Using the Brain when the Ears are Challenged helps Healthy Older Listeners Compensate and Preserve Communication Function

M. Kathleen Pichora-Fuller

Abstract

In contrast to the frequently negative focus on the downward spiral in functioning that occurs with aging, the present chapter emphasizes the positive role of compensation and the preservation of functioning in the everyday lives of older adults. It is well known that age-related declines in auditory processing can make it difficult for many older adults to communicate and to maintain a high level of social interaction. Furthermore, with increasing age, the deleterious effects of hearing loss on communication are increasingly likely to combine with the deleterious effects of other impairments, such as vision loss. Hearing loss can even exacerbate the apparent degree of other impairments, such as cognitive loss. Importantly, the interactions between sensory and cognitive functioning suggest that the ears and the brain operate as parts of a system. This integrated system can either undermine or support the achievement of everyday goals by older communicators. The interplay between components of the system is usually viewed from a negative perspective, but it can also be viewed from a positive perspective with respect to rehabilitation and health promotion. From a rehabilitation perspective, it is important to understand how older adults may compensate to offset the functional costs associated with impairments. From a health promotion perspective, it is important to understand how it may be possible to preserve functioning and slow the rate of age-related declines. There is potential for the quality of life of older adults to benefit significantly from a positive approach to rehabilitation and health promotion insofar as engaging in communication and social interaction fosters healthy and active lifestyles.

Heterogeneity and Complexity of Age-Related Changes: Need for a Systems View

The most well-known characteristics of "presbycusis" are high-frequency sensorineural hearing loss (ISO, 2000) and difficulty understanding speech in noise (CHABA, 1988). Because these characteristics are very common and they are similar to the age-general characteristics of sensorineural hearing loss, the simplest approach in hearing health care practice would be to assume that age-related hearing loss can be managed using a uniform approach that is not that different from the approach used for any case of sensorineural hearing loss. Despite the allure of such simplicity, it is necessary to call this assumption into question if we are to make advances in hearing care for older adults (Kiessling, Pichora-Fuller, Gatehouse et al., 2003). A deeper understanding of the special needs of older communicators necessitates an appreciation of age-specific changes in auditory processing, as well as an appreciation of how auditory functioning interacts with age-related changes in a variety of other health issues as the person engages in communication during a wide range of everyday activities. The heterogeneity and complexity of these age-related changes in hearing and other health issues that affect communication defy explanations in terms of isolated components and are best appreciated by adopting a systems view (Pichora-Fuller & Singh, 2006).

Address correspondence to: M. Kathleen Pichora-Fuller, Ph.D., Aud (C), Department of Psychology, University of Toronto, 3359 Mississauga Rd N., Mississauga, Ontario, Canada L5L 1C6, Phone: 905-828-3865, Fax: 905-569-4326, Email: k.pichora.fuller@utoronto.ca.

Heterogeneity in Age-Related Hearing Loss

Age-related changes in auditory processing are heterogeneous and greater awareness of this heterogeneity may help hearing health care professionals to understand better the needs of older individuals. Age-related hearing loss may involve damage to one or more structures in the cochlea and/or the auditory nervous system resulting from many causes, including environmental factors such as exposure to noise and ototoxic drugs, genetic factors, and generalized effects of aging such as cell damage and neural degeneration. The classification of sub-types of presbycusis, defined according to the particular structures of the auditory system affected by age, has continued to be refined for over four decades (e.g., Gates & Mills, 2005; Mills, Schmiedt, Schulte & Dubno, 2006; Schuknecht, 1955, 1964; Schuknecht & Gacek, 1993; Willott, 1991), and current research is attempting to find ways to differentiate these sub-types clinically (Mills, 2006). Unfortunately, there is not a straightforward correspondence between damage to particular structures and perceptual deficits, but damage at multiple sites likely contributes to the differences in auditory processing that are observed between older adults and younger adults who have similar hearing thresholds but more localized pathologies.

As in younger adults, high-frequency pure-tone threshold elevation associated with outer hair cell pathology is very common in older adults, especially those who have had more lifelong exposure to noise. In addition, research conducted over the last two decades has greatly advanced knowledge of the more age-specific structural and perceptual aspects of presbycusis (Gates & Mills, 2005). Changes in the endocochlear potentials associated with strial-type presbycusis may be responsible for high-frequency threshold elevations in cases where the outer hair cells have not been damaged by noise. Furthermore, the difficulties understanding speech in noise that are often reported even by older adults who have no clinically significant threshold elevation in the speech range may be explained by age-related declines in auditory temporal processing associated with neural-type presbycusis (Gates, Feeney & Higdon, 2003; Pichora-Fuller & MacDonald, 2008; Pichora-Fuller & Souza, 2003).

Hearing health care for older adults will no doubt become much better tailored to the needs of older individuals as new clinical protocols are developed to differentiate sub-types of presbycusis. Such protocols will likely incorporate audiometry along with testing of otoacoustic emissions and evoked potentials (Mills, 2006). Furthermore, there is also a need to develop more ecologically relevant questionnaires and behavioural tests that are adapted to facilitate the assessment of listening in everyday complex environments. In the meantime, at least hearing health care professionals should be mindful of the complexities and the heterogeneity of age-related hearing loss. A better appreciation of the variation in the older population will guide the design of comprehensive rehabilitative solutions for individuals using a combination of selected technologies, environmental modifications, and interventions to change communication behaviours (Gates, Feeney & Mills, 2008).

Heterogeneity in Other Age-Related Health Issues

Beyond the heterogeneity in auditory aging per se, there is also heterogeneity insofar as there are many ways in which age-related hearing problems will interact with other age-related changes. The individual's abilities to participate in everyday life will inevitably be influenced by hearing loss in combination with a variety of other age-related changes. There are dramatic increases with age in the prevalence of many other disorders (e.g., vision, speech, language, cognition) that affect communication and social interaction. As well, there are increases in the prevalence of impairments in balance, mobility, touch, and dexterity that may exacerbate barriers to communication because they alter the individual's ability to interact in physical environments or use communication technologies (see Lemke, this volume; Davis, this volume).

