age relative to a standard observer of age 20. For the six successive age decades from 25 through 75, the relative transmittances are 1.000, 0.886, 0.691, 0.507, 0.369, and 0.247, respectively. The relative transmittance of a 75-year-old person's lens is estimated to be only a fourth of that of a 25-year-old's lens.

The same age-related thickening of the lens which contributes to its increased density and light scatter also results in the loss of accommodation (the ability of the lens to bend and increase its effective focusing power) – a condition known as presbyopia (Weale, 1963). According to Weiss (1959), maximum accommodative amplitude decreases linearly from approximately 20 diopters at age 5 to about 0.5 diopter at age 60. As a result, the closest distance at which an object can be viewed without blur lengthens from about 5 cm to 50 cm over this same age range. Hence, pres-

byopia accounts for the loss of near visual acuity, and the emerging dependence upon bifocal lenses, which typically becomes manifest around age 45.

### *Compensating for age-related loss of visual function*

#### *Increase illumination*

Our ability to detect objects, read text and discriminate color improves dramatically as illuminance increases from the dim levels provided by a single candle (1 lux) to the high levels provided by a well-positioned fluorescent luminaire (500–1000 lux). The improvement of visibility over this range of illuminance is nonlinear and can be approximated by the square-root law: performance =  $\sqrt{\text{luminance}}$  (Olzak and Thomas, 1986). The application of this rule for designing environments which optimize visual performance must be modulated by the inclusion of other factors such as the ratio of task area illumination to overall room illumination, task speed versus accuracy requirements, reflectivity of environmental surfaces and the need to control discomfort glare (McCormick and Sanders, 1982). However, our knowledge of decreased transmissivity of light through the senescent optic media strongly suggests that age must also be considered as an important factor for illumination engineering. Indeed, there is a well established database which demonstrates the potential of increased illumination for improving the visual performance of the elderly population.

Ferree and Rand (1933) assessed the acuity of young (25–27-year-olds) and older (42–64-year-olds) adults over a range of illuminance from 5 to 108 lux. The improvement in acuity seen across this range of illuminance was greater for the older group. This finding is consistent with the notion that the average older adult experiences a 'sun-glasses effect' which shifts the individual downward on the square-root performance curve – where small increments in illumination can be expected to yield large gains in function. Boyce (1973) investigated the time required to read through a chart of Landolt-ring acuity targets presented at varying levels of spatial detail (1.5 vs. 2.4 minarc), contrast (0.4 vs. 0.7) and illumination (approximately 200 to 1600 lux). Three groups of observers ages 16–30, 31–45 and 46–60 years old were examined. Varying illumination, contrast and target size had little systematic influence upon the

performance of the youngest group. However, significant improvements in reading speed were seen in the oldest group as illuminance was increased, especially under the reduced contrast condition. Peak performance for old observers was reached between 500 and 1000 lux. Relatedly, Smith and Rea (1978) investigated proof-reading accuracy in a sample of 18–22 and 49–62-year-olds. Text quality and illumination were varied. The young observers demonstrated small improvements in performance as illumination increased from 10 to 100 lux for poor, but not good, quality text materials. The older observers showed improvement for both poor and good quality text as illumination increased from 10 to 100 lux. In fact, their proof-reading performance for poor quality text continued to improve until reaching asymptotic levels at approximately 1000 lux. Similar findings have been summarized by Hughes and Neer (1981).

Increases in illumination above traditional levels used in design have also been shown to yield reduced age differences in other domains of visual performance. For example, Boyce and Simons (1977) demonstrated that age differences in color discrimination performance on the FM-100 hue test decreased as illuminance increased from 400 to 1200 lux. Similarly, Knoblauch et al. (1987) found that color discrimination performance attained by 20–40-year-olds at 5.7 lux could be achieved by persons 50–60 and 70–80 years old when illumination was increased to 57 and 180 lux, respectively. Hughes and McNelis (1978) examined the effects of age and illumination upon the performance of a complex clerical task. Both the young (19–27) and older (46–57) clerical worker participants demonstrated improved performance as illumination level increased (538 to 1077–1614 lux). However, more improvement was

demonstrated by the older group (9 vs. 6.7 percent). Both age groups rated the low illuminance condition as requiring more psychological effort. In addition, older workers reported a distinct preference for working under the two higher levels of illumination. Note that these higher levels of illumination are well above the values recommended for office illumination by several well-known standards organizations (see Boyce, 1981, pp. 377–397).

Recently, the need for higher levels of illumination by older adults has been translated into specific design guidelines by the Illuminating Engineering Society (IES) of North America. The IES Lighting Handbook (Kaufman and Haynes, 1981) set forth a new set of procedures for selecting appropriate illumination levels across various environmental settings and tasks. Instead of providing a single illumination value for each area/activity group as in the past, a range of 3 values are now given. Designers chose from among the three values using a new weighting system which includes the provision for specific changes in recommended illumination level depending upon the age of the observer. In most cases, recommended illumination levels are reduced for observers under the age of 40, but increased for those over the age of 55 years old. Some sample age-weighted illumination recommendations for tasks where speed is not critical and average surface reflectance is in the range of 30–70 percent are presented in table 1, based on data taken from Kaufman and Haynes (1981).

Because the age of persons engaged in many vision-critical tasks varies widely at most sites, Fozard and Popkin (1978) have recommended the use of 'user-adjustable' lighting strategies in many settings. This recommendation seems to have

Table 1

IES illumination recommendations (in lux) for five classes of tasks by age, constructed from data in Kaufman and Haynes (1981)

IES (1981)		Age of observer (years)		
Category	Type of activity	Under 40	40–55	Over 55
A	Public spaces with dark surroundings	20	30	50
B	Simple orientation for short, temporary visits	50	75	100
C	Working spaces where visual tasks are only seldom performed	100	150	200
D	Performance of visual tasks with targets of high contrast or large size	200	300	300
E	Performance of visual tasks with targets of medium contrast or small size	500	750	750

merit. However, Charness and Bosman (1990) have warned that there are no data available, which suggests that users who are free to adjust the level of lighting will necessarily select the optimal illumination for the task at hand. In fact, evidence from the auditory domain suggests that when older adults are free to adjust the loudness of speech stimuli, they select intensities which match typical conversational levels rather than optimizing the stimulus energy to their own specific recognition requirements (Gelfand et al., 1985).

#### *Control glare*

The apparent need of the elderly for increased task area illumination is accompanied by an insidious paradox. Namely, increased task illumination carries the risk of introducing unacceptable levels of discomfort glare in some situations. Exacerbating this problem is the absence of clear quantitative design rules for detecting and eliminating offending light sources for the older population. Boyce (1981, pp. 305–317) discusses several systems which have been developed for evaluating the potential for visual discomfort in illuminated environments: the IES Visual Comfort Probability method (Kaufman and Haynes, 1981), the British Glare Index system (Illuminating Engineering Society, 1967), and the European Glare Limiting method (Fischer, 1972). Unfortunately, none of these systems explicitly addresses the influence of the age factor in contributing to visual discomfort caused by glare.

