Gerontechnology and perceptual-motor function:

New opportunities for prevention, compensation, and enhancement

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J.L. Fozard, Gerontechnology and perceptual-motor function:New opportunities for prevention, compensation, and enhancement, Gerontechnology, 2001; 1(1): 5 - 24.
This article reviews recent scientific literature on age-related declines in perceptual motor functioning in hearing, vision, and proprioception. The first goal of the review is to identify opportunities for multidisciplinary research and development efforts designed either to prevent or delay the loss of perceptual-motor function or to compensate for existing losses. The second is to identify ways in which technology can be used to support new opportunities for communication, artistic expression, education and work that often occur for older persons, particularly those who have retired. METHODS AND RESULTS: **Prevention**. Long-term intervention trials are proposed to prevent or delay age-related declines in hearing sensitivity and physical functioning as related to gait and balance. **Compensation**. Programs of environmental interventions and consumer education are proposed to compensate for age-related losses in the quality of auditory and visual images. Opportunities for improving the description of equal audibility and visibility functions as related to environmental interventions were identified. Programs combining environmental interventions and training are proposed for tasks requiring visual search, manual guidance, and gait and balance. **Enhancement**. Opportunities for increasing the use of technological products and environments to support social communication, group and individual artistic activities, work, and education were described. At present, research and development efforts in this area are limited; so the discussion of opportunities is based largely on informal observations and non-scientific sources. CONCLUSIONS: Research and development efforts using the combined scientific and engineering disciplines represented in gerontechnology can make a significant impact on reducing the negative consequences of age-related declines in perceptual-motor functioning. Such efforts can also be used to support activities that may improve quality of life for older persons. Together, such efforts will help create the "enabling environment for healthy aging" proclaimed during the 1999 United Nations International Year of the Elderly.

Key words: gerontechnology, aging, vision, hearing, proprioception, interventions

September 2001, Vol 1, No 1

www.gerontechjournal.net

The major concern of gerontechnology, an integrative discipline, is the development and distribution of technologically based products, environments, and services that improve functioning and quality of life for aging and aged persons. The phrase, "aging and aged," means that gerontechnology is concerned with how technological products and environments can influence the course of the aging process itself, not just affect persons in a particular age group. Applications of gerontechnology are based on five broad ways of using technology:

(1) to prevent or delay age-related declines in functioning;
(2) to compensate for existing age related limitations in functioning;
(3) to enhance enjoyment and participation in activities that for many older persons may result from changes in work and family responsibilities;
(4) to support the caregiver of disabled elderly persons with technology; and
(5) to improve applied and basic research on aging using technology that addresses the major scientific problems of gerontology[1].

The present review discusses the role of prevention, compensation, and enhancement as applied to age-related declines in perceptual motor functioning. Some proposed uses of gerontechnology for prevention are based on recently published research identifying modifiable health and lifestyle factors that contribute to age-related perceptual motor declines in hearing, vision, and proprioception. Technology is already widely used to compensate for age related losses in perceptual motor function, so the present review will identify recent research that could expand the range of applications. The use of technology for enhancement, i.e. the support of new opportunities in older age for self-expression, education, alternative work settings, social interaction, and artistic activities has received little attention--either from the point of view of development or evaluation of use. Accordingly, the opportunities to be discussed are based more on discussions with current users and experts and personal observation than published scientific data. With respect to activities related most directly to perceptual function, technological advances are occurring in virtual reality, simulators, and computer-aided devices for creating, altering, and combining sounds and images. These provide vast opportunities for creation of user-friendly technology for artistic and educational opportunities for older persons. A major barrier to using the technologies results from difficult user interfaces[2] for older persons.

A basic tenet of gerontechnology is that aging or aged consumers should be involved in the development and distribution of technological products--both directly through evaluation and advice during the process of product design and development, and indirectly through providing scientific information about user characteristics used in product design[1]. Many technological products and environments related to perception are particularly difficult for older persons to use. Recent advances in ergonomics of user interfaces, application of universal or inclusive design principles to product design, and improved ways of studying user behaviors in natural settings are improving the use and usefulness of technology by older persons. With respect to distribution, significant barriers to the use of beneficial technology by older persons continue. Some problems relate to poor consumer education and product information provided to the user; others result from exaggerations of product usefulness in advertising. For example, aggressive advertising and marketing of hearing aids in the USA sometimes create difficulties in procedures to match user to hearing aids.

The present review represents a snapshot of a dynamic, rapidly changing interplay between the aging processes of people and the continuous changes in the physical and social environment in which they age. The definition of aging itself is undergoing continuous change. Examples of processes that fit the traditional biological definition of aging as universal, time-dependent, and irreversible are increasingly harder to find. Even the widely-held belief that there is predictable period of increased morbidity prior to death, sometimes referred to as the fourth age, is a topic of scientific controversy[3]. The natural history of scientific knowledge obtained from repeated observations of the same persons as they age, indicates that aging as an explanatory concept is increasingly being replaced by more specific concepts about the influences of environmental or non-universal pathological factors. So pervasive is this trend that some scientists believe that aging is defined 'by default' after other contributing factors have been taken into account[4]. Increasing numbers of studies that appear to alter biological aging through genetic and pharmacological interventions also challenge the concept of the universality of aging.

The environment in which people age is also changing at a rapid rate, changes driven largely by developments in technology as reflected in the built environment and technology of materials, communications, and transportation. The interplay between knowledge about aging and the changes in the environment in which people age means that the application of the concepts of prevention, compensation, and enhancement that will be discussed in the present review will certainly change in the next few years.