Most hearing health care professionals will easily recognize that the use of visual cues can be extremely helpful to a person who has difficulty hearing and that dual sensory loss puts considerably more strain on communication than would hearing loss alone, although best practices for the assessment and treatment of dual sensory loss in aging are not yet developed (Saunders & Echt, 2007; Smith, Bennett & Wilson, 2008). Similarly, it seems obvious that communication would be supported or undermined depending on whether or not the person with hearing loss also had speech and/or language impairments. However, the direct and indirect connections between audition and cognition may be less well known, even though they could be even more important to consider in shaping advances in hearing health care for older adults (Arlinger, Lunner, Lyxell, & Pichora-Fuller, 2009).

A core assumption of cognitive information processing theory has been that an individual has limited cognitive resources for memory and attention. According to this theory, when information processing becomes effortful, more resources are consumed such that demands on resources for some processes can deplete the resources available to be allocated to other processes. When a person with good hearing listens in ideal conditions that are familiar, quiet and without distraction, listening is largely effortless or automatic and there is little if any drain on the pool of available cognitive resources. Thus, when listening is easy the connection between auditory and cognitive processing is relatively unimportant. In contrast, there can be a direct connection between hearing loss and cognition because, in a limited capacity system, when listening becomes effortful there could be a depletion of cognitive resources such that other processes required for comprehension and/or memory are starved (Pichora-Fuller, 2007). There can also be an indirect connection between hearing and cognition when a person is multi-tasking. Even if listening does not consume an excessive share of the available cognitive resources, when a person must listen while performing a concurrent task then the combined demands may reduce the cognitive resources available for higher-level information processing; e.g., conversing while driving in traffic or walking with a cane is more resource-demanding than repeating words in a speech recognition test in quiet conducted in a soundbooth. In many realistic everyday situations, because the cognitive resources required for listening will trade with the cognitive resources allocated to other tasks, auditory processing interacts with cognition and we are only beginning to understand how to take these interactions into consideration when designing rehabilitation (Arlinger et al., 2009).

Compensation

From a rehabilitation perspective, it is important to understand how older communicators may compensate to offset the functional costs associated with hearing and other impairments. The notion of compensation refers to the closing of a gap or the reduction of a mismatch between current accessible skills and environmental demands (Dixon & Bäckman, 1995). Compensation can occur by drawing on relatively intact abilities to off-set declines in other abilities.

Fluid and Crystallized Intelligence

For younger adults, models of intelligence differentiate several factors, but this differentiation is reduced with aging (Baltes, Cornelius, Spiro, Nesselroade & Willis, 1980). “Fluid” and “crystallized intelligence” are two main factors of general intelligence (Cattell, 1971). In older adults, crystallized intelligence (knowledge) of the sort accrued through social experience and education tends to remain relatively intact, whereas fluid intelligence (processing) associated with the integrity of the nervous system declines (Cunningham, Clayton, & Overton, 1975). For example, vocabulary continues to grow over the lifespan and plateaus after 60 years of age, whereas reasoning and working memory decline steadily between the 20 and 80 years of age (Salthouse, 2004). The differential effects of age on these dimensions of intelligence are highly relevant to compensation during spoken language comprehension (Kemper, 1992). Relating these factors to spoken language comprehension in older adults, declines are more pronounced in fluid abilities or the moment-to-moment cognitive operations involved in information processing, including the ability to find meaning and understand the relationships between concepts, resolve ambiguities, draw inferences, and formulate responses (i.e., working memory and reasoning), whereas crystallized abilities or the use of skills, knowledge, and expertise remain largely intact (West, Stanovich & Cunningham, 1995).

The different trajectories over time of age-related changes in fluid processing compared to crystallized knowledge enables older listeners to compensate during spoken language comprehension. In addition to individual differences which might exist in specific components of the cognitive system (e.g., the auditory components), there can be important individual differences in the effectiveness of compensation when resources are reallocated to relatively intact and away from relatively impaired components of the cognitive system. Indeed, perceptual learning and brain plasticity suggest that changes can be achieved in how information is processed (Sternberg, 2008). Crucially, a goal of rehabilitation is to optimize the trading or re-balancing of the contributions within the cognitive system, by exploiting compensation when it is advantageous for reducing effort and the overall demand on information processing resources.

Bottom-Up and Top-Down Processing

To comprehend spoken language, the listener must map the incoming signal to stored linguistic and world knowledge. Older listeners may compensate by re-balancing the use of bottom-up (signal-driven) and top-down (knowledge-driven) information processing to take advantage of knowledge when processing is challenged by degradation of incoming auditory information. According to the information degradation hypothesis (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994, 1997), one of the possible explanations for the strong correlations that have been observed between sensory and cognitive aging is that impoverished sensory input stresses cognitive processing. Additional cognitive resources would be required to draw on stored knowledge to disambiguate and recover meaning from an impoverished speech input and/or to repair errors in understanding as the meaning of discourse is integrated over time. When effortful listening (e.g., due to auditory processing deficits and/or the adversity of the listening condition) drains cognitive resources away from other types of processing, the apparent cognitive declines in memory, attention, and comprehension that are often observed in older listeners are exacerbated (e.g., McCoy, Tun, Cox, Colangelo, Stewart & Wingfield, 2005; Pichora-Fuller, Schneider & Daneman, 1995; Pichora-Fuller, 2003, 2006, 2007; Schneider & Pichora-Fuller, 2000; Schneider, Pichora-Fuller & Daneman, 2009; Wingfield, Tun, Koh & Rosen, 1999). Consistent with the notion that listening in challenging conditions increases demands on processing is the finding that the ability of older adults to understand time-compressed speech is strongly correlated with measures of working memory involving sequencing (Vaughan, Storzach & Furukawa, 2006). Thus, age-related changes in auditory processing can conspire with changes in fluid information processing abilities to reduce the spoken language comprehension of older adults.

Fortunately, declines in fluid processing abilities can be offset to some extent by the preserved crystallized abilities and expert knowledge of older adults. When bottom-up auditory processing of the incoming auditory signal is impoverished or stressed, top-down processing may enable compensation insofar as stored knowledge and converging inputs facilitate the listener in anticipating and resolving the degraded incoming information (see Craik, 2007). Thus, paradoxically, it seems that older adults demonstrate cognitive strengths that counter-act or compensate for cognitive declines during spoken language comprehension. The ability of older adults to use "environmental support" has been related to compensation on memory tasks (e.g., Craik, 1983, 1986). Similarly, various types of linguistic and situational "context" can be used to advantage by older adults to compensate when performing spoken language comprehension tasks (e.g., Wingfield & Stine-Morrow, 2000; Wingfield & Tun, 2007).