Numerous factors have been found to influence subjective reports of discomfort as well as diminished visual function due to glare. These include: size and shape of the room; maximum as well as minimum illumination levels; luminaire type, size, number and location; luminance distribution; observer location and line of sight; and, individual differences in glare sensitivity. Knowledge about the role of these factors has led to the development of qualitative recommendations and suggestions for minimizing the potential for environmental glare in illumination designs. For example, the IES Lighting Handbook (Kaufman and Haynes, 1981, pp. 2–25) suggests that discomfort glare can be reduced by: (1) decreasing the luminance of lighting equipment or other sources of objectionable glare such as windows and overhead skylights, relative to the overall luminance, (2)

diminishing the area of uncomfortable luminance, (3) increasing the angle between the offending light source and the line of sight, and (4) increasing the general luminance in the room while maintaining recommended maximum luminance ratios (typically 3:1 for office work). More exhaustive qualitative guidelines may be found in Boyce (1981) and McCormick and Sanders (1982). In response to the absence of general quantitative design criteria, recommendations for controlling glare problems among elderly users in specific application areas have begun to emerge (e.g., Mortimer, 1988; Olson and Sivak, 1989).

#### *Contrast enhancement*

Blackwell and Blackwell (1971; 1980) have demonstrated that age-related declines in retinal contrast can negatively impact visual performance, especially under conditions of low illumination and/or low stimulus contrast. Blackwell and Blackwell (1971) have developed an empirical model which demonstrates the need to increase stimulus contrast as a function of age in order to achieve equivalent levels of target 'visibility'. They have developed a series of contrast multipliers required by persons of different ages for achieving the visibility level of a standard observer – the healthy 20-year-old. For the 5 age decades from 25 through 65, the multipliers for the 50th percentile of the population are 1.00, 1.07, 1.34, 1.90, and 2.66, respectively. The corresponding figures for the 95th percentile are 1.76, 1.98, 2.74, 4.37, and 6.92. It should be noted that the Blackwells' data were collected from individuals having 20/25 (1.25 minarc) visual acuity or better. As such, their model relating chronological age to increased stimulus contrast requirements appears to represent a 'conservative' estimate of age-related change in visual function. Other studies also support the need for increased luminance contrast by older observers (Boyce, 1973; Hughes and McNelis, 1978; Richards, 1977).

There is some evidence for a need to be concerned with color contrast in the design of environments for older adults. The known age-related changes in color discrimination result in the perception of a world having 'washed out' blues and greens and diminished color saturation. In addition to problems of esthetic appearance for the design engineer, age-related changes in the

color sense can have critical consequences in the discrimination of color-coded medication capsules. Many older adults are dependent upon multiple medications which must be self-administered at different schedules. Often such medications are taken under conditions where lighting levels are poorly controlled (e.g., restaurants, waiting areas, etc.). Hence, the use of color coding combinations which minimize the probability of errors of discrimination by older observers should be employed. Empirical data is available to guide such a color design process (e.g., Knoblauch et al., 1987). For example, critical tasks involving color perception by older observers should avoid discriminations within the blue-green range as well as discriminations among colors within the same hue.

Finally, Archea (1985) has described how poor 'figural contrast' in environmental design can contribute to functional problems among the elderly. For example, the use of certain patterned textures in carpeting, tile and other architectural and building materials can greatly diminish depth perception at stairs and landings and contribute to the increased rate of fall-related accidents in older adults. In the qualitative tradition of design research, this investigator offers several excellent pictorial examples of such 'problem' textures. In summary, visual designs for the elderly must attempt to maximize luminance, color and figural contrast.

#### *Text size and style*

The Bell Laboratories' Human Factors Handbook (Israelski, 1979) recommends that the minimum acceptable size of print on commercial products should be no less than 3 point type (1 point =  $1/72$  in = 0.35 mm). Similar recommendations concerning the minimum size of text characters to be used in consumer product labeling have been proposed by Poulton (1969; 1972). However, these very small text sizes appear to be inappropriate where populations of older adults are concerned. Most younger adults can read such small text sizes because they have outstanding visual acuity and also possess the ability to functionally magnify the printed material by bringing it very close to their eyes. However, many older persons have diminished acuity and cannot rely upon an excess reserve of accommodative amplitude for reading fine print. Such age-related prob-

lems in reading small print appear to be reflected in the IES Lighting Handbook (Kaufman and Haynes, 1981), which recommends a minimum acceptable text size of 8 points. The IES also recommends that minimum text size be increased to 10–12 points where prolonged reading exposure is required. This recommendation is consistent with research findings which indicate that reading speed in young adults with normal visual acuities declines if text size is significantly smaller or larger than 10–11 point type (Poulton, 1969; Tinker, 1963). However, epidemiological data detailing age-related changes in visual acuity suggests that 10 point typefaces may not be optimal for prolonged reading among the elderly population. For example, data from the Framingham Eye Study indicates that 99 percent of the population below age 50 can be corrected to 20/25 acuity or better whereas only 69 percent of those ages 75–85 can be corrected to this level of spatial resolution (Kahn et al., 1977). Indeed, studies of age differences in highway sign legibility requirements have demonstrated that the conventional 50 foot : 1 inch (6.0 m : 1 cm) design rule relating viewing distance to character height should be reduced to 40 ft : 1 in (4.8 m : 1 cm) to accommodate the changing visual requirements of our older driving population (Mace, 1988; Olson et al., 1983).

Research investigating the effects of typeface style upon reading performance under ideal conditions have reported little variation in speed and/or accuracy as a function of font type (Boyce, 1981, pp. 116–123). However, little is known about the effects of font styles under non-ideal conditions. Such information would be useful in estimating the potential for age by font style performance interactions. That such interactions may exist is suggested by Sloane et al.'s (1987) report, which indicates that older adults appear to be more susceptible to 'crowding effects' – the reduction in functional acuity which occurs when text characters are placed closely together. This age-related crowding effect suggests that variations in 'kerning' (character-dependent proportional spacing) approaches used in the construction of typefaces may place unanticipated performance limitations upon older readers. These concerns merit additional attention given the recent proliferation of typefaces which have emerged in the printing industry.

### *Modifying the individual*

Much can be done to maintain and/or improve the visual status of many older adults. However, this premise is based upon the assumption that visual problems can be detected and treated in a timely manner. Significant age-related visual pathologies such as cataract and glaucoma respond well to currently available treatment regimens. Most older persons who suffer acuity losses can benefit from refractive correction. Hence, it would appear that more frequent and extensive visual screening of the elderly population might represent one of the most promising intervention strategies for optimizing the productivity, mobility and safety of older individuals (Schieber, 1988). Specific ergonomics engineering could contribute to this effort. For example, innovative solutions for correcting presbyopia (loss of near vision) in dynamic environments need to be developed (see Gwin, 1987). Also, recent findings suggest that complex age-related visual performance deficits which cannot be improved through medical intervention might be amenable to treatment using psychological training techniques (Ball et al., 1988; Waller, 1988).

## Hearing

Degenerative changes with age have been observed at every site of the peripheral and central auditory systems (Kirikae, 1969). As a consequence, age-related alterations in auditory function are common among elderly individuals. The two principal effects of aging on auditory function are in hearing loss and disorders of speech recognition. The impact of these impairments on the elderly person's life and methods to alleviate them will be presented.

### *Auditory thresholds*

#### *Cross-sectional studies*

Numerous large-scale studies have been conducted to determine average detection thresholds for pure tone stimuli among elderly listeners (Corso, 1963; Goetzinger et al., 1961; Harford and Dodds, 1982; Moscicki et al., 1985). Figure 4 presents mean pure-tone threshold data from Moscicki et al. (1985) that exemplify age-related

threshold differences. These data indicate that by age 60 years, pure-tone thresholds are within normal limits in the low-mid frequencies (0.25 kHz, 0.5 kHz, 1.0 kHz, and 2.0 kHz), and are within the mild-to-moderate hearing loss range in the higher frequencies (3.0 kHz–8.0 kHz). Additional increases in detection thresholds occur at all frequencies through age 89 years, resulting in a mild hearing loss of the low frequencies and a moderately severe loss in the higher frequencies. Females tend to exhibit better threshold sensitivity than males in each age group. The incidence of measured pure tone sensitivity loss among older citizens is estimated at between 31% and 94%, depending on the criteria for hearing loss (Moscicki et al., 1985).