PREVENTION

Aging is universal but not uniform either within or across physiological systems. Many aspects of physical aging can be modified or retarded, usually by early intervention--primary prevention. There is now a reliable literature demonstrating that significant changes in diet, exercise, and smoking cessation decrease morbidity and mortality and increase independent functioning in middle aged and elderly adults[5]. Longitudinal studies of cardiovascular health in children[6,7] have shown that variations in diet, exercise, and other lifestyle factors during childhood and adolescence affect cardiovascular health measured in young adulthood.

The opportunities for prevention in hearing and vision to be proposed relate to the long-term control of exposure to potentially damaging environmental noise and light and to cardiovascular health. The idea of postponing or preventing 'normal' age-associated declines in perceptual motor function is relatively new; definitive scientific evidence justifying consideration of such efforts has only recently become available. The exception is the use of prevention of sensory problems that are secondary to other age-associated diseases such as Type 2 diabetes or hypertension. Intense light and sound are known to exacerbate if not cause age-related losses in visual and hearing acuity[8]. However, in everyday activities, the levels of intervention needed to protect people from potentially damaging effects is poorly understood with respect to the efficacy of preventive measures such as tinted spectacles and hearing protectors. The exposure to intense sounds is increasing with the use of personal amplifying devices for recorded music and some recreational activities. It will be proposed to use technology for long-term monitoring of exposure to environmental noise as part of an effort to implement meaningful public health programs.

Age related exercise and strength training might retard declines in perceptual motor behavior including walking and balance[9]. The contribution to these activities by visual and auditory information is important but secondary to that of proprioception which in turn is affected by muscle strength. Accordingly, proposals for this area will focus on strength training.

Prevention: Hearing

Noise exposure contributes to age-related hearing loss; most knowledge about how comes from observations in extreme exposure conditions in natural settings and research on temporary threshold shifts (TTS) produced in laboratory situations, not the amount, duration and type of noise in everyday situations. The frequently cited recommendations on noise protection by the National Institutes of health are very general and usually based on noise levels measured at the source rather than at the listener's ear[10]. Conversely, in situations where a strong case can be made for noise induced hearing loss, estimation of its extent is complicated by normal age associated hearing losses. Some procedures used to measure the impact of occupational noise exposure on hearing loss effectively subtract out the expected hearing loss associated with age from the total measured loss leaving the effects of the hearing loss attributable to occupational noise exposure as the residual[11].

The effects of aging and noise exposure on hearing loss appear to occur over long periods of time. An intervention for control of noise requires knowledge of long-term effects of noise exposure in adults of different ages and an adaptable procedure for controlling noise levels for different individuals in a variety of noisy environments. An outline of a proposal for developing a clinical trial is offered that builds on recently published data on long-term changes in hearing levels in adults and advances in hearing aid technology. Development of an intervention program requires several types of information. First, a means of classifying persons at risk for noise associated hearing loss is needed that takes into account the natural history of age-related changes in hearing levels in cohorts with varying levels of initial hearing loss. Ideally, the classification of persons at risk should be nested within two or three classes of noisy environments within the range of environments considered 'normal' by contemporary standards. Second, a procedure is needed that can unobtrusively and continuously measure the amount of noise received at the ear of the listener. For purposes of an intervention, the same procedure should be able to automatically limit the level of noise within preset limits. Third, sensitive measures of auditory system response to noise exposure should be employed in addition to the audiometric data currently available used in population based research. Two candidate measures would be periodic assessments of temporary threshold shift (TTS) and a measure of masking thresholds.

One approach to defining levels of risk is provided by recently published longitudinal data on changes in pure-tone threshold[12]. These data confirm cross-sectional results indicating that age differences in thresholds increase directly with age and frequency of test tone and are smaller in women than men. Of greater importance for the present proposal, the amount of change, especially in men depends on the initial threshold levels; it is relatively smaller for men with less than average initial hearing levels than those with poorer initial levels.

The estimates of change in relation to initial hearing levels are based on an analysis of a subset of data published in Pearson et al[12] selected on the basis of rigid exclusionary criteria related to audiometric signs of a history of noise exposure and medical conditions that might affect hearing[13]. Estimates were made of longitudinal changes in pure tone thresholds (0.5, 1, 2 and 4 kHz) over 15 years for male cohorts with various initial levels of hearing loss representing initial age decades from the 30s through the 70s and a shorter period for men initially in their 80s. The predicted changes for men and women were different. For men, the amount of change over 15 years depended on the initial hearing level for men in that cohort--for men with hearing levels better than average for their group, the change was relatively small in comparison to that in age peers whose initial hearing levels were lower. The relative difference in the amount of change between the two groups increased in older cohorts. For example, the expected 15-year thresholds for the combined frequencies of 2, 3, and 4 kHz in men representing the top 10%

of initial hearing levels increased by about 0, 4 and 7 dB for men with initial ages in the 30s, 50s and 70s, respectively ([13], Figure 9). The corresponding figures for men representing the bottom 10% of initial hearing levels are 2, 8, and 12 dB, respectively. The effects of aging were smaller in women ([13], Figure 10). The changes with age observed in this study occur over longer periods of time than have usually been considered in intervention trials. Because the rate of change in hearing levels for frequencies in the speech range is related to initial hearing levels in men in different age cohorts, there is a basis for comparing the long-term effects of noise exposure in groups with different levels of initial hearing loss. One hypothesis would be that the effects of noise exposure would be greater in groups with greater initial hearing loss. The definition of levels of noisy environments in a 'normal' range can be based on variations in living and/or working environments and commuting requirements.

The second requirement concerns measurement and control of noise experienced in daily activities for an extended period of time. As an alternative to using problematic portable noise level devices, the existing technology of digital hearing aids could be adapted to monitor the sound level at the ear continuously and unobtrusively. In the second, intervention phase of the research, the noise suppression capability of the hearing aid would be used to control the level of noise exposure just as it is used to protect current hearing aid users from excessive amplification. Additional technology would be required to analyze and store the data on noise. Using the technology of hearing aids to suppress loud sounds rather than to enhance weak ones is simply a different use of existing smart technology.

