# Hearing Loss in Older Adulthood

## What It Is and How It Interacts With Cognitive Performance

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ABSTRACT—*Adult aging is accompanied by declines in many areas of cognitive functioning, including reduced memory for new information. Potential sources of these declines are well established and include slowed processing, diminished working-memory capacity, and a reduced ability to inhibit interference. In addition, older adults often experience sensory decline, including decreased hearing acuity for high-frequency sounds and deficits in frequency and temporal resolution. These changes add to the challenge faced by older adults in comprehension and memory for everyday rapid speech. Use of contextual information and added perceptual and cognitive effort can partially offset the deleterious effects of these sensory declines. This may, however, come at a cost to resources that might otherwise be available for "downstream" operations such as encoding the speech content in memory. We argue that future research should focus not only on sensory and cognitive functioning as separate domains but also on the dynamics of their interaction.*

KEYWORDS—*aging; verbal memory; hearing; speech perception; effort*

It is a stark reality that the ability to remember new information and the cognitive resources necessary to support this ability often decline in older adulthood. These declines have been characterized by Salthouse (1991) in terms of the metaphors of time (a slowing of processing rates), space (reduced storage capacity in working memory), and energy (reductions in attentional capacity, whether conceptualized as limitations in the executive component of working memory or as a reduction in allocatable attentional resources). Working memory refers to the ability to temporarily hold and manipulate information in active use. The central executive component of working memory organizes and coordinates multiple mental operations to be performed. To this list of age-related slowing and reductions in the capacity of working memory and attention, one may add also a reduced ability to inhibit potential sources of interference both at the level of perception and in mental operations (Stoltzfus, Hasher, & Zacks, 1996). Beyond the recognition that age-related changes in auditory and visual acuity may affect an older adult's performance, less attention has been paid to how cognitive effort may ameliorate such effects, or the extent to which perceptual effort may drain processing resources and result in a negative effect on cognitive performance. We will argue that this latter effect may be a significant one.

Although the arguments we offer can be applied widely across many domains of cognitive aging, our focus here is on comprehension and memory for spoken language. Unlike reading, where one can control the rate of input with eye movements or reread sections of text, speech rate is controlled by the speaker and any processing not completed as the speech is occurring must be conducted on a fading trace in memory of what the listener has heard. The real-time nature of natural speech makes a significant demand on speed of processing and working memory, two domains in which aging takes a toll.

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## AGE AND HEARING LOSS

Although many adults retain good hearing well into old age, some degree of age-related hearing loss (presbycusis) is not uncommon among older adults. A general hearing loss can arise from less efficient transmission of sound through the eardrum and ossicles in the middle ear (conductive hearing loss), but of greatest concern in aging are changes in the cochlea in the inner ear; loss of hair cells in the high-frequency region of the basilar membrane causes a loss of acuity for high-frequency sounds (sensorineural hearing loss), which can be especially debilitating for speech perception.

These peripheral changes may be assessed behaviorally by audiometric measures such as pure-tone and speech reception thresholds (the lowest intensities at which tones of various frequencies or specially recorded words can be detected 50% of the time). In addition to these measures, loss of outer hair cells (structures in the cochlea that respond to sound) can be assessed by measuring distortion-product otoacoustic emissions (a by-product of hair-cell movement); such emissions are absent or reduced in amplitude with hair-cell loss, which can compromise speech understanding. In spite of remarkable progress in hearing-aid technology, allowing selective amplification to match a user's audiometric profile and increasingly sophisticated signal processing, it has been estimated that 2 out of 3 older adults with hearing loss do not use hearing aids; nonuse is especially prevalent among people with mild hearing loss (National Academy on an Aging Society, 1999). In part, this may be due to a perceived social stigma associated with using hearing aids or delayed awareness of the hearing loss due to the gradualness of its onset. There are, however, additional factors that play a role.

In addition to the peripheral losses that hearing aids can help rectify, aging can also produce what we will refer to here as a deficit in central auditory processing: decreased efficiency of temporal resolution (the ability to detect and maintain the ordering of rapidly arriving sounds) and spectral resolution (isolation and discrimination of the frequency components of complex signals) as incoming sounds are processed. Although the loci of these deficits are a matter of interest in hearing science (Humes, Christopherson, & Cokely, 1992), there is no question that efficient spectral and temporal processing are critically important for speech perception.

Given that average speaking rates range from 140 to 180 words per minute in ordinary conversation, one can see how poor temporal resolution would have a negative impact on the recognition of speech and other complex signals. Difficulties with frequency discrimination may make it especially difficult to separate speech from background noise and the "babble" of other speakers (Gordon-Salant & Fitzgibbons, 1997; Schneider & Pichora-Fuller, 2000), a problem that adds to older adults' slowing in attention switching and declines in attentional focus at the cognitive level (Tun, O'Kane, & Wingfield, 2002). When these central auditory deficits are present, they cannot be ameliorated with simple sound amplification.

### Adult Aging and the Sensory–Cognitive Processing Chain

Although in the simplest sense one might contrast between cognitive declines on the one hand, and hearing declines on the other, one should rather think in terms of three levels of information processing, each of which may show age-related decline: (a) peripheral hearing acuity, (b) central auditory processing, and (c) cognitive operations. There is considerable blurring at the boundaries and there are interactions among the different levels. For example, to comprehend spoken language, a listener needs to extract stable linguistic information from a constantly changing speech stream. This is referred to as normalizing the speech signal, to allow speech sounds to be recognized in spite of variability in pronunciation or accent from one speaker to another. In an elegant set of studies, Sommers (1996) has shown how such normalization may impose especially heavy processing demands on older adults' more limited resources. Normalization would clearly be affected by peripheral hearing loss at the high frequencies, by central auditory changes affecting temporal and frequency resolution, and, as Sommers has pointed out, by declines in cognitive resources.

We list these interacting operations and limitations schematically in Figure 1. The first operation depicted in Figure 1, labeled as perceptual operations, requires an adequate level of function in both peripheral and central auditory processing. The second two levels of information processing represented in the diagram are the cognitive operations of encoding in working memory and higher-level encoding. The diagram illustrates the principle of multiple processing operations drawing to varying degrees on a limited-capacity resource system that is generally presumed to decrease with age. Terms such as working memory capacity and processing resources coexist as characterizations of this resource-limited system; there is also a major question of whether there are process-specific resources that may not draw on general resource capacity.

### Contextual Support Can Compensate for Sensory Loss

Although aging may be accompanied by performance declines at multiple levels, linguistic knowledge is well preserved into older adulthood. This knowledge can be effectively used by older adults in word recognition, whether the challenge comes from underarticulation of the speech signal, as is common in ordinary conversation (Wingfield, Alexander, & Cavigelli, 1994); from speech being masked by noise (Schneider & Pichora-Fuller, 2000); or from reduction of sensory richness due to presbycusis (Gordon-Salant & Fitzgibbons, 1997; Schneider & Pichora-Fuller, 2000). Older adults are also frequently adept at using linguistic knowledge to support recall by reconstructing missing elements to give coherence to what they have heard (Wingfield, Tun, & Rosen, 1995). That a weakened signal may be compensated for by context has been well documented in the literature. Only recently, however, has there been renewed attention to the possibility that this compensation may come at a cost.

## A COST OF SUCCESSFUL PERCEPTION

When the older adult shows poorer recall for