#### *Longitudinal studies*

Repeated threshold determinations from the same individuals over a period of time describe the rate at which thresholds change. Brant and Fozard (1990) examined pure tone thresholds on Bekesy audiograms obtained from 813 men in seven different age groups over a 15-year time period. The rates of change in pure tone thresholds

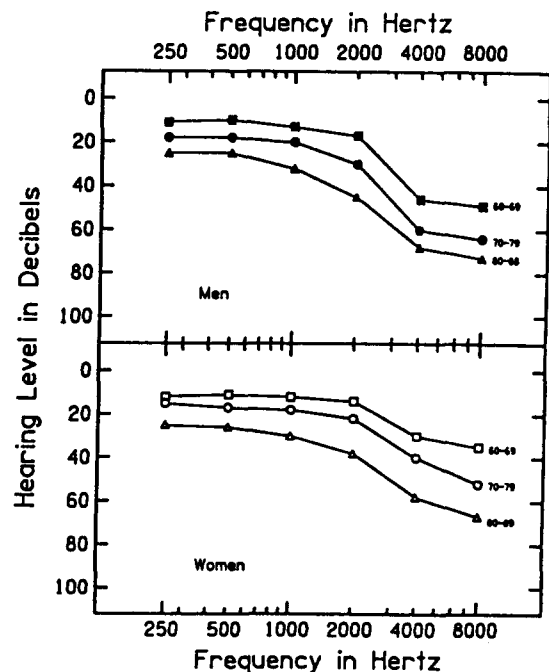


Fig. 4. Mean pure tone thresholds for men (top) and women (bottom) as a function of age decade. Figure constructed from data of Moscicki et al. (1985).

in the speech frequencies (0.5 kHz, 1.0 kHz, and 2.0 kHz) exhibited a relatively small change (about 0.3 db/year) from 20 through 50 followed by a marked increase up to 1.3 db/year between 60 and 95 years of age. In contrast, the rate of decline in hearing loss at the highest frequency (8.0 kHz) was relatively constant at about 1 db/year at all ages. These results suggest that among elderly males, the relatively more rapid threshold changes in the speech frequencies in older age may occur because hearing in the high frequencies has already declined significantly in earlier years, and because deterioration of sensory and neural structures of the peripheral auditory system is spreading to previously unaffected areas.

#### *How much is aging?*

Do the changes in pure tone thresholds reflect innate senescent changes in the auditory system, the combined effects of external factors, or both? 'Pure' presbycusis refers to threshold hearing loss associated solely with age effects. For instance, the results of Brant and Fozard (1990) were for persons without subjective complaints of hearing loss or diseases of the ear. One recent epidemiologic study of hearing impairment in 2,293 subjects aged 57 to 89 years reported that only 16% of all subjects had a negative otologic history (Moscicki et al., 1985). Thus, most hearing losses in an elderly population can be explained at least partially by acquired, exogenous factors. The major exogenous factors are work-related noise exposure (in industry or the military), or acquired disorders of the ear (including middle ear disease, ototoxicity, Meniere's Disease, labyrinthitis, etc.). Hearing loss attributed to these otologic conditions is called 'nosocusis' (Kryter, 1983), and accounts for an average increase in mean pure tone thresholds of 6 dB at all frequencies (Burns et al., 1977).

Hearing loss associated with exposure to everyday noises ('sociocusis') also affects pure tone thresholds of elderly people. Individuals living in industrialized societies are known to have poorer thresholds than age and sex-matched individuals living in noise-free societies (Kryter, 1983). Pure tone thresholds of individuals of various ages living in a noise-free environment reflect 'pure' presbycusis and are shown in figure 5. These thresholds are averages from male and female data because there were no inherent gender differences with

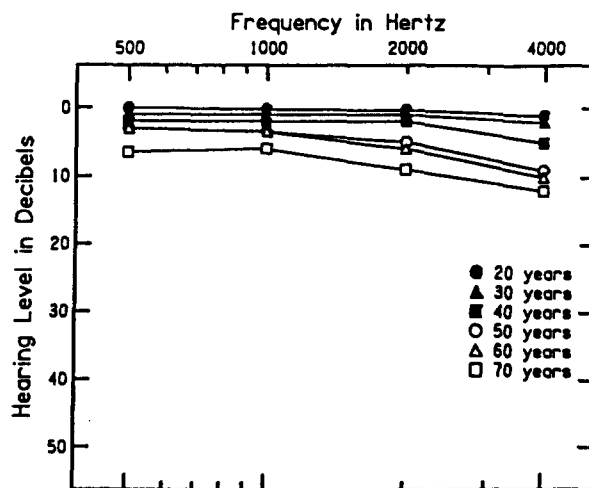


Fig. 5. Pure tone thresholds of males and females, in a noise free society, as a function of age. Constructed from data of Kryter (1983).

aging, and indicate that presbycusis produces a slight hearing loss. Other factors in addition to everyday noise exposure may contribute to differences in pure tone thresholds between elderly individuals in industrialized and non-industrialized societies. Possible risk factors for hearing loss in our society include diet, multiple medications, cardiovascular disease, and arteriosclerosis.

The shifts in air conduction pure tone sensitivity with age discussed above are usually accompanied by equivalent shifts in bone conduction pure tone sensitivity (Goetzinger et al., 1961; Marshall et al., 1983), reflecting a pure sensorineural hearing loss. This type of hearing loss is generally not treatable with medical intervention. In some cases, a conductive component may be present in addition to the sensorineural hearing loss (Milne, 1977; Moscicki et al., 1985). A conductive lesion may result from active middle ear pathology or senescent changes in the middle ear system, and may be treatable with medical intervention.

#### *Speech recognition*

Suprathreshold speech recognition is an indication of the distortion effects imposed by the hearing loss in perceiving speech, when the loss of

sensitivity is compensated. Speech recognition scores are useful for diagnosing peripheral site of lesion, for predicting benefits of amplification, and for determining the need for aural rehabilitation.

#### *Quiet backgrounds*

Speech recognition scores for monosyllabic word stimuli presented in a quiet background appear to decrease with increasing age (Goetzinger et al., 1961; Jokinen, 1973). These findings are attributed in large part to the confounding effects of increasing sensitivity loss among the older subjects coupled with insufficient speech presentation levels.

Age differences in recognition in quiet backgrounds are not significant at high presentation levels. Gordon-Salant (1987a) compared word recognition of groups of young and elderly listeners matched for normal hearing and sensorineural hearing losses at two high presentation levels. The results showed no significant age effects for normal and hearing-impaired groups. Jerger and Hayes (1977) reported maximum word recognition scores obtained from performance-intensity functions of 204 subjects with cochlear lesions. The maximum scores indicate no systematic decreases in performance between age 35 and age 85 years.

#### *Noisy backgrounds*

Is the speech recognition of elderly listeners in noisy backgrounds more adversely affected than that of younger listeners? The usual test consists of presenting monosyllabic word stimuli at fixed presentation levels (usually 30–40 dB above threshold), in a background of noise at a fixed intensity level (i.e., fixed signal-to-noise ratio, or S/N) (Jokinen, 1973). Test subjects with pure tone sensitivity typical of their age group show performance decrements as age increases.