Recent circumstantial evidence that tobacco use is a risk factor for hearing loss and that moderate alcohol use is protective against it mirrors data relative to the same relationships existing between the use of these substances and cardiovascular disease[8]. Compelling evidence for a relationship between elevated systolic blood pressure and age associated hearing loss comes from the same study mentioned above[14]. Groups of men with ages <50, 50-59, 60-69, 70+ were divided with average systolic blood pressure levels over the observation period of 120-139, 140-159 and >160 mmHg. A hearing loss event was defined as an average loss of 25dB or greater for pure tone frequencies of 0.5, 1, 2 and 4 kHz. With systolic blood pressure, the number of events increased in all four groups and the time from initial observation to the event was shorter. Table 1 shows the approximate percentages of men in each cohort who had a hearing loss as defined above at the end of the observation period. The elevated blood pressure may have damaged the small arteries serving the receptors in the ear. Accordingly, an intervention study in this area would profit by using measures of damage to the coronary arteries based on imaging procedures that have been shown to identify early signs of calcification of arterial tissues[15]. The design of an intervention study could be essentially the same as described above.

Prevention: vision

As in the case of hearing, the level and duration of exposure to intense light in everyday situations required to induce visual damage is unknown. Occupational groups such as professional fishermen who experience prolonged exposure to intense light and ultraviolet radiation from sunlight reflected from the surface of water are at relatively high risk for developing significant lens opacities[8]. Validated technology for unobtrusive monitoring of exposure to light is not currently available.

In comparison to hearing there is less literature relating cardiovascular health to age associated visual problems. Observational data from one longitudinal study established a correlation between elevated blood pressure and elevated intraocular pressure, the latter a risk factor for the development of glaucoma[16]. Visual impairments, e.g., diabetic retinopathy are serious consequences of Type 2 diabetes but interventions outside of treating or preventing diabetes itself have not been attempted. One laboratory study of visual information processing[17] compared the speed of decision making in 51 unmedicated adults representing three age groups with hypertension defined as blood pressures greater than 140/90 mmHg and an equal number of normotensive age peers. The laboratory task was to decide which of two target letters was presented in an array of 8 letters. Decision times, averaged across different experimental conditions, were higher in the hypertensive groups in all age groups studied. At present, there is little basis for prevention trials for age associated visual problems except for those that address the diseases for which the visual problems are secondary.

Prevention: strength

Gait and balance decline with age. These complex behaviors require integration among multiple physiological systems--both structural, e.g., bone muscle and connective tissue and control, e.g., proprioceptive information to control body movements, and visual and vestibular information to guide movement and maintain orientation. With respect to age, proprioceptive control is of primary importance.

Current research suggests that two structural systems, bone and muscle, provide opportunities for long-term preventive approaches to age related losses in gait and balance. Both bone density and thickness decrease with age; bone density has been studied most extensively. Most authorities agree with Bailey[18] that the best defense against age-related loss of bone density is a reserve acquired during the period of life when the density gain exceeds the loss in the bone turnover process. Longitudinal data indicate that both men[19] and women[20] lose bone density with age at about the same rate until, after menopause, the loss increases more in women. Post-menopausal hormone replacement therapy reduces but does not eliminate loss in bone density[21]. It is only the year of this writing that clinical trials show promise for a pharmaceutical intervention that increases bone density in old age.

The role of strength loss in the muscles required in gait and balance is receiving considerable research at present. Muscle strength, modifiable in old age as well as youth, provides an attractive approach to long term prevention because strength training improves the neural control of muscle as well as increasing muscle mass. Strength training by young and elderly adults improves and maintains strength over a long period after training is terminated[22]. Even modest exercise can reduce the development of functional limitations requiring walking[23,24].

Table 1: Approximate Percentages of Men with Hearing Loss in the Speech Frequencies at the End of Observation Period (yrs) According to Groupings of Systolic Blood Pressure (BP). Data of Brant JL et al Am Acad Audiol 1996;7;152-160.

Systolic BP	< 50 yrs	50-59 yrs	60-69 yrs	>70 yrs
120-139	25	27	25	45
140-159	32	36	32	54
160-+	42	45	39	70
yrs observation	22	20	16	11

Development of a long-term intervention based on strength training requires scientific definition of the time and intensity parameters needed to achieve and maintain a physiological reserve of strength and the definition of the threshold below which reserve should not fall.

Longitudinal research documents both long-term age-related declines in leg strength, arm strength, and power[25]. Little is known about the period of time over which strength acquired relatively early during aging can influence strength at a later age. The question of how much and what kind of reserve strength at a younger age is necessary for good functioning at an older age is being actively studied[22,26]. A variety of studies indicate that strength training can improve physical functioning even in very old age[27].

The temporal relationship between the development of a physiological reserve and its usefulness in functioning in later life is beginning to receive research attention. On the basis of earlier literature on physical frailty, Pendergast and colleagues[28] estimated that a 70 year-old person needs about 40% of their strength at 25 years to be functionally independent. A recent epidemiological study related measured strength in middle age to functional ability in old age. Measures of grip strength were obtained in male volunteers in the Honolulu Heart Study ranging in age from the 40s to the 60s. Assessments of their functional ability were made about twenty five years later[29]. In old age, 2 to 14% of the men studied reported difficulty in walking up 10 stairs or doing housework, had walking speeds of less than 0.4m/s, or were unable to rise from a chair without using their arms. As shown in Figure 1, the percentage of persons with self-reported difficulties or performance increased systematically with lower grip strength. The robustness of the findings is impressive because of the long interval between assessments of strength and functional outcomes and because grip strength is not the primary source of strength for the activities assessed at the time of follow-up. In the study, efforts were made to statistically control for confounding variables at time of follow-up such as the number of medical problems. There was no assessment of grip strength at the time of follow-up and no information was obtained about the routine habits related to strength of the participants in the three groups.