During spoken language comprehension, compensation involving the re-balancing of the relative contributions of bottom-up and top-down processing may occur in two ways. Successful, but slower and more effortful, comprehension can be achieved when knowledge and expertise is used in the later integration stages of comprehension to resolve ambiguities and repair errors. Successful, but faster and less effortful, comprehension can be achieved when context is used in the earlier prediction stages of comprehension to prime expectancies about the incoming signal that facilitate comprehension (Federmeier & Kutas, 1999). Even in healthy young normal-hearing listeners, there is evidence that in dual-task conditions, when cognitive resources are at a premium, there is a shift away from more signal-dependent auditory-phonetic processing to more knowledge-dependent lexical processing during word recognition (Mattys, Brooks, & Cooke, 2009). Either the prediction or integration stages of spoken language comprehension, compensation can enable older adults to maintain performance even in challenging listening conditions. Long-term use of compensation during spoken language comprehension over the years during which presbycusis develops, or shorter-term changes in compensation during acclimatization to a new hearing aid (Foo, Rudner, Rönnberg & Lunner, 2007; Rudner, Foo, Sundewall-Thorén, Lunner & Rönnberg, 2008), may result in permanent changes in the balance between bottom-up and top-down processing and in brain organization.

Perceptual Learning and Brain Plasticity

It has been suggested that more widespread brain activation is an indication of "thinking harder", and that it may reflect the allocation of more working memory resources (Just & Carpenter, 1992; Petrides, Alivisatos, Meyer & Evans, 1993). Recent studies using brain imaging have shown that there is more widespread brain activation, including activation of the left dorsolateral prefrontal cortical areas that are thought to be involved in semantic processing and working memory, when context is available to support listening to noise-vocoded sentences (Obleser, Wise, Dresner & Scott, 2006; Scott & Johnsrude, 2003; Zekveld, Heslenfeld, Festen & Schoonhoven, 2006). A general function of the prefrontal cortex is temporal integration of information (West, 1996) and when listeners engage in more top-down, context-driven processing involving greater activation of prefrontal cortex, there is accelerated perceptual learning of speech distorted by noise-vocoding (e.g., Davis, Johnsrude, Hervais-Adelman, Taylor & McGettigan, 2005). Similar brain activation patterns have been found when the perception of sentences in noise is facilitated by meaningful semantic context (MacDonald, Davis, Pichora-Fuller & Johnsrude, 2008). Furthermore, poor performance on tests of speech in competing noise is associated with dementia of the Alzheimer's type (Gates, Cobb, Linn, Rees, Wolf & D'Agostino, 1996) and deterioration of frontal lobe executive function rather than deterioration of the central auditory pathways (Sinha, Hollen, Rodriguez & Miller, 1993) is presumed to be a key factor (Gates & Mills, 2005). Thus, increased prefrontal brain activation is observed when context is used to support spoken language comprehension in conditions in which the signal is degraded and frontal lobe pathology seems likely to undermine listening in challenging conditions.

In general, a compatible set of findings concerning compensation has emerged from cognitive neuroscience research on age-related differences in the distribution of activation in prefrontal cortex (for a review see Pichora-Fuller & Singh, 2006). The influential HAROLD model (hemispheric asymmetry reduction in older adults) is based on the findings from cognitive neuroscience that under similar circumstances, prefrontal activity during cognitive performance (perception, memory, and attention) tends to be less lateralized with age (Cabeza, 2002). This functional reorganization, or plasticity, of the brain might result from de-differentiation of brain function as a consequence of difficulty in activating specialized neural circuits, or it might result from compensatory adaptation to offset age-related neurocognitive declines. Evidence supporting the compensatory interpretation is that healthy older adults who have low performance on cognitive measures recruit the same prefrontal cortex regions as young adults, whereas older adults who achieve high performance engage bilateral regions of prefrontal cortex (Cabeza, Anderson, Locantore & McIntosh, 2002). Prefrontal activation is also associated with self-initiated and controlled processing of information to be remembered which can be triggered in older adults by supportive environmental cues. Such compensatory brain activation could be consistent with the finding that older adults are better than younger adults at using contextual support to compensate in challenging listening conditions (for a discussion see Pichora-Fuller & Singh, 2006; Pichora-Fuller, 2008).

Use of Supportive Context During Listening

A number of sources of supportive context can serve such compensation when older adults communicate. Supportive context may be provided by redundant cues in the external signal(s) and/or by internally stored knowledge about structures that are functionally significant in communication. It seems that listeners may achieve correct word identification in various ways depending on the challenges and supports available in complex auditory scenes. Mounting evidence suggests that older adults benefit as much or more than younger adults from supportive context at multiple levels where expectations or constraints may be related to redundancies in semantic, syntactic, lexical, phonological, or other sub-phonemic cues in the signal and/or to expert knowledge of structures at these levels (for a review see Pichora-Fuller, 2008).

The comprehension of spoken language involves mapping the unfolding speech signal to the appropriate semantic meaning given the situational constraints of real-world scenarios and the constraints of relevant linguistic structures (phonology, morphology, syntax). This mapping between speech signal and meaning is complex and intuitively integrative, involving information from both low-level and high-level processes that is woven together over time. Of course, a listener may also coordinate the comprehension of spoken language with the processing of visual speech information and non-linguistic inputs in multiple modalities. Furthermore, attention may be allocated depending on the task-related goals of the listener. Ultimately, comprehension enables the individual to respond appropriately.

At the sentential level, a well-known finding has been that younger adults out-perform older adults when there are reductions in the quality of the signal such as when there is background noise, time-compression, or distortion by jittering or noise-vocoding. Importantly, a recurring finding is that less age-related difference is observed when it is possible for older adults to compensate by taking advantage of the supportive sentential context provided by syntactic and semantic constraints within the sentence or by pre-sentential priming (e.g., Dubno, Ahlstrom & Horwitz, 2000; Gordon-Salant & Fitzgibbons, 1997; Perry & Wingfield, 1994; Pichora-Fuller, 2006; Pichora-Fuller et al., 1995; Pichora-Fuller, Schneider, MacDonald, Pass & Brown, 2007; Sheldon, Pichora-Fuller & Schneider, 2008b; Sommers & Danielson, 1999; Wingfield, Tun & McCoy, 2005). Thus, supportive context seems to be used to advantage by older adults during both the predictive and integrative stages of comprehension.