As with speech in quiet backgrounds, differences in threshold sensitivity combined with insufficient presentation level contribute to the apparent age-related deficit. Also, direct masking by the low-frequency noise energy affects low-frequency hearing, where elderly subjects have their better thresholds. High-frequency energy, available to younger subjects, is unavailable to the elderly subjects because of the age-associated high

frequency loss in combination with an insufficient presentation level. When recognition tests are presented at high levels in fixed S/N conditions to young and elderly subjects who are matched for pure-tone sensitivity, no consistent age-related differences in performance are found (Gordon-Salant, 1987a).

Greater stimulus difficulty increases age-related performance differences in noise backgrounds. The Speech Perception in Noise (SPIN) test consists of high-predictability (HP) sentences, which provide contextual information to cue the final test word of the sentence, and low-predictability (LP) sentences, which use a neutral sentence context prior to the test word. Noise in the SPIN test is a 12-talker babble. Dubno et al. (1984) determined the S/N ratio required for 50% criterion performance by young and elderly normal and hearing-impaired subjects. They found a significant age effect for the LP sentences, but not for the HP sentences. Thus, combining a difficult stimulus material in noise with the adaptive S/N ratio procedure created added stimulus and task complexity, sufficient to reveal age-related performance differences.

#### *Reverberation*

Reverberation is a prolongation of sound which often occurs in large rooms having walls, ceiling and floor composed of hard, smooth surfaces. Reverberation is defined as the number of seconds for a sound to decay 60 dB below its steady-state value after termination. Nabelek and Robinson (1982) tested recognition performance for speech presented at three reverberation times by subjects between 10 and 72 years of age. Recognition was poorer for subjects age 60 years and older. However, high frequency loss was present in the older subjects. Hearing impairment has been shown to reduce speech intelligibility in reverberant conditions (Nabelek and Mason, 1981). Consequently, possible differences in stimulus audibility between young and elderly subjects may confound interpretation of the significant group effects. Harris and Reitz (1985) reported that the effects of reverberation were more detrimental to elderly subjects than to younger subjects when noise was added. Moreover, hearing-impaired elderly subjects were more adversely affected than were

elderly subjects with normal hearing. Thus, regardless of specific age-associated differences, speech recognition performance by elderly individuals is reduced in difficult, everyday listening situations that include reverberation and noise.

#### *Fast speech*

Speeded speech is characterized acoustically by a reduction in the duration of phonetic segments (i.e., vowels and consonants) and the duration of interword pauses (Picheny et al., 1986). Moreover, cognitive theories of aging propose a generalized slowing of mental and/or perceptual processing (Birren et al., 1980; Salthouse, 1985). Both factors could cause elderly listeners to experience particular difficulty recognizing rapidly presented speech.

Laboratory methods for studying the effects of speeded speech utilize a method of time compression (Fairbanks et al., 1954), that speeds speech without producing spectral distortion. Elderly subjects usually perform more poorly than younger subjects on time-compressed speech tests (Konkle et al., 1977; Schon, 1970; Sticht and Gray, 1969). However, hearing sensitivity in the higher frequencies varied systematically with age in these previous studies. High frequency hearing loss among young listeners is known to have a detrimental effect on recognition of time-compressed speech (Grimes et al., 1984; Harris et al., 1963). Thus, the performance of elderly subjects needs to be compared to that of younger subjects with matched hearing sensitivity in order to confirm the presence of a specific age effect. At least one study (Otto and McCandless, 1982) compared performances of young and elderly subjects with matched pure-tone averages on a time-compressed speech task. Young and elderly hearing-impaired subjects did not exhibit significantly different scores, although their scores were poorer than those of the young normal hearing subjects.

#### *Interventions*

According to the National Academy of Sciences (1990), the design of successful intervention strategies requires a three-dimensional approach that includes: (a) an assessment of the problems encountered in daily activities by the elderly population, (b) an analysis of specific task demands in relation to individual capabilities, and (c) basic

research on sensory and perceptual changes with age and on the ameliorating effects of emerging technologies. With respect to hearing, the problems faced by older individuals are multifaceted. As described earlier, these problems include reception of the speech signal, even in quiet. Elderly individuals also experience substantial difficulty understanding speech under less-than ideal conditions, such as noisy environments, reverberant environments, and listening to fast talkers. Unfortunately, these conditions characterize most everyday communication situations. The elderly person's difficulty in degraded environments may be linked to a sensitivity loss, a peripheral distortion problem, a central auditory processing disorder, and/or cognitive decline (Jerger et al., 1989). Hence, solutions to these problems are complex, and ultimately need to be developed on an individual basis.

Efforts have been made to assess the elderly individual's perception of his/her own communication difficulties. Perhaps the best known scale developed for the non-institutionalized elderly is the Hearing Handicap Inventory for the Elderly (HHIE) (Ventry and Weinstein, 1982). It consists of 25 items assigned to two subscales that sample social/situational effects and emotional effects of the hearing loss, respectively. Some of the specific hearing problems encountered by elderly individuals, as reflected in the test items selected for HHIE, include difficulty hearing a spoken message in group situations, in noisy environments, and in large auditoria. Each of these situational difficulties potentially affects the elderly person's function in daily activities.

#### *Intervention strategies*

The foregoing analysis suggests that intervention strategies toward improved auditory function for elderly individuals require an increase in signal level, a decrease in noise level, a reduction in reverberation time, and expansion of the duration of a spoken message. Fortunately, these methods should improve speech understanding for younger individuals as well. The methods that currently exist to accomplish some of these goals include signal amplification and processing, environmental control, and training. This section will describe



the various intervention strategies that are available, as well as their associated benefits and limitations.

#### *Personal hearing aids*

The primary means of surmounting the negative impact of a hearing loss involves the use of a hearing aid. Traditional hearing aids are known as 'analog' devices. 'Analog' refers to the voltage created by the microphone transducer, which is an exact analog of the input signal. The analog voltage can then be filtered, amplified, limited, and transduced by the receiver into an acoustic output signal. Hearing aids are usually selected on the basis of gain/frequency and saturation sound pressure level (maximum output level) to amplify the incoming speech signal to target levels that would enable the user to hear all speech sounds at comfortably loud levels.

Unfortunately, the amplification characteristics may limit the usefulness of analog hearing aids for some potential users. First, environmental noise and the target speech signal are both amplified. The effective S/N of the amplified signal is usually comparable to the environmental S/N, which can be detrimental to speech intelligibility. Second, the signal received by the hearing aid may have been subjected to reverberation. Typical reverberation times of acoustically untreated rooms (0.6–1.2 sec) produce speech recognition deficits among elderly individuals (Nabelek and Robinson, 1982). Moreover, studies have shown that hearing-impaired listeners using hearing aids exhibit decrement in recognition scores with increases in reverberation time (Nabelek and Mason, 1981). Third, difficulty in speech processing often accompanies hearing loss. Amplifying the speech signal doesn't aid the clarity of the signal if transmitted through an internal system with high distortion. Fourth, acoustic feedback, a high-pitched squeal, is generated by the hearing aid as a result of amplified sound being re-amplified. It occurs because the earmold or hearing aid doesn't fit tightly in the ear canal, allowing amplified sound to leak out of the ear canal and be picked up again by the hearing aid microphone.

About 50% of individuals aged 65 years and over use their hearing aids continuously (Bender and Mueller, 1984; Upfold and Wilson, 1983), and between 20% and 25% don't use them at all. The

highest ranked reasons for not using hearing aids are cost, amplification of noise, and sounds too loud (Franks and Beckman, 1985). The focus of the necessary improvements in hearing aids should be their functioning in poor acoustic environments.