The basis for specifying strength goals for walking is being addressed in several laboratories[30,31]. There is a critical range of knee extensor strength and power within which there is a moderate positive correlation between strength and gait speed. Below the critical range, the slope relating strength to gait speed is flat at zero. Above the critical range, higher levels of strength do not result in faster gait and the slope of the correlation is also flat. The excess strength at the high end of the function defines the physiological reserve. Kwon and colleagues[31] found that in comparison to male coevals, women had less or no physiological reserve over a wide range of ages. Using data from elderly subjects, Rantanen and Avela[30] plotted the cumulative distributions of leg power (Watts/kg) observed for five gait speed groupings ranging from <1m/s to >2m/s. The measure of power was adjusted by body weight because of the known correlation between body size and strength. The differences were striking. The tenth, fiftieth and ninetieth percentiles of strength associated with gait speeds less than 1m/s were in round numbers, 1, 2, and 4 W/kg. Corresponding figures for speeds ranging from 1.3-1.5m/s and >2m/s were 4, 5, and 12 and 8, 12, and 15 W/kg, respectively.

The research summarized provides a promising but incomplete guide for the development of long-term interventions for minimizing the effects of age losses in strength on gait and balance. Other factors influencing strength and gait must be considered in interventions, e.g., nutrition, reduction of joint pain, passive stimulation of muscles, and hormonal therapies[9]. Also there is a need for taxonomy of environmental challenges for different living situations.

A second, more speculative approach is based on pharmacological interventions using hormones, e.g., growth hormone, DHEA, sex hormones, etc. A landmark study of elderly men by Rudman and colleagues[32] showed the reversal of several signs of aging including loss of muscle mass resulting from administration of growth hormone. Since then there has been a considerable amount of research investigating the preventive as well as the medical application of hormone replacement therapy[33, 34]. To date, there has been little clinical research directed at comparing the usefulness of the approach either as a substitute for or a supplement to strength training.

The role of technically based equipment in the interventions discussed above would be motivational and to improve monitoring of results, both at the level of strength and muscle quality. Participation by the elderly in regular programs of physical activity and especially strength training is very low[35]. In comparison with machines that provide constant and meaningful information about the progress and status of a person using machines for aerobic training, very little meaningful information is provided by strength training machines beyond the amount of weight used in the training session[36]. For example, no specific information is provided that relates the actual effort expended by a person to individually prescribed or group goals, as is the case in cardiovascular training equipment.

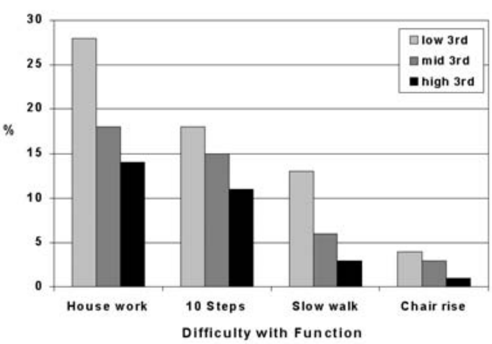

Figure 1: Percentage of Elderly Men with Limitations in Functioning (see text) Classified by Tertile (low, mid, high) of Grip Strength Measured about 25 Years Earlier. Constructed from data by Rantanen T et al[29]

COMPENSATION

A review of over 600 research papers on vision and hearing in relation to aging since 1994 identified several general trends including two relevant to the present discussion[8]. The first is the publication of several population-based studies that confirm earlier laboratory findings. In addition to validating the results of specialized laboratory studies, the generality of the findings greatly increases the confidence that applicable environmental compensations will have widespread usefulness. The second trend is the repeated finding that age related losses in acuity and contrast sensitivity cannot be explained fully by peripheral factors; neural losses are also involved. In some areas this limits the role of environmental interventions inasmuch as compensations for such losses are either unavailable or, if available, of limited or uncertain value, e.g., cochlear implants.

Most current opportunities for compensatory interventions are based on familiar principles:
(1) increasing signal strength either directly or by improved signal/background contrast;
(2) slowing the rate of presentation of information;
(3) increasing signal distinctiveness either by providing simultaneous auditory and visual presentation of the same message; or by using different modalities for separate messages, e.g., vibration in addition to auditory or visual signals;
(4) using smart technology to find optimal signal strength;

(5) improving the priming or focussing of attention of the observer; and
(6) training to improve attention and to utilize better the current strategies of seriously impaired persons, e.g., skill training in using magnifying devices and lip reading.

The importance of improving lip reading and listening skills is important partly because many new hearing aid users have unrealistic expectations about the value of amplifying devices.

Compensation: hearing

Partly because auditory images are relatively transient, compensations are needed for weak signals, reverberation, and speed of presentation. Compensating for weak signals through wearable hearing aids and special broadcasting systems is necessary but not sufficient. Although the recent research on age differences in speech perception in noise is controversial[8], results of studies of frequency perception[37], stimulus duration[38], and backward masking[39] show that many cognitive factors contribute to age losses in hearing independently of weak signal strength. Multiple approaches to compensation are necessary[40, 41].

Auditory sensitivity

High frequency hearing loss reduces recognition of consonants characterized by high frequency and low energy. Personal hearing aids and local direct broadcasting techniques in theaters and other public places provide the main means for compensating for losses in sensitivity. In the past decade significant advances in the quality of hearing aids have occurred. In addition to selectively amplifying frequencies, contemporary hearing aids can help protect against damage and discomfort produced by very loud sounds and to a limited extent enhances the distinctiveness of speech against a noisy background. Smart technology for amplification in combination with multiple microphones in the aid is the main factor contributing to these advances. Continuing research is addressing more complex couplings of the aid to the ear, e.g., bone conduction, closer coupling with the eardrum, and direct coupling to the cochlea. Considerable research now shows that the hearing aids are more effective if the user also receives training in listening skills including lip reading[8].