At the lexical level, even when words are tested in isolation, without the possibility of compensation based on the rich support available in sentence contexts, knowledge of the lexicon seems to explain why some words are easier to understand than other words. For example, in an experiment in which words were noise-vocoded (Sheldon, Pichora-Fuller & Schneider, 2008a), older adults needed significantly more bands (8.55) than younger adults (6.13) to achieve 50% correct word identification. However, there was a strong significant correlation between age groups in the number of bands needed to identify the 200 words ($r = .768$, $p = .000001$), with the number of bands needed to identify the words being significantly correlated with word frequency for both younger adults ($N = 200$ words, $r = -.225$, $p < .0007$) and older adults ($r = -.267$, $p < .00007$), as well as with word familiarity for the older adults ($r = -.119$, $p < .047$). Importantly, the age-related differences observed when each word was presented only once were eliminated in a related experiment using a procedure in which the number of bands was incremented until the word was correctly identified and feedback was provided. This pattern of results suggest that knowledge of words in terms of both word frequency and word familiarity seems to be even more highly related to the performance of older listeners than to the performance of younger adults and that the opportunity to hear a slightly enriched repetition of the words and the provision of feedback can enable older adults to compensate for their difficulties hearing distorted words.

Even though older adults are able to compensate by using lexical knowledge, the possibility remains that their word recognition would be slower in challenging listening conditions. Measures of the accuracy of word recognition do not provide the information about the time course of comprehension as the word unfolds that can be obtained using on-line measures such as evoked response potentials or eye-movement tracking. To investigate if there are age-related differences in the time course of lexical processing for words spoken in quiet or noise, we conducted a study of word discrimination using eye-movement tracking (Ben-David, Chambers, Daneman, Pichora-Fuller, Reingold & Schneider, submitted). After adjusting the signal-to-noise ratio so that the accuracy of word discrimination was matched for younger and older listeners, both groups performed similarly except when the target and alternatives shared rhymes, suggesting that the dynamics of real-time lexical processing appear overall to be quite similar for younger and older adults. These findings are consistent with the idea that age-related declines in spoken language comprehension result primarily from changes in bottom-up processing of auditory inputs rather than in the use of lexical knowledge.

At the phonological level, age-related differences in gap and duration detection and discrimination have been related to the perception of specific phonemic contrasts (e.g., Gordon-Salant, Yeni-Komshian, Fitzgibbons & Barrett, 2006; Pichora-Fuller, Schneider, Bensen, Hamstra & Storzer, 2006). For example, when gap detection thresholds were compared for analogous speech and non-speech materials, age-related differences in mean gap detection thresholds were about 50 ms less for speech than for the corresponding non-speech conditions, with the pattern of results being interpreted as evidence that older adults were able to compensate for their auditory temporal processing difficulties by activating well-learned, gap-dependent, phonemic contrasts and their knowledge of the phonological structure of language (Pichora-Fuller et al., 2006).

In addition to compensating by using knowledge at the sentential, lexical, and phonological levels of processing, even when the same materials are spoken by different talkers, the ease and accuracy of speech understanding by older listeners may also be supported by non-linguistic auditory cues such as those derived from voice fundamental frequency differences (Vongpaisal & Pichora-Fuller, 2007), sub-phonemic inter-talker differences (Goy, Pichora-Fuller, van Lieshout, Schneider & Singh, 2007) and spatial expectancies (Singh, Pichora-Fuller, & Schneider, 2008). Thus, various sorts of knowledge and top-down processing can be used successfully by older adults to compensate for their problems in bottom-up auditory processing. Training in the use of supportive context may be one of the most important keys to rehabilitation, including optimizing the mapping between sound and meaning during acclimatization to hearing aids, especially since it is not possible to correct hearing back to normal even when the most advanced technology is used.

Preservation

From a health promotion perspective, it is important to understand how it may be possible to preserve function and slow the rate of age-related declines. In regard to hearing health, there may be beneficial effects of antioxidants and dietary restrictions (e.g., Rosen, Olin & Rosen, 1970; Seidman, 2000; Willott, Erway, Archer & Harrison, 1995) or health-compromising effects of exposure to noise or ototoxic drugs. However, the most urgent health promotion issue facing older communicators arises from the strong connection between hearing impairment and cognitive impairment. As discussed above, in healthy older adults, when listening is difficult, auditory problems may masquerade as or exacerbate apparent declines in cognitive processing; conversely, the ability to use context and expertise may enable cognitively healthy older adults to compensate for hearing difficulties. The interactions between auditory and cognitive functioning become even more dramatic when both systems are impaired. Effective rehabilitation for older adults that improves hearing should, in turn, enable listeners to continue to enjoy social interactions which, in turn, should facilitate the maintenance of the sort of active lifestyle that seem to be conducive to the preservation of cognitive health. Thus, in addition to simply improving hearing, there is potential for the work of hearing health care professionals to contribute to a broader health promotion agenda to try to slow cognitive decline.

Connection Between Hearing Impairment and Cognitive Impairment

The strong connection between hearing impairment and cognitive impairment is not new; however, there is now a pressing need to position hearing health care as an important component in the larger context of health and aging. The degree of dementia is significantly over-estimated in about 1/3 of cases if tests are conducted without versus with hearing aids (Weinstein & Amsel, 1986), hearing loss is found in up to 9/10 cases with dementia (Gold, Lightfoot & Hnath-Chisolm, 1996), and it is more prevalent in those with dementia than in controls (Uhlmann, Larson, Rees, Koepsell & Duckert, 1989; Ulhmann, Teri, Rees, Mozlowski & Larson, 1989). Even more striking is the finding that auditory speech processing problems are predictive of future manifestations of dementia (Gates, Beiser, Rees, Agostino & Wolf, 2002). It is likely that the association between hearing impairment and cognitive impairment is so strong because individuals with better hearing simply exhibit less apparent cognitive decline and/or that those with better hearing experience slower cognitive decline because they are better able to maintain healthy active lifestyles thereby slowing cognitive decline.