Perhaps the most promising development in hearing rehabilitation technology is the digital hearing aid. It is a wearable computer that digitizes the electrical output of a microphone, modifies the signal by a microprocessing unit, converts the digitized signal to an analog signal, and delivers it to the hearing aid receiver.

Several so-called digital hearing aids have been developed and marketed. Most of them are more accurately described as 'quasi' digital instruments that use a digital control mechanism to adjust the performance of an essentially analog circuit. The hybrid circuitry uses digital technology to sample the ongoing voltage in the circuit, and to control the gain, filtering, or output limiting parameters of the hearing aid. These hearing aids offer advantages over analog hearing aids in terms of better precision in hearing aid fitting, acoustic feedback control, and greater flexibility in frequency response.

One type of hybrid circuit incorporates an adaptive noise filter that samples the incoming signal for noise, and selects filter characteristics to reduce the bandwidth of the amplified signal if noise is detected. The theory is that everyday noise is composed of aperiodic low frequency energy; hence, the adaptive filter's reduction of the signal bandwidth would restrict amplification of low frequency energy (i.e., noise) and thereby improve the S/N. Two recent studies evaluated hearing-impaired listeners' word recognition performance in noise using one type of adaptive noise filter, the Zeta Noise Blocker (Graupe et al., 1986). Both studies found that recognition performance in noise did not improve with the filter activated when there was spectral overlap between the speech information and noise energy (Klein, 1989; Van Tasell et al., 1988). Other types of adaptive noise-rejection filters, as well as other digitally-controlled components in quasi-digital hearing aids, are appearing on the market. The effectiveness of each new device needs to be evaluated with elderly hearing-impaired listeners to determine if anticipated benefits are supported empirically.

### *Assistive listening devices*

Assistive listening devices include a variety of electronic devices that aid communication for hearing-impaired listeners. One class of assistive listening device includes amplifying systems that are not personal hearing aids. The amplifying systems are especially useful because they improve the effective S/N and reduce the effects of reverberation.

Amplifying systems use a microphone located near the signal. In an FM system, the signal is then transmitted to a frequency-modulated signal, demodulated by a receiver, amplified, and delivered to the user's ear through an earphone. The signal received at the earphone is essentially the signal that was generated by the source, and therefore retains a good signal-to-noise ratio. Because the signal is not transmitted through the environment, it is not affected by reverberation. Speech intelligibility is significantly better with FM systems than with personal hearing aids in rooms with better-than-average S/Ns and reverberation times (Hawkins, 1984). However, if an environmental microphone is turned on, then the benefits of the FM system are reduced. The amplification system described can stand alone or can be used in conjunction with a personal hearing aid.

In addition to FM transmission, other adequate systems include hardwire induction loop and infrared systems. Infrared systems transmit the signal through infrared 'radiators' situated in the room, which preserve excellent signal quality at the receiver. However, infrared rays from the sun can interfere with this form of transmission, restricting the use of infrared systems to theaters and auditoriums without windows. Hardwire systems can be used individually with a television set, or in group settings with permanently fixed chairs to increase the intensity of the signal and improve the S/N.

In recent years, group amplification systems have been installed for elderly individuals in nursing homes and other environments. These systems should effectively improve receptive communication for the elderly hearing-impaired individual, without altering the environment for normal-hearing people. There are a few limitations of these systems, however, including minimum flexibility of amplification characteristics, and changes in amplification characteristics when interfaced with

a personal hearing aid. Installation of the group systems also requires careful planning. A pressing need is adequate training of individuals in the use and maintenance of these systems.

### *Environmental control*

Environmental control is directed toward reducing background noise and reverberation. These goals are achieved with preventive measures during the planning of new facilities and with noise/reverberation reduction measures in existing facilities.

Noise prevention in new facilities can be implemented easily and economically (Nabelek, 1985). Some suggestions include locating the new facility far from existing noise sources (e.g., highways and airports), selecting quiet machinery for heating, air conditioning and ventilation, enclosing noisy machinery in separate sound absorptive chambers, and installing steel doors and double-pane glass windows. Soft, porous, absorptive materials covering hard surfaces also can be used to reduce sound reflection and reverberation in rooms. Appropriate materials include acoustic tiles (ceiling), carpeting (floor), curtains (windows), and textiles (walls). Couches and chairs that are upholstered with porous fabric will also help absorb reflections of energy in a room.

Controlling noise and reverberation in an existing facility is accomplished by reducing sound production and transmission from a noise source, reducing radiation of vibrations from a noise source in the building, and reducing the amount of sound reaching the receiver from the air (Teplitzky and Paolillo, 1984). Machine noise may be reduced by maintenance, part substitution, or enclosure. Vibration transfer from the source is reduced using mounts to isolate the source from the supporting structure. Sound reflections in a room can be minimized by absorbing incident energy at the walls, floor, and ceiling. In particular, floor carpeting absorbs high frequency sound, whereas sound absorbers suspended from the ceiling absorb a wide range of frequencies. Finally, gasketing placed around doors, pipe openings, and cracks reduces transmission of sound into the room.

Acoustically acceptable rooms should improve speech intelligibility, especially when older, hearing-impaired people use hearing aids. According

to Plomp and Duquesnoy (1980), an acceptable reverberation time for elderly subjects with an average hearing loss of  $X$  dB for speech in noise is  $(0.75)X$  in auditoria and classrooms, and  $(0.82)X$  for lounges and restaurants. For example, if the average hearing loss for speech is 5 dB, then the reverberation time requirement in an auditorium is 0.25 sec. The data of Plomp and Duquesnoy also indicate that an adequate S/N for speech intelligibility by elderly listeners is +15 dB. Since the level of average conversational speech is 65 dB SPL, background noise should be maintained at 50 dB SPL or less to produce an average S/N of 15 dB. It should be noted that the average S/N is estimated at +8 dB (Pearsons et al., 1977), and the average reverberation time is approximately 0.6 sec (Hawkins and Yacullo, 1984). Thus, environmental controls for reduction of noise and reverberation are necessary if elderly hearing-impaired individuals are to use their hearing aids effectively in most enclosed rooms.

### *Training*

Aural rehabilitation refers to training techniques employed with hearing-impaired adults to improve receptive communication. These techniques include speech-reading training, auditory training, and counseling. Often, these components of aural rehabilitation are combined into a comprehensive training program.

In speech-reading an individual is taught how to capitalize on all visual cues during communication, including lip movements, facial expressions, gestures, and the environment. Speech-reading lessons for senior citizens usually acquaint the participants with speech-reading problems and hints to improve speech-reading performance.

Auditory training involves a series of activities during which the acoustic environment changes gradually from optimal to poor. The goal is for participants to make better use of their residual hearing, with or without a hearing aid. Lessons typically begin with the discrimination or identification of gross environmental sounds and progress to discrimination of discrete sounds in words. Listeners are taught to rely on contextual cues and knowledge of the topic of conversation.

The counseling component of the aural rehabilitation process mimics a group therapy situation, with specific discussion about attitudes and behav-

iors related to the hearing loss. Participants are encouraged to modify the listening situation to their best advantage by requesting that music be turned lower, requesting that the speaker face them when talking, or moving their own seat to be closer to the speaker. The hearing-impaired person can also request that the talker speak more clearly. Research conducted at MIT has shown that naturally produced 'clear' speech does improve speech intelligibility compared to 'conversational' speech for hearing-impaired listeners (Picheny et al., 1985). Role playing may be used to demonstrate why a breakdown occurs in communication, and to suggest appropriate strategies for improving the situation. Most aural rehabilitation programs for senior citizens also provide consumer-oriented information about hearing aids, assistive listening devices, and professional services.