Although survey data indicate that poor hearing is the fourth leading health com-

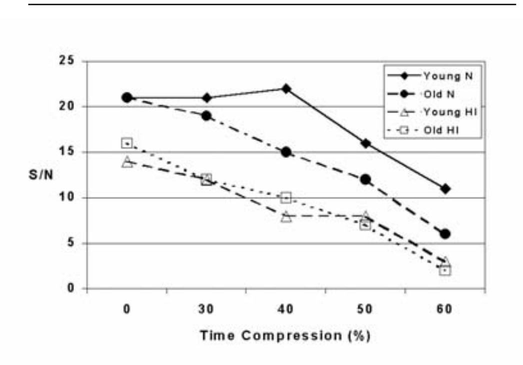

Figure 2: Equivalent Signal to Noise Ratios (ESN) for 0 to 60% Time Compression for Normal Hearing (N) and Hearing Impaired (HI) Listeners in Young and Elderly Adult Groups. Constructed from data by Gordon-Salant S, Fitzgibbons PJ. Speech Hear Res 1995; 38:711.

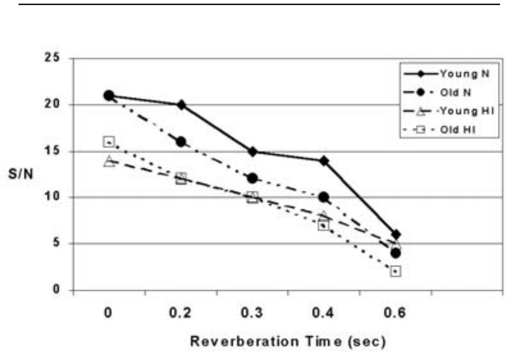

Figure 3. Equivalent Signal to Noise Ratios (ESN) for 0 to 0.6 s Time Compression for Normal Hearing (N) and Hearing Impaired (HI) Listeners in Young and Elderly Adult Groups. Constructed from data by Gordon-Salant S, Fitzgibbons PJ. Speech Hear Res 1995; 38:711.

plaint of older Americans, only about 20% of persons who could benefit from hearing aids use them. A recent survey[42] indicates that high costs and fear of social stigma contribute to reluctance to use hearing aids, particularly high-end digital devices. Discussions with clinicians and users indicate that skepticism and suspiciousness about product advertising and unfavorable comments by current users are frequently cited reasons for not using hearing aids. Ethical and informative advertising and consumer education such as that provided in product evaluation reports by the Consumers Union in the United States might increase the use of hearing aids.

Reverberation and time compression

Slowing of speech without frequency distortion has been achieved in some Japanese television broadcasting[43]. The application has helped older listeners and those with hearing impairments and has been successfully used in news programs.

Reverberation and time compression produce significant age-related losses in speech intelligibility; often, one or both occur in large public spaces, e.g., airports, train stations, and sports arenas. Moreover, the amount of distortion tolerable to normal hearing people is more than that tolerable to hearing impaired persons. Because of the variety of settings in which speech intelligibility is compromised by reverberation and speech distortion, acoustic engineers need design goals for combinations of reverberation and distortion that provide equivalent levels of audibility and speech intelligibility. A recent effort was reported[44] to provide an index of equal audibility, the equivalent signal to noise ratio (ESN). The ESN was constructed from correct word recognition percentages in the Speech Perception and Noise Test (SPIN) by adults with ages from 18-40 or 65-76 years. About half the listeners in each group had normal (N) hearing, defined as hearing levels no greater than 15 dB at 250-4000 Hz or were hearing impaired (HI) defined clinically as mild to moderated sensorineural hearing loss. The ESN ratio was defined as the S/N ratios associated with the observed percentages of correct recognition of words by the young, normal hearing groups at different S/N ratios in the SPIN test. Listeners in the four groups were tested for word recognition under five levels of time compression (0, 30, 40 50, 60%) and five levels of reverberation (0, 0.2, 0.3, and 0.4, 0.6 sec). Time compression was used as the surrogate for speech distortion not attributable to reverberation. The observed word recognition scores were expressed as ESN ratios. The mean ESN ratios for time compression and reverberation area shown in Figures 2 and 3. The recognition levels of all participants declined with increasing time compression and reverberation and the amount of decline was greater in the HI in both age groups. The data of HI listeners were combined across both age groups.

Post-hoc statistical tests identified clusters of mean ESN scores that were not significantly

Table 2: Clusters of Equivalent ESN ratios for Normal (N) and Hearing Impaired (HI) adults. Table constructed from data of Gordon-Salant & Fitzgibbons[44]

Percent Compression (T30-T60) and Reverberation Times (R.2-R.6) with Equivalent ESN

N	0	T30	T40	R.2	T50	R.3	R.4	T60	R.6
ESN	19	19	19	19	13	13	13	8	8
HI	0	R.2	T30	R.3	T40	T50	R.4	R.6	T60
ESN	15	12	12	8	8	8	8	3	3

different from one another. The ESN levels that did not differ significantly from one another are grouped as shown in Table 2. The different levels of reverberation and speech compression that yielded equivalent ESN scores are named in the column headings for N and HI listeners. Zero (0) refers to the conditions without speech degradation. For normal hearing listeners (N), speech compression levels of 30-40% and reverberations of 0.2s had ESN scores approximately equal to the conditions with no degradation of the speech signal. The most extreme levels of speech degradation resulted in much lower ESN scores of approximately 8. The ESN scores of the HI group were lower than those in the N group even without speech distortion. Six of the ESN scores for the HI group were as low (8) or lower (3) than the lowest ESN scores for the N group.