Factors that Protect Cognitive Health

Topics of great interest to clinical neuropsychologists working with older adults are the discovery of factors that seem to protect individuals from the onset of cognitive decline and the design of interventions to slow further decline for those with mild cognitive impairment. Longitudinal studies suggest that there may be biologically plausible associations of different lifestyles with dementia and Alzheimer's disease (AD), including the effects of social network, physical leisure activities, and non-physical activity (Fratiglioni, Paillard-Borg & Winblad, 2004). All three lifestyle components (social, mental and physical) seem to have a common pathway that has a beneficial effect on cognition and a protective effect against dementia. The convergence of these components in an active and socially integrated lifestyle and their positive effects are consistent with three hypotheses. The cognitive reserve hypothesis is that individuals who have higher cognitive functioning will be more resilient than those who have lower cognitive functioning as young adults. The vascular hypothesis is that cognitive performance is improved with the increased blood supply that is associated with activity such as physical exercise. The stress hypothesis is that the reduction of stress, for example by social support or physical exercise, will increase cognitive functioning.

The factors that are correlated with better cognitive health in old age include specific genetic factors (Hsiung, Sadovnick & Feldman, 2004), as well as other biological factors such as being male. Cognitive health is associated with lifestyle factors that are generally considered to be positive for physical health, such as eating a "Mediterranean" diet that is high in fish, fruits, vegetables, legumes and cereals and low in meat and dairy products (i.e., low in saturated fats) and exercise (Colcombe et al., 2006). Of course, these factors are inevitably inter-related (Scarmeas et al., 2009). Consistent with the vascular and stress hypotheses, healthy diet and exercise are also well-known to promote good cardiovascular health (normal blood pressure, weight, blood glucose and blood cholesterol) and to reduce stress.

Other protective factors are rooted in social experience with associated cognitive expertise. Those with more education are less prone to manifest cognitive declines (Sando et al., 2008). Bilinguals also seem to be resilient to dementia, with the onset of dementia being delayed about four years compared to its onset in monolinguals, presumably because frontal lobe executive functioning has been honed by the experience of communicating in two or more languages (Bialystok, Craik & Freedman, 2007). Employment experience can also be protective. Occupational complexity of work with people (Andel, Crowe, Pedersen, Mortimer, Crimmins, Johansson & Gatz, 2005; Kroger, Andel, Lindsay, Benounissa, Verreault & Lauri, 2008), with things (Kroger et al., 2008), and with ideas (Smyth, Fritsch, Cook, McClendon, Santillan & Friedland, 2004) is associated with lower dementia risk, and occupational complexity with ideas is associated with better cognitive functioning in older adults (Potter, Helms & Plassman, 2008). Higher cognition and lower rates of dementia were found in people living with spouses or partners and those with larger social networks for whom social and emotional support was more available.

Interventions to Promote Cognitive Health

Given the protective effects of physical, cognitive and social activity, it is not surprising that a variety of programs to promote cognitive health in older adults have been developed. As mentioned above, physical exercise has been shown to be beneficial (Colcombe et al., 2006). Also as mentioned above, more engagement in cognitive activities is associated with better cognitive functioning, less cognitive decline, and lower risk of dementia (Fratiglioni et al., 2004). Training with a computer-based program to increase cognitive activity has provided encouraging results based on changes in measures on standardized neuropsychological tests (Mahncke et al., 2006). Using a group memory intervention for those with mild cognitive impairment, positive outcomes have also been demonstrated, including improvement in memory skills and generalization of their use in everyday life (Troyer, Murphy, Anderson, Moscovitch, Craik, 2008). Using a social model of health promotion to increase physical, cognitive and social activity, older adults participated in a volunteer program in elementary school. Compared to controls, the volunteers demonstrated cognitive improvements on measures of executive functioning and memory (Carlson et al., 2008), with increased frontal activity during a task involving executive function (Carlson et al., 2009). Volunteers also demonstrated physical improvements on measures of walking speed and grip strength (Fried et al., 2004). Social benefits were also realized in terms of an increase in the number of people to whom they felt they could turn to for help.

Although the intersection of hearing health care with interventions to promote cognitive health has not been explicitly considered, it seems likely that there is a connection. It is well known that those with untreated hearing loss are at risk for withdrawal from social interaction. Participation in social interaction provides opportunities for cognitive stimulation and physical exercise. In order to maintain the active lifestyles that seem to slow cognitive decline, it would be very advantageous to maintain good communication function and social interaction. Thus, successful rehabilitation of hearing impairment may have much broader health benefits.

Conclusions

Auditory aging is complex and heterogeneous. New protocols need to be developed to enable more precise assessment of the sub-types of presbycusis. These variations in age-related hearing loss combine with a wide range of other health issues that can create additional barriers to communication. Hearing health care must take many factors into consideration when planning comprehensive interventions that meet the needs of older individuals. Importantly, there is a close connection between auditory and cognitive aging, both in healthy older adults and those who have impairments. In healthy aging, difficulty listening in challenging conditions can masquerade as or exacerbate cognitive processing declines. However, preserved knowledge and expertise can be used in a compensatory fashion to offset auditory processing problems. Thus, the use of supportive context is a useful strategy that should be incorporated into rehabilitative training for healthy older adults who are hard of hearing. For those with hearing and cognitive impairment, hearing health care professionals have an opportunity to contribute to promoting cognitive health as well as hearing health. Accurate assessment of auditory processing is necessary to accurately assess cognitive function, and it may even predict future cognitive function. Most importantly, the active lifestyles that seem to slow cognitive decline are likely to be achieved by those who retain good communication function and social interaction. Thus, the benefits of hearing rehabilitation may have even broader positive health consequences.

References

Andel, R., Crowe, M., Pedersen, N. L., Mortimer, J., Crimmins, El., Johansson, B., & Gatz, M. (2005). Complexity of work and risk of Alzheimer's disease: A population-based study of Swedish twins. *Journal of Gerontology: Psychological Sciences and Social Sciences,* 60B, 251–258.

Arlinger, S., Lunner, T., Lyxell, B., & Pichora-Fuller, M.K. (2009). The emergence of cognitive hearing science. *Scandinavian Journal of Psychology,* 50, 371–384.

Baltes, P. B., Cornelius, S. W., Spiro, A., Nesselroade, J. R., & Willis, S. L. (1980). Integration versus differentiation of fluid/crystallized intelligence in old age. *Developmental Psychology,* 16, 625–635.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: a new window into the study of cognitive aging? *Psychology and Aging,* 12, 12–21.

Ben-David, B.M., Chambers, C., Daneman, M., Pichora-Fuller, M.K., Reingold, E., & Schneider, B.A. (submitted). Effects of aging and noise on real-time spoken word recognition: Evidence from eye movements. *Journal of Speech, Language and Hearing Research.*

Bialystok, E., Craik, F. I. M. & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia,* 45, 459–464.