Aural rehabilitation programs for the elderly are underutilized; McCarthy (1985) estimates that less than 25% of hearing-impaired elderly receive them. The major reasons for this underutilization are lack of awareness of services, advice that services are of little benefit, limited financial resources, and lack of professional referrals (Hardick and Gans, 1982; Shadden and Raiford, 1984). Educating the public and professionals about hearing rehabilitation services is essential to increase the utilization of these services by elderly hearing-impaired individuals who could benefit substantially from them.

### *Future directions and research needs*

Digital hearing aid technology will undoubtedly revolutionize hearing rehabilitation for elderly hearing-impaired people in the coming decade. One pressing issue is the specific software needed for these devices to achieve improved speech intelligibility in realistic environments. The research of Picheny et al. (1986) on speaking clearly for the hearing-impaired provides some clues for speech processing schemes. These researchers found that the acoustic modifications in clear speech are increases in the duration of speech phonemes, increases in interword pause time, and increases in consonant energy relative to vowel energy, or consonant-vowel ratio (CVR). Gordon-Salant (1986, 1987b) assessed the relative benefits of increasing consonant duration and increasing CVR

on digitally-modified nonsense syllables for elderly listeners with normal hearing and mild-moderate sloping sensorineural hearing losses. The consonants were the target speech phonemes because they are the information-bearing elements of speech. Unmodified and modified nonsense syllables were presented at two high levels in a background of multiple talkers. The results indicated significant improvements in nonsense syllable recognition over the unmodified nonsense syllables with CVR increments, but not with consonant duration increments. Additional research is needed on the benefits of CVR increments incorporated in more realistic speech materials. The benefits of other types of speech modification schemes for elderly listeners also need to be explored. For example, increasing pause time between words effectively increases the total message duration, and therefore may help the elderly individual with a slowed speed of mental and perceptual processing.

The dizzying array of potential quasi-digital hearing aid options, including an infinite number of programmable hearing aid parameters, requires refined protocols for hearing aid selection, especially for older individuals with limited attention. Once the major complaint of hearing difficulty is identified, the underlying cause of the problem (sensation, perception, cognition) also needs to be identified. Valid and reliable behavioral tests will need to be developed that evaluate the usefulness of simulated hearing aid characteristics, in order to identify hearing aid parameter settings that are most beneficial. Continued development of the wearable master hearing aid and its associated protocol (Levitt et al., 1976) is a most promising tool for this purpose. Computer simulations of different acoustic environments (i.e., reverberation, fast talkers, poor S/N) need to be developed to verify rapidly the most significant performance problems.

Future progress toward improving communication for senior citizens requires rigorous research on all of the intervention strategies presented. Few controlled studies have assessed the effectiveness of assistive listening devices, hearing aids, environmental controls, and aural rehabilitation programs for elderly individuals. Efficacy studies should evaluate realistic benefits of each method for improving speech intelligibility in poor acoustic en-

vironments for this population. Moreover, the long-term benefits of these methods, in terms of daily function, need to be validated with the elderly. A critical need is basic science aimed at understanding the effects of age-related peripheral distortions, central auditory processing disorders, and cognitive decline, and the interactions of each with different acoustic environments. Finally, effective strategies must be developed for improving attitudes about hearing aids and other rehabilitative techniques. Education of hearing-impaired individuals, their families, and particularly professionals dealing with hearing-impaired elderly individuals is essential for successful utilization of any intervention method.

## **Taste and smell**

In considering differences in eating behavior between younger and older individuals, it is critical to determine the nature and extent of age-related changes in the sense of taste, smell and other senses that cooperate with taste in the control of ingestion. Until recently no data on thresholds in relation to age were available (Stahl, 1973). Since feeding is more than a sensory event, age differences in cognitive, emotional, social and behavioral factors must also be considered.

### *Taste thresholds*

Older persons demonstrate reduced taste sensitivity when sensory function is assessed by taste thresholds (Weiffenbach, 1984). The taste threshold is the minimum stimulus strength required to detect or recognize simplified stimuli representative of the four basic taste qualities. Threshold measurement has reached a level of sophistication that supports remarkable agreement between studies with respect to the baseline sensitivity of young individuals and only slightly less agreement concerning changes with age (Weiffenbach, 1987). While it is clear that taste threshold sensitivity does not decline uniformly for all substances, the pattern of quality specific age differences varies from study to study. For example, Weiffenbach et al., (1982) report that average threshold sensitivity declined for the salty and bitter tastants while the thresholds for sweet and for sour stimuli were age

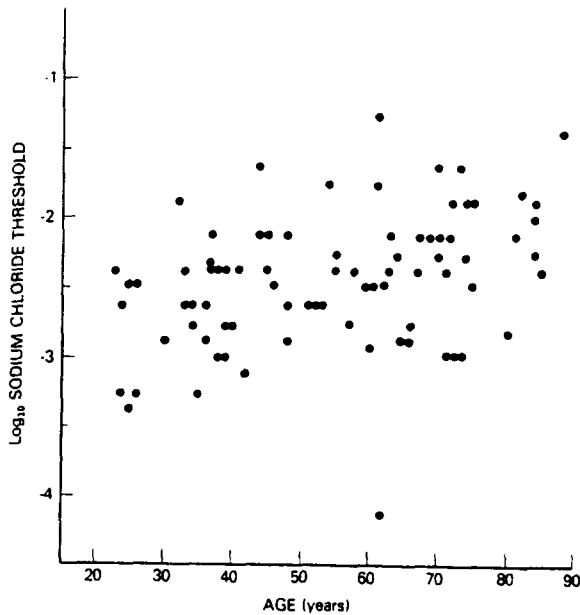


Fig. 6. Taste detection thresholds for sodium chloride obtained from 42 men and 39 women demonstrate a significant increase as a function of age. Reproduced with permission from Weiffenbach, Baum and Burghauer (1982), *Journal of Gerontology*, 37, 372–377.

stable (see figures 6 and 7). Very few subjects showed generalized loss. While thirty-eight of the 145 subjects had threshold sensitivity below the tenth percentile for at least one quality, only six of these individuals displayed reduced sensitivity for more than one quality. More importantly, reductions in threshold sensitivity are small and likely to have only limited impact on important environmental interactions. Taste threshold changes, when they occur, have little practical effect because the taste system rarely functions as a detector of weak stimuli in everyday life. The more common use of this sensory system is to provide information on the strength of clearly detectable tastes.

#### *Intensity judgments*

Direct scaling procedures assess intensity perception by requiring subjects to judge the taste intensity elicited by stimuli at various strengths clearly above threshold. The rate at which subjective intensity increases is traditionally quantified by the slope of the psychophysical function relating the logarithm of intensity judgments to the logarithm of stimulus strength (Stevens, 1956).

Marked differences between younger and older individuals with respect to the slope of the psychophysical functions for taste have not emerged (Weiffenbach, 1987). Although group functions for older individuals may have only marginally shallower slopes, other age-related differences have been noted. The group functions for older individuals may, for example, be differently shaped. Variant functions in which older subjects give relatively reduced responses to stronger stimuli (Cowart, 1982) or augmented responses to weak ones (Bartoshuk et al., 1986) have been reported.