This study was discussed in some detail because the research represents one significant effort to relate speech intelligibility to complex environmental conditions in which speech is degraded in more than one dimension. It illustrates the complexity of the task in comparison, say to the equal loudness functions that identify the combinations of frequency and intensity that yield equivalent sensations of loudness. Further research is needed to validate the ESN measure in practical situations. The research indicates that the distortion levels with a given level of intelligibility to non-impaired listeners are significantly worse for those with hearing impairments typical of aged persons.

Compensation: vision

Opportunities for compensation for age-related losses in visual function include interventions related to: quality of the visual image; flexibility of lighting arrangements; adjustments for accommodative loss; and adjustments of the time requirements in tasks requiring visual attention, search and visual guidance of manual ballistic and tracking movements.

Image quality

Lighting and contrast can diminish but not eliminate age differences in visibility[45, 46]. Under the illumination and contrast levels commonly used in clinical testing for visual acuity, both longitudinal[47] and cross-sectional[8] data indicate that resolution and recognition acuity with usual corrections appears stable into the 60s and 70s. However, recent research[8] illustrates the profound effects on acuity and contrast sensitivity produced by variations in illumination, contrast, and glare--for both achromatic and colored stimuli[48, 49]. Studies in Japan, the Netherlands, and the United States[50-52] clearly document the need for improvements in illumination of letters and Chinese symbols. Now efforts are needed to define some of the different combinations of illumination, contrast, and target type required for equal visibility across age. Two such efforts are described.

The Dutch study mentioned above[51] determined the size of Times Roman type required for "comfortable reading" by volunteers representing 4 age groups from the 20s to the 80s.Volunteers read aloud standard passages printed in type sizes ranging from 3.2 to 12.6 points (1 point=0.3758mm). There were 4 levels of contrast ranging from 10 to 100% and 3 illumination levels, 10, 100, and 1000 lx. They wore their usual corrective lenses and held the test card at their preferred distance. "Comfortable reading" was a complex threshold measure based on the relation of type size to reading time. For each reader 1.5 times the time required by that person to read a passage under 100% contrast (black letters on a white background) was determined. The times required for reading the other passages were also measured. Reading times for the smallest type size that fell into that range defined the threshold for "comfortable reading". A sample of the median type sizes required for reading as defined above are displayed in Table 3 for the youngest and oldest age group. The age differences are striking. The variations in contrast for the young adults were important only at the 10 lx level of illumination. The age differences were about 2-fold throughout except at the highest illumination levels and at the 10 lx level where the task was impossible for most of the 80-year-olds.

A second approach by Akizuki and Inoue[53] requires determination of resolution acuity under optimal illumination and viewing distances. The obtained values are adjusted for individual differences to give an idealized acuity function called ratio of the Maximum Visual Acuity for targets at different viewing distances and luminance levels. Various functions are then derived that predict the character size required for equal visibility across age. The validation of this interesting approach is in progress.

With some effort, there is probably enough current information to make reasonable recommendations for improving lighting, target size, and contrast for older persons. The use of such information in everyday conditions is low. Results of a field study[54] in the United States indicated that existing illumination standards--already too low for many older individuals--were seldom met in either public or private settings. Data from such surveys and everyday observation show that older persons seldom provide themselves with optimal lighting. Moreover, stores and restaurants often do not supply price tags, product description tags, and menus that are easily legible by older persons.
Changes in marketing and consumer education are needed. Lighting goods stores and the sales rooms of spectacle vendors could provide mockups of home situations where lighting is important. Simulated environments could include the kitchen where the cookbook and miniature printing for cooking directions on packages is being read, the armchair where reading is done and the control for the television set is located, the home office, and hobby and work areas. In each, some practical demonstrations of ways to improve the local illumination could be available so that persons can appreciate firsthand the problems resulting from poor lighting and learn some ideas for improving their visual environment. For opticians, this salon approach might supplement or replace some displays of dozens of frames for spectacles; for lighting stores lighting options in functional groupings would replace parts of the typical displays of hundreds of fixtures jammed together on the ceiling, display tables, and floor. As an alternative to locating these displays in expensive retail selling space, the mockups could be located in senior recreation centers under the sponsorship of the stores. In settings such as restaurants where lighting changes might not be desired, customer service could be improved by improving the visibility of menus and bills or by providing customers who need them with small flashlights to aid reading of the menu. Small flashlights perhaps with magnifying glass attached with the name of the restaurant embossed on it could provide excellent advertising as well as a welcome service to older patrons.

The recommendations just made about illumination and contrast assume that age declines in the ability to change focal length are properly compensated for and that age declines in binocular depth perception are not a major factor in the visual tasks discussed (viewing distances up to about 2m). Sometimes, one or both of these assumptions are not met. Monocular cues for depth perception are particularly important to older persons whose binocular depth perception is deficient. By their nature the visibility of such cues is highly sensitive to contrast and illumination differences. Many presbyopic persons have multiple spectacles or several levels of magnification in one pair to provide clear vision at viewing distances other than the 40 cm common in reading tasks. At present there are no practical wearable devices that would automatically adjust for different focal lengths although such technology is common in contemporary cameras. Nor are there practical light sources on devices attached to spectacles to adjust illumination levels of targets. In specialized applications such as the lights in miners' hats or surgeons' mirrors, local light amplification is common, but it is not in widespread use. Challenging opportunities exist to create wearable prostheses that address these problems in a manner comparable to contemporary hearing aids.