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging,* 17, 85–100.

Cabeza, R., Anderson, N., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: Compensatory brain activity in high-performing older adults. *NeuroImage,* 17, 1394–1402.

Carlson et al. (2005). *Gerontologist,* 48, 793

Carlson, M. C., Erickson, K. I., Kramer, A. F., Voss, M. W., Bolea, N., Mielke, M., McGill, S., Rebok, G. W., Seeman, T., & Fried, L. P. (2009). Evidence for neurocognitive plasticity in at-risk older adults: The Experience Corps Program. *Journal of Gerontoly A Biological Science Medicine,* 64, 1275–1282.

Carlson, M. C., Saczynski, J.S., Rebok, G.W., Seeman, T., Glass, T. A., McGill, S., Tielsch, J., Frick, K. D., Hill, J., & Fried, L. P. (2008). Exploring the effects of an "everyday" activity program on executive function and memory in older adults: Experience Corps. *Gerontologist,* 48(6), 793–801.

Cattell, R. B. (1971). *Abilities: Their structure, growth, and action.* New York: Houghton Mifflin.

CHABA (Committee on Hearing, Bioacoustics, and Biomechanics), Working Group on Speech understanding and Aging, National Research Council. (1988). Speech understanding and aging. *Journal of the Acoustical Society of America,* 83, 859–895.

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., Elavsky, S., Marquez, D. X., Hu, L., & Kramer, A. F. (2006). Exercise: An active route to healthy aging: Aerobic exercise training increases brain volume in aging humans. *Journal of Gerontology: Medical Sciences,* 61A, 1166–1170.

Craik, F. I. M. (2007). Commentary: The role of cognition in age-related hearing loss. *J Am Acad Audiol,* 18, 539–547.

Craik, F. I. M. (1983). On the transfer of information from temporary to permanent memory. *Philosophical Transactions of the Royal Society, Series B* 302, 341–359.

Craik, F. I. M. (1986). A functional account of age differences in memory (pp. 409–422). In F. Klix, & H. Hagendorf (eds.). *Human memory and cognitive capabilities: Mechanisms and performances.* New York: Elsevier Sciences.

Cunningham, W. R., Clayton, V., & Overton, W. (1975). Fluid and crystallized intelligence in young adulthood and old age. *Journal of Gerontology,* 30, 53–55.

Davis, M. H., Johnsrude, I. S., Hervais-Adelman, A., Taylor, K., & McGettigan, C. (2005). Lexical information drives perceptual learning of distorted speech: Evidence from the comprehension of noise-vocoded sentences. *Journal of Experimental Psychology,* 134, 222–241.

Dixon, R.A., & Bäckman, L. (1995). *Compensating for psychological deficits and declines: Managing losses and promoting gains.* Lawrence Erlbaum Associates: Mahwah, NJ.

Dubno, J. R., Ahlstrom, J. B., & Horwitz, A. R. (2000). Use of context by young and aged adults with normal hearing. *Journal of the Acoustical Society of America,* 107, 538–546.

Federmeier, K. D., & Kutas, M. (1999). Right words and left words: electrophysiological evidence for hemispheric differences in meaning processing. *Cognitive Brain Research,* 8, 373–392.

Foo, C., Rudner, M., Rönnberg, J., & Lunner, T. (2007). Recognition of speech in noise with new hearing instrument compression release settings requires explicit cognitive storage and processing capacity. *Journal of the American Academy of Audiology,* 18, 618–631.

Fratiglioni, L, Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. *Lancet Neurology,* 3, 343–53

Fried, L.P., Carlson, M.C., Freedman, M., Frick, K.D., Glass, T. A., Hill, J., McGill, S., Rebok, G. W., Seeman, T., Tielsch, J., Wasik, B. A., & Zeger, S. (2004). A social model for health promotion for an aging population: Initial evidence on the Experience Corps Model. *Journal of Urban Health: Bulletin of the New York Academy of Medicine,* 81, 64–78.

Gates, G. A., Feeney, M. P., & Mills, D. (2008). Cross-sectional age-changes of hearing in the elderly. *Ear and Hearing,* 29, 865–874.

Gates, G. A., Beiser, A., Rees, T. S., D'Agostino, R. B., & Wolf, P. A. (2002). Central auditory dysfunction may precede the onset of clinical dementia in people with probable Alzheimer's disease. *Journal of the American Geriatrics Society,* 50, 482–488.

Gates, G.A., Cobb, J.L., Linn, R.T., Rees, T., Wolf, P.A., & D'Agostino, R.B. (1996). Central auditory dysfunction, cognitive dysfunction, and dementia in older people. *Archives of Otolaryngology Head and Neck Surgery,* 122,161–67.

Gates, G. A., Feeney, M.P., & Higdon, R. J. (2003). Word recognition and the articulation index in older listeners with probable age-related auditory neuropathy. *Journal of the American Academy of Audiology,* 14, 574–81.

Gates, G. A., & Mills, J. H. (2005). Presycusis. *The Lancet,* 366, 1111–1120.

Gold, M., Lightfoot, L.A., & Hnath-Chisolm, T. (1996). Hearing loss in a memory disorders clinic: A specially vulnerable population. *Archives of Neurology,* 53, 922–928.

Gordon-Salant, S., & Fitzgibbons, P. J. (1997). Selected cognitive factors and speech recognition performance among young and elderly listeners. *Journal of Speech and Hearing Research,* 40, 423–431.

Gordon-Salant, S., Yeni-Komishian, G. H., Fitzgibbons, P. J., & Barrett, J. (2006). Age-related differences in identification and discrimination of temporal cues in speech segments. *Journal of the Acoustical Society of America,* 119, 2455–2466.

Goy, H., Pichora-Fuller, M. K., van Lieshout, P., Singh, G., & Schneider, B. A. (2007). Effect of within- and between-talker variability on word identification in noise by younger and older adults. *Canadian Acoustics,* 35, 108–109.

Hsiung, G.-Y. R., Sadovnick, A. D., & Feldman, H. (2004). Apolipoprotein E ™4 genotype as a risk factor for cognitive decline and dementia: Data from the Canadian Study of Health and Aging. *Canadian Medical Association Journal,* 171, 863–867.

ISO (International Organization for Standardization). (2000). *ISO 7029-2000: Acoustics – statistical distribution of hearing thresholds as a function of age.* 2nd ed. Geneva: International Organization for Standardization.