Although average functions usually fail to show overall age differences, the performance of individual elderly subjects may deviate substantially from that of the group. Some of these individuals give intensity judgments that are so poorly related to stimulus strength as to suggest that usable information on stimulus strength is not available to them. In one study, nine of 170 subjects who had performed direct scaling of four taste substances generated functions that failed to rise monotonically with stimulus strength for at least one taste category (Weiffenbach et al., 1986). Such severe deficits in the appreciation of taste intensity are most frequent among older men and usually

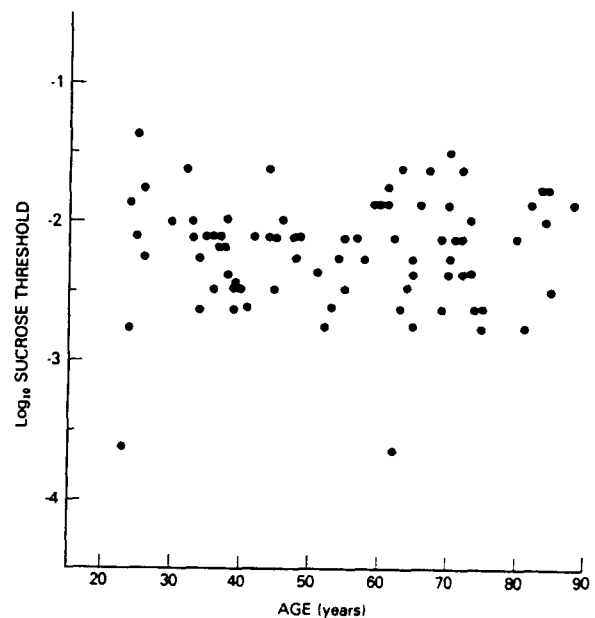


Fig. 7. Taste detection thresholds for sucrose obtained from 42 men and 39 women show no significant changes with age. Reproduced with permission from Weiffenbach, Baum and Burghauer (1982), *Journal of Gerontology*, 37: 372–377.

affect judgments of bitter substances. However, it is clear that only a limited portion of the population is affected.

In the study just cited older individuals showed greater variability on repeated presentation of taste stimuli than did younger persons. These deficits in the consistency of intensity judgments from presentation to presentation are quality specific. As a group, older people demonstrate significant declines in the consistency of their judgments for salty, sour and bitter but not for sweetness. Elderly individuals who fail to make orderly judgments of one taste quality may perform adequately for another. Thus, their poor performance cannot be attributed to a generalized inability to perform the judgment task. The clear inference is that sensory registration for the affected quality is inadequate to support reliable performance.

#### *Other taste-related senses and age changes*

Other senses cooperate with the sense of taste in the control of eating. Food stuffs commonly stimulate not only the oral chemosensors responsible for taste per se but also provide airborne stimuli to olfactory or nasal trigeminal chemoreceptors.

#### *Nasal chemosensitivity*

Older individuals are less able to identify airborne stimuli (Doty et al., 1984) and demonstrate decrements in the perceived intensity of odors. Moreover, when the intensity of representative odor and taste stimuli are judged during a single testing, the decline with age for odor is significantly greater than that for taste (Stevens et al., 1984). In addition to the decline in odor intensity, older individuals have been shown to have reduced appreciation of the intensity of other airborne stimuli. Specifically, they show decrements in the perceived intensity, not only for odor, which is mediated by the first, or olfactory nerve, but also for pungency or irritation, which is elicited by stimulation of nasal chemoreceptors of the trigeminal or fifth cranial nerve. Interestingly, a study using iso-amyl butyrate to elicit a non-irritating, fruity odor and CO<sub>2</sub>, which is essentially odorless, but elicits pungency, showed that age-related declines in function for these two nasal chemosensory systems are independent of each

other (Stevens et al., 1982). Such laboratory findings do not, of course, establish the functional significance of the observed loss.

An association between reductions in nasal chemoreception and reduced appreciation of food is demonstrated by the altered food perception that commonly accompanies the stuffy nose of a head cold. To show that loss of sensitivity to airborne stimulation underlies the reduced perception of food stuffs by the elderly requires more complex experimental observations. In a two-phase study Murphy (1985) showed that older subjects were initially inferior to younger ones in recognizing or identifying pureed foods and judged them to be less intense. This perceptual disadvantage was then shown to depend on the older subjects' relative insensitivity to airborne stimulation by subsequent tests which required all subjects to hold their noses while 'tasting' the stimuli. Under these conditions, which reduced the access of both groups to airborne stimuli, the younger group lost the advantage of their greater nasal sensitivity and their performance deteriorated toward that of the older group. Thus, not only is sensitivity to airborne stimulation reduced with age but the reduced sensitivity affects dining relevant perceptions.

#### *Non-taste oral stimuli*

Just as nasal chemosensitivity includes both olfaction and nasal trigeminal components, oral chemosensitivity includes both taste and oral trigeminal ones. The prototypical sensation associated with oral trigeminal chemostimulation is the burn or tingle produced by capsaicin, the active factor in chili peppers. Alcohol and CO<sub>2</sub> also activate oral trigeminal sensitivity. To study the effects of age on this type of oral chemosensitivity it is desirable to compare oral trigeminal chemosensitivity with sensitivity to the oral chemosensory stimuli that elicit taste.

In common parlance taste specifies the whole of ingestive chemosensory experience or at least the whole of its oral component. Yet the mouth is clearly sensitive not only to taste and oral trigeminal stimuli, but also to other non-chemosensory characteristics of food samples. For the present, sensitivity to stimulus characteristics such as temperature, volume and viscosity and to the number, size, hardness, brittleness, etc. of individual food

particles must be specified in terms of the eliciting stimulus since the receptor mechanisms for these complex perceptions are unknown. A recent study conducted by Weiffenbach et al. (1990) contrasting the effects of age on taste, temperature, touch and viscosity represents an initial attempt to characterize age changes in underlying nonchemosensory mechanisms of oral perception associated with feeding.

#### *Dysomia and dysguesia*

Sensory changes other than reductions in sensitivity may occur and affect the environmental interactions of the elderly. Sensory experiences occurring in the absence of an appropriate stimulus include unpleasant odors which no one else can smell, as well as bad tastes that are present independent of eating or other oral stimulation. These conditions, dysomia and dysguesia respectively, can be very distressing and elicit persistent care seeking. Like chronic pain, they motivate multiple visits to doctors, clinics and hospitals over extended periods of time. Similar anomalous experience may be generated by a disordered neural system or result from some condition that makes persistent stimulation available to the receptors of a normally functioning sensory system. In general, if the taste can be reduced by rinsing or the smell reduced by closing the nostrils, some substance is 'causing' the experience and treatment can be directed toward identifying and eliminating it. The possibility that the incidence of dysguesia may increase with age has recently been raised by the observation that older individuals are more likely than younger ones to give positive intensity ratings to water (Bartoshuk et al., 1986).

#### *Oral complaints and intervention*

##### *Taste*

Oral complaints and complaints referred to taste increase with age (Cohen and Gitman, 1959). As in other cases of age-related alterations, it is desirable to separate complaints due to normal aging from those associated only casually with age (Shock, 1988). This distinction has practical implications for dysfunctions associated with treatable diseases or conditions which differentially affect the elderly. For the purpose of designing interventions, it is also desirable to characterize com-

plaints with respect to their sensory base. Is the disruption caused by a sensory change and if so does it affect taste, olfaction, trigeminal or non-chemosensory oral sensitivity? Alternatively, is the dysfunction caused by determiners of behavior not directly involving any of these sensory systems, and might manipulation of some nonsensory influence ameliorate it?