Improving temporal factors

Age differences in critical flicker fusion[55] decrease with improved target illumination. Results from a rapidly growing number of laboratory studies of detection and discrimination of patterns of moving dots (called lamellar and radial motion) suggest that the observed age differences can be somewhat reduced by proper choice of comparison or background targets[8]. However, age-related behavioral slowing contributes to longer response speed in complex visual tasks involving attention and search, manual control, and balance and gait, all of which involve saccades and pursuit eye movements. Eye movements involved in perception of movement when the observer is in also in motion are also slower in older observers as revealed by studies of age differences in the vestibular-ocular reflex[56].

Visual attention and search

In cued visual attention tasks, the strategies employed by elderly and young adults are similar when the visual information used for cueing is made equally visible to old observers by manipulations of size, illumination, or viewing time[57-59]. Eye movements are particularly important in search tasks that encompass the 14-16 deg retinal area often named the useful field of view (UFOV). Scialfa and colleagues[60] found that reaction times and the number of repetitious eye movements increased with eccentricity of the target, more so for the older observers. Some decreases in age differences in search times may achievable by training such as those used to improve the useful field of view of older drivers[61].

Visually guided hand movements

Age related changes occur in single or repetitive ballistic movements--important in manipulating the mouse control of the computer cursor--and continuous movements such as steering an automobile[62]. In a classic study[63, 64] men and women ranging in age from 25-84 made alternating pencil tapping movements between two paper targets. For each of three separations of the two targets, response speed slowed relatively more with aging as the width of the target decreased. A single index of difficulty based on Fitts law described the observed mean response times for nine combinations of target separation and target width. To understand the behavior changes reflected in the index of difficulty, analyses under the direction of Dr. Max Vercryussen, are examining the spatial distributions of the pencil tap marks within the targets. The data come from successive tests of 154 male participants ranging in age from 25 to 84 years of age at time of first visit. Two findings from this research are relevant to the present discussion. First, the average movement time (MT) decreased over the first five visits (8 years), then increased as the participants grew older. The second was that the variability of the pencil taps increased over the eight visits. The two results were expressed as a ratio of the variability measure to the response time measure. Over the eight visits the ratio first increased or stayed the same, then decreased, meaning that the long-term adaptation to this task by aging individuals is characterized by faster times with greater variability of the repetitive movements. The amount of variability increases relative to movement speed with aging, more rapidly with older cohorts.

One implication of the study is that the gains in speed and accuracy with practice observed in young adults will occur less often in older persons. Results of laboratory studies indicate that the time spent in the last portions of a ballistic movement is disproportionally longer for older subjects[65]. A later study[66] investigated the changes in the first and final parts of a ballistic arm movement that could be achieved with practice by participants in their 20s and 70s. On some baseline trials, a moving cursor display representing the participant's arm movement was extinguished. On such trials the total movement time was about 300 ms longer than when the cursor was visible and the time of the initial component of the movement was shorter while that of the last was longer. Practice with the cursor present followed, and then the baseline condition described above was repeated. The performance of the younger participants improved to the same level both when the cursor was present and when it was not. In the older group, the level of performance with the cursor present was the same as on the first baseline condition and performance on the trials with cursor absent was still below that when the cursor was present. The two conclusions from the research summarized are that elderly persons are relatively more dependent on visual guidance than younger ones when making ballistic movements and that they benefit from practice relatively less.

The main implication is that age differences in visually controlled manual movements are best minimized through improving the characteristics of the visual displays through better illumination, contrast or target magnification. Damping the control being guided may also help[67]. On many computer systems it is possible to utilize these interventions to a degree using existing software.

Driving an automobile is one of the most complicated perceptual motor tasks dependent on vision. Successively older cohorts of current drivers as well as those who have recently ceased driving, cite visual problems as the major challenge to their driving[68, 69]. Improvements in highway sign can decrease age differences in the time available to read the signs. Studies of the relative legibility of simulated highway signs under viewing conditions in daylight, nighttime, and nighttime plus glare showed that adults aged 65-79 years was about 0.8, 0.64 and 0.50 that of adults 18-25, respectively in the three conditions. The relative visibility of the signs for the young adults declined from 1.0 (the ref-

Table 3. Size, Expressed as the Number of Points of Times Roman Type Needed for Comfortable Reading by Dutch Adults with Mean Ages of 25 and 75 Years under Three Levels of Illumination (10, 100, 1000 Lux) and Four Levels of Contrast (10, 33, 100--White on Black Background, 100--Black on White Background). Data taken from Steenbekkers[51], p. 134.*

Contrast (%)	Age Group (Years)					
	25	75	25	75	25	75
	Illumination Level (Lux)					
	10		100		1000	
10	10.0	12.6	4.0	8.0	3.2	6.3
33	5.0	10.0	4.0	8.0	3.2	6.3
100 WonB	4.0	8.0	3.2	6.3	3.2	5.0
100 BonW	3.2	8.0	3.2	5.0	3.2	4.0

*One point=0.3759mm height in Times Roman Type. Data taken from (51), Table 5.2-1, p.134.

erence for maximum relative visibility) to 0.70 in the other two conditions. A middle-aged group had values in between[70]. The results were used to propose improvements in the visibility of highway signs, mostly by employing more information with relatively low frequency components in the letters and symbols.

A variety of visual problems including steering are cited as reasons for self-restriction of driving at night common among older persons. One study measured steering in an automobile simulator in young, middle aged, and elderly adults under four levels of illumination ranging from daylight to total darkness levels[71]. The number of steering errors during the simulated course increased with age as illumination level decreased, but markedly so in the oldest group. As lighting changes from twilight to dark, the relatively faster rate of dark adaptation in young adults preserves visual information about changes in position and movement better than in older ones, but this does not compensate for the loss of sensitivity for foveal vision that mediates information about objects.