Just, M. A. & Carpenter, P. A. (1992). A capacity theory of comprehension: individual differences in working memory. *Psychological Review,* 99, 122–149.

Kemper, S. (1992). Language and aging (pp. 213–270). In F. I. M. Craik & T. A. Salthouse (eds.), *The handbook of aging and cognition.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Kiessling, J., Pichora-Fuller, M. K., Gatehouse, S., *et al.* (2003). Candidature for and delivery of audiological services: special needs of older people. *International Journal of Audiology, 42 (Supplement 2),* 2S92–2S101.

Kroger, E., Andel, R., Lindsay, J., Benounissa, Z., Verreault, R., & Lauri, D. (2008). Is complexity of work associated with risk of dementia? The Canadian Study of Health and Aging. *American Journal of Epidemiology,* 167, 820–830.

Lindenberger, U. & Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A sensory connection. *Psychology and Aging,* 9, 339–355.

Lindenberger, U. & Baltes, P.B. (1997). Intellectual functioning in old and very old age: Cross-sectional results from the Berlin Aging Study. *Psychology and Aging,* 12, 410–412.

Mahncke, H. M., Connor, B. B., Appelman, J., Ahsanuddin, O. N., Hardy, J. L., Wood, R.A., Joyce, N. A., Boniske, T., Atkins, S. M., & Merzenich, M. M. (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: A randomized, controlled study. *Proceedings of the National Academy of Science USA,* 103, 12523–12528.

Mattys, S.L., Brooks, J., & Cooke, M. (2009). Recognizing speech under a processing load: Dissociating energetic from informational factors. *Cognitive Psychology,* 59, 203–243.

McCoy, S. L., Tun, P. A., Cox, I. Colangelo, M., Stewart, R. A., & Wingfield, A. (2005). Hearing loss and perceptual effort: Downstream effects on older adults' memory for speech. *Quarterly Journal of Experimental Psychology,* 58A, 22–33.

MacDonald, H., Davis, M., Pichora-Fuller, M.K., & Johnsrude, I. (2008). Contextual influences: Perception of sentences in noise is facilitated similarly in young and older listeners by meaningful semantic context – neural correlates explored via functional magnetic resonance imaging (fMRI). *Journal of the Acoustical Society of America,* 123, 3887.

Mills, D.M. (2006). Determining the cause of hearing loss: Differential diagnosis using a comparison of audiometric and otoacoustic emission responses. *Ear and Hearing,* 27, 508–525.

Mills, J. H., Schmiedt, R. A., Schulte, B. A., & Dubno, J. R. (2006). Age-related hearing loss: A loss of voltage, not hair cells. *Seminars in Hearing,* 27, 228–236.

Obleser, J., Wise, R. J., Dresner, A. M., & Scott, S. K. (2006). Functional integration across brain regions improves speech perception under adverse listening conditions. *Journal of Neuroscience,* 27, 2283–2289.

Petrides, M., Alivisatos, B., Meyer, E., & Evans, A.C. (1993). Functional activation of the human frontal cortex during the performance of verbal working memory tasks. *Proceedings of the National Academy of Science USA,* 90, 878–882.

Perry, A. R., & Wingfield, A. (1994). Contextual encoding by young and elderly adults as revealed by cued and free recall. *Aging and Cognition,* 1, 120–139.

Pichora-Fuller, M.K. (2007). Audition and cognition: What audiologists need to know about listening (pp. 71–85). In C. Palmer, & R. Seewald (Eds.). *Hearing care for adults.* Phonak: Stäfa, Switzerland.

Pichora-Fuller, M. K. (2003). Cognitive aging and auditory information processing. *International Journal of Audiology,* 42 (Supp 2), S26–S32.

Pichora-Fuller, M.K. (2006). Perceptual effort and apparent cognitive decline: Implications for audiologic rehabilitation. *Seminars in Hearing,* 27, 284–293.

Pichora-Fuller, M.K. (2008). Use of supportive context by younger and older adult listeners: Balancing bottom-up and top-down information processing. *International Journal of Audiology,* 47 (Supp. 2), S144–154.

Pichora-Fuller, M.K., & MacDonald, E. (2008). Auditory temporal processing deficits in older listeners: A review and overview (pp. 297–306). In T. Dau, J. Buchholz, J. Harte, & T. Christiansen (eds), *Auditory signal processing in hearing-impaired listeners: Proceedings of the First International Symposium on Audiological and Auditory Research (ISAAR 2007).* Centertryk A/S: Holbæk, Denmark.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. *Journal of the Acoustical Society of America,* 97, 593–608.

Pichora-Fuller, M. K., Schneider, B. A., Hamstra, S., & Benson, N., & Storzer, E. (2006). Effect of age on gap detection in speech and non-speech stimuli varying in marker duration and spectral symmetry. *Journal of the Acoustical Society of America,* 119, 1143–1155.

Pichora-Fuller, M. K., Schneider, B. A., MacDonald, E., Pass, H. E., & Brown, S. (2007). Temporal jitter disrupts speech intelligibility. *Hearing Research,* 223, 114–121.

Pichora-Fuller, M. K., & Singh, G. (2006). Effects of age on auditory and cognitive processing: implications for hearing aid fitting and audiological rehabilitation. *Trends in Amplification,* 10, 29–59.

Pichora-Fuller, M.K., & Souza, P. (2003). Effects of aging on auditory processing of speech. *International Journal of Audiology,* 42 (Supp 2), S11–S16.

Potter, G. G., Helms, M. J., & Plassman, B. L. (2008). Associations of job demands and intelligence with cognitive performance among men in late life. *Neurology,* 70, 1803–1808.

Rosen, S., Olin, P., & Rosen, H.V. (1970). Dietary prevention of hearing loss. *Acta Otolaryngologica,* 70, 242–247.

Rudner, M., Foo, C., Sundewall-Thorén, E., Lunner, T., & Rönnberg, J. (2008). Phonological mismatch and explicit cognitive processing in a sample of 102 hearing aid users. *International Journal of Audiology,* 47, S91–S98.

Salthouse, T. (2004). What and when of cognitive aging. *Current Directions in Psychological Science,* 13, 140–144.

Sando, S. B., Melquist, S., Cannon, A., Hutton, M., Sletvold, O., Saltvedt, I., White, L. R., Lydersen, S., & Aasly, J. (2008). Risk-reducing effect of education in Alzheimber's disease. *International Journal of Geriatric Psychiatry,* 23, 1156–1162.