The taste system is generally robust with age. The age-related declines in sensitivity measured in the laboratory are slight or have questionable relevance to ingestive experience. When a taste loss occurs, intervention is handicapped by the absence of specific or effective therapies. Taste loss that may be sufficient to interfere with or reduce the appreciation of food is likely to be quality specific and to affect only a restricted portion of the population. This implies that environmental manipulations or interventions should be specific to an individual's altered sensory function. In one successful intervention to reduce overall sodium intake, individual differences were taken into account by allowing each individual to add seasoning at the table to the reduced sodium meals they all were served (Beauchamp et al., 1987). However, since most older individuals appear to escape declines in the sense of taste which affect their ingestive experience, one might well look to other sensory and nonsensory determiners of 'taste' complaints.

##### *Smell*

Age-related declines in nasal chemosensation that affect the perception of foods arise either from a decline in the sensitivity of the receptors or a reduction in the number of stimulus molecules reaching them. One practical intervention strategy is to manipulate the concentration of the effective stimulus. Increasing the strength of airborne stimuli by adding essences to taste stimuli has been tried and appears to be an effective countermeasure against the reduced nasal sensitivity of the elderly (Schiffmann and Warwick, 1988). Even in the absence of any change in the effective stimulus, it might be possible to increase the effect of the residual sensations by techniques which increase the capacity of the elderly to respond to them meaningfully (Schempter et al., 1981). Some anosmics, for example, find they still enjoy eating out; eating at a good restaurant provides other

sensory inputs which are capable of reinstating much of the pleasure that they once derived from olfaction.

Even in the absence of chemosensory loss, many elderly suffer reduced appetite and thus are exposed to nutritional risks and experience the associated alterations in quality of life. Interventions to alleviate geriatric anorexia (loss of appetite) or weight loss arising from other than chemosensory dysfunction may borrow with caution from successful models developed for younger populations. For example, treatment of depression is an equally appropriate strategy for the depression associated with anorexia in older as well as younger individuals. Bereavement anorexia, feeding problems associated with ill-fitting dentures or difficulty with bolus formation and swallowing may be age-related but require individualized intervention. Whether there exists a truly generalized anorexia of the elderly is an open question.

Hunger and thirst may call for substitution of an external control mechanism for the dysfunctional internal one. Responsibility for meal initiation may, for example, be taken over by the caregiver, or the community dwelling elderly may establish a clear schedule for meals and snacks. On the other hand, the elderly may be faced with circumstances which provide unusual challenges to even adequately functioning regulatory mechanisms. For example, the reduced appetite of older individuals living in institutions may be due to objective differences between institutionally prepared and home-cooked meals.

Older individuals may also chew the food available to them less efficiently. If age-related declines in oral motor function or inadequate dental prostheses reduce the efficiency of mastication and bolus formation, access of food stuff to chemosensors may be reduced. In this regard it is worth noting that the production of saliva which participates in the actual delivery of stimuli to the oral sensors is not measurably impaired by age alone (Baum, 1989).

#### *Meal preparation and serving*

Meal preparation has received specific attention in two stimulating books. The first (Fishman and Anrod, 1982) emphasizes the preparation of calorically dense, easily ingestible menu items which can be prepared in advance and dispensed

easily. The other is specifically applicable to both home and institutional settings detailing practical techniques for making meals attractive (Breslin, 1988). It is possible, for example, to present pureed food, not as mush reminiscent of baby food, but as a visually substantial item molded into an appropriate shape.

The importance of the social and emotional context of dining was illustrated in the course of an intervention directed at altering cognitive, affective and social functioning by means of increased sensory stimulation (Loew and Silverstone, 1971). Severely deteriorated male patients (80 to 96 years of age) on one ward received extra attention and stimulation relative to appropriate controls on another ward. The patients receiving the experimental enrichment were encouraged to gather in groups of four at mealtime rather than eating alone at their bedsides. In a ten-month follow-up interview, feedback from the staff emphasized the eagerness of these patients to group around card tables for meals.

Designing effective interventions to support the taste mediated environmental interaction of the elderly is complex because geriatric chemosensory loss is neither unitary nor occurs generally in the population and because the determiners of oral ingestion are multifaceted. Taste loss has a less severe impact on wellbeing than does loss of sensitivity to airborne stimuli because the loss itself is less marked. Reduced sensitivity to airborne stimuli is clearly a potential contributor to reduced appetite. Nasal trigeminal chemosensitivity appears, like olfaction, to decline with age but the two sensitivities are independent. Age effects on oral trigeminal chemosensitivity are not yet defined. Interventions which increase the concentration of airborne stimulants are promising. Modification of the environment in light of age-related changes in the functioning of biological regulatory mechanisms may include alteration in the physical, social and psychological environment in which eating takes place.

#### **General discussion**

The results of the present survey indicate that there is no single 'aging' problem either within or across the sensory and perceptual systems dis-



cussed. There are, however, several opportunities for helpful environmental interventions in all areas.

Three recommended environmental interventions in vision and hearing are based on the same principles: (1) increasing signal intensity; (2) enhancing contrast between signal and background by a variety of means; and, (3) decreasing visual (glare) or auditory (background) noise. The effects of context and of background or non-focal stimulation is also important in chemosensory perception. Enhanced visual contrast includes brightness, color and figural aspects as well as improvements in temporal contrasting elements. In hearing, contrast is enhanced by methods that improve the signal independently of the background.

The principle of increasing adjustability of light, sound sources and tastants by the user were mentioned as potentially useful environmental interventions (Fozard, 1981). Virtually nothing is known about the conditions under which such interventions might be used by the elderly to optimize sensory and perceptual experiences.

Interventions with people that were described include prosthetic devices, training and counseling, and medical treatment. The use of training and counseling as an intervention for the elderly seems most advanced in hearing although even there it is insufficient. To the extent that newer digital hearing aids overcome the limitations of currently used devices, it will decrease the need of training in lip reading and similar techniques to aid in speech understanding. The potential for useful medical and related interventions to alleviate age-associated sensory problems of elderly adults can increase a great deal. Improvements in fitting and maintenance of prosthetic devices, e.g., dentures and bifocal lenses, treatment of systemic medical problems which affect sensory experience, and screening for treatable sensory and perceptual related disease processes are all on the rise, thanks to developments in geriatric medicine and dentistry.

The National Academy of Sciences' (1990) recommendations for ergonomics/human factors research for older persons emphasized the need for good distributional data on tasks, problems and abilities; and, to perform detailed task analyses where the benefit is likely to be greatest (p. 66). All are relevant to the present topic, but perhaps

the major limitation of all of the literature reviewed is the lack of specific quantitative guidelines. In vision, only the engineering guidelines for illumination levels and, to a more limited degree those for contrast, included an age factor in its considerations. Some qualitative guidelines for glare were described. In taste and smell none of the guidelines take age into account (Stahl, 1973). Guidelines for acoustical engineering practice seldom include age as a design consideration. Whether or not the sensory problems of the elderly are uniquely age specific or simply represent extensions of those for 'normal adults', it is clear that engineering guidelines need to pay more attention to age as a design variable.

In none of the areas reviewed was there evidence that an intervention that would help the elderly would adversely affect the young. While such situations might occur in some specialized tasks, the tasks could be arranged so that the 'better' display could be overridden much in the way experts can bypass the menus which help the novice computer user.

The knowledge base concerning the changing sensory and perceptual capacities of older adults expanded tremendously during the last decade. Numerous opportunities for remediating age-related sensory deficits have been demonstrated for the domains of vision, hearing, taste and smell. The next decade should witness the widespread application of these data and opportunities toward improving the safety, efficacy and productivity of an industrialized population whose members continue to grow increasingly old.

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