Compensation: gait and balance

Gait speed decreases, and the probability of falls increase with only modest losses of acuity and contrast sensitivity[72, 73]. A variety of safety problems result from the design and decoration of walking surfaces and stairs[74, 75]. Vision's role in maintaining balance increases, as proprioceptive information becomes poorer. In one study, postural sway was measured on a platform in adults mean ages of 25 or 70 years[76]. Sway was expressed in millimeters/second (mm/s) as the center of pressure (COP) velocity in ten second periods under four conditions: normal vision and normal proprioception; vision blocked with goggles and normal proprioception; proprioception blocked by vibrations applied to ankle tendons and normal vision; and both vision and proprioception blocked. COP velocity was always relatively greater when proprioceptive information was blocked; the availability of visual information reduced COP by almost twice as much in the older as in the younger group. The lesson from the research reported is that improved balance can be achieved by improved visibility, but that the best interventions would also involve training that has been shown to improve balance and gait[77].

Field studies suggest that some equipment and environments that compensate for losses in personal mobility, driving, and home activities may unintentionally affect perceptual-motor performance adversely when their use diverts or limits visual attention. Many aids to personal mobility were developed to meet the short-term needs of persons recovering from an injury more than for those needing them all the time. Problems of safety secondary to the use of the devices are common. Where applicable, static aids to mobility such as grab bars are often preferable to portable aids, e.g., walkers, because they do not limit visual functioning as much. Recent improvements in portable aids include development of protective hip pads, and the walking aids with three or four wheels that also serve a useful function for transporting parcels and clothes.

ENHANCEMENT

Aging brings with it challenges which are addressed by prevention and compensation as described above. For many, it also brings opportunities[78] for new:

(1) social opportunities and friendship;
(2) adventuresome and challenging activities;
(3) artistic expression;
(4) learning; and
(5) work.

The largest increases in the use of technology for enhancement in the past five years have been in the area of communication and learning through e-mail, the internet, virtual neighborhoods, and chat rooms such as the many available on Seniornet. Retirement, relocation, empty nest, widowhood--all may create opportunities for new social opportunities as well as an interest in electronic communication with children and grandchildren. In the United States, colleges are rapidly increasing the number of continuing education courses on computer use provided to older persons both on their campuses and through community senior centers. Universities are providing ever more interactive educational courses that can and are being used by older students.

Less is known about the potential use of technology for enhancement in the other classes of activity listed above. Some speculations follow. With respect to amusements involving perceptual-motor activities, adventure games and games of skill played in virtual environments (bridge, for example) provide many opportunities for recreation. There has been some informal clinical efforts to use youth oriented adventure games as part of physical rehabilitation programs for older persons. It is possible that reconfiguring them for a slower pace would increase their enjoyment by older persons. The possibilities for role playing and acting while moving around virtual landscapes and people are being actively explored now in laboratories.

I anticipate that the next areas for significant developments of technology that enhances quality of life for older persons will be in artistic activities. Demographic information concerning the extent of interest by older persons in using technology for artistic activities is unknown as well as the timetable for its development. However, for persons who take up painting, amateur music or other artistic endeavors, technology offers the amateur many potential aids for creating complex images, word art, and music. With respect to artistic activities, opportunities for group and individual artistic endeavors are becoming increasingly available. Bouma and Harrington[79, p. 156-159] describe a virtual group painting activity in which all artists can see and share in the others' painting, a scenario possible with existing technology. Virtual musical jam sessions could be supported with similar applications of technology. Professional musicians already collaborate in creating musical recordings by performers located in different locations.

With respect to individual artistic activities, existing, relatively user-friendly software can support individual computer-based artistic activities such as making, copying, and altering digital images, drawing, creating animation and cartoons. The digital camera and the associated programs that allow persons to enhance and alter images are already fairly user-friendly and users can have their 'negatives' or images made with conventional cameras stored in electronic form, allowing the altering of images either in a commercial establishment or on their home computer.

There are many existing models of the use of computers and other technology that allow persons to work at home or in a setting remote from the workplace. Although some older persons take longer than young adults do to acquire the skills needed in these activities, there will be an ever-increasing number of possibilities such as those being developed in Japan[79, p. 95]. The interest in continuing the employment of older workers has played a major role in spurring research into the design of computer interfaces and ergonomics of technological devices such as banking machines[67].

CONCLUSIONS

The opportunities for gerontechnology as related to perceptual-motor aging are in three broad areas: prevention or delaying of age associated declines, compensation for existing age limitations in perceptual motor functioning and the use of technology for enhancement of the activities of older persons. Smart, self-adaptive technology has considerable potential for application in all three areas[78-80]. The idea of using technology in long term prevention of age-related declines in perception is based mostly on relatively recent findings from longitudinal studies. In all areas, development and distribution of technology must be consumer oriented to be effective.

ACKNOWLEDGMENTS

Some parts of the material in this article were presented at the International Workshop on Gerontechnology, Tsukuba, Japan, March 2001; Ageing in the Community, Heidelberg, Germany, April 2001, and the Fifth International Conference on Health, Aging and Communication, Vancouver, Canada, July 2001. The concepts of gerontechnology described in the article are based on a decade of collaboration with colleagues at the Eindhoven (NL) University of Technology where it all began. In addition to co-authors named in[1] and[78] I am indebted to Professors Don Bouwhuis, Annelies van Bronswijk, Ir Wim Koster and Dr Cor Vermeulen. The proposals on prevention are based in part on discussions with colleagues at the National Institute on Aging named in the references and the late Dr. George T. Baker III: those on compensation are based in part by discussions with colleagues who are active in aging and ergonomics, especially Drs Frank Schieber, Sara Czaja, and Neil Charness. I greatly appreciate the constructive comments of the editor and anonymous reviewers of an earlier version of this manuscript.

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