Saunders, G.H., & Echt, K. (2007). An overview of dual sensory impairment in older adults: Perspectives for rehabilitation. *Trends in Amplification,* 11, 243–258.

Scarmeas, N., Luchsinger, J. A., Schupt, N., Brickman, A. M., Cosentino, S., Tang, M. X., & Stern, Y. (2009). Physical activity, diet, and risk of Alzheimer Disease. *Journal of the American Medical Association,* 302, 627–637.

Scott, S. K., & Johnsrude, I. S. (2003). The neuroanatomical and functional organization of speech perception. *Trends in Neuroscience,* 26, 100–107.

Seidman, M. D. (2000). Effects of dietary restriction and antioxidants on presbycusis. *Larynoscope,* 110, 727–738.

Singh, G., Pichora-Fuller, M. K., & Schneider, B. A. (2008). Auditory spatial attention in conditions of real and simulated spatial separation by younger and older adults. *Journal of the Acoustical Society of America,* 124, 1294–1305.

Smith, S. L., Bennett, L.W., & Wilson, R.H. (2008). Prevalence and characteristics of dual sensory impairment (hearing and vision) in a veteran population. *Journal of Rehabilitation Research & Development,* 45, 597–610.

Sheldon, S., Pichora-Fuller, M. K., & Schneider, B. A. (2008a). Effect of age, presentation method, and training on identification of noise-vocoded words. *Journal of the Acoustical Society of America,* 123, 476–488.

Sheldon, S., Pichora-Fuller, M. K., & Schneider, B. A. (2008b). Priming and sentence context support listening to noise-vocoded speech by younger and older adults. *Journal of the Acoustical Society of America,* 123, 489–499.

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

Schneider, B. A., Pichora-Fuller, M. K., & Daneman, M. (2009). The effects of senescent changes in audition and cognition on spoken language comprehension (pp. 167-210). In S. Gordon-Salant, R. D. Frisina, A. Popper, & D. Fay (Eds), *The aging auditory system: Perceptual characterization and neural bases of presbycusis,* Springer Handbook of Auditory Research. Springer: Berlin.

Schuknecht, H. F. (1964). Further observations on the pathology of presbycusis. A*rchives of Otolaryngology,* 80, 369–82.

Schuknecht, H. F. (1955). Presbycusis. *Laryngoscope,* 65, 402–19.

Schuknecht, H. F., & Gacek, M. R. (1993). Cochlear pathology in presbycusis. *Ann Otol Rhinol Laryngol,* 102, 1–16

Sinha, U.K., Hollen, K.M., Rodriguez, R., & Miller, C.A. (1993). Auditory system degeneration in Alzheimer's disease. *Neurology,* 43, 779–85.

Smyth, K. A., Fritsch, T., Cook, T. B., McClendon, M. J., Santillan, C. E., & Friedland, R. P. (2004). Worker functions and traits associated with occupations and the development of AD. *Neurology,* 63, 498–503.

Sommers, M. S., & Danielson, S. M. (1999). Inhibitory processes and spoken word recognition in young and old adults: The interaction of lexical competition and semantic context. *Psychology and Aging,* 14, 458–472.

Sternberg, R. J. (2008). Increasing fluid intelligence is possible after all (Commentary). *Proceedings of the National Academy of Sciences U.S.A.,* 105 (19), 6791–679.

Troyer, A. K, Murphy, K. J., Anderson, N. D., Moscovitch, M., & Craik, F. I. M. (2008). Changing everyday memory behaviour in anmestic mild cognitive impairment: A randomised controlled trial. *Neuropsychological Rehabilitation,* 18, 65–88.

Uhlmann. R.F., Larson, E.B., Rees, T.S., Koepsell, T.D., & Duckert, L.G. (1989a). Relationship of hearing impairment to dementia and cognitive dysfunction in older adults. *Journal of the American Medical Association,* 261, 1916–1919.

Uhlmann, R.F., Teri, L., Rees, T.S., Mozlowski, K.J., & Larson, E.B. (1989b). Impact of mild to moderate hearing loss on mental status testing. *Journal of the American Geriatric Society,* 37, 223–228.

Vaughan, N., Storzach, D., & Furukawa, I. (2006). Sequencing versus nonsequencing working memory in understanding of rapid speech by older listeners. *Journal of the American Academy of Audiology,* 17, 506–518.

Vongpaisal, T., & Pichora-Fuller, M.K. (2007). Effect of age on F0 difference limen and concurrent vowel identification. *Journal of Speech, Language and Hearing Research,* 50, 1139–1156.

Weinstein, B.E, & Amsel L. (1986) Hearing loss and senile dementia in the institutionalized elderly. *Clinical Gerontologist,* 4(33), 3–15.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin,* 120, 272–292.

West, R. F., Stanovich, K. E., Cunningham, A. E. (1995). Compensatory processes in reading (pp. 275–296).

In Dixon, R., & Bäckman, L. (eds.). *Compensating for psychological deficits and declines:* Managing losses and promoting gains. Mahwah, NJ: Lawrence Erlbaum Associates.

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

Wingfield, A., & Tun, P. A. (2007). Cognitive supports and cognitive constraints on comprehension of spoken language. *Journal of the American Academy of Audiology,* 18, 548–558.

Wingfield, A., Tun, P. A., & McCoy, S. L. (2005). Hearing loss in older adulthood: What it is and how it interacts with cognitive performance. *Current Directions Psychological Sciences,* 14, 144–148.

Wingfield, A., Tun, P. A., Koh, C. K., & Rosen, M. J. (1999). Regaining lost time: adult aging and the effect of restoration o recall of time-compressed speech. *Psychology and Aging,* 14, 380–389.

Willott, J. F. (1991). *Aging and the auditory system: anatomy, physiology, and psychophysics.* San Diego: Singular.

Willott, J. F., Erway, L. C., Archer, J. R., & Harrison, D. E. (1995). Genetics of age-related hearing loss in mice II. Strain differences and effects of caloric restriction on cochlear pathology and evoked response thresholds. *Hearing Research,* 88, 143–55.

Zekveld, A. A., Heslenfeld, D. J., Festen, J. M., & Schoonhoven, R. (2006). Top-down and bottom-up processes in speech comprehension. *Neuroimage,* 32, 1826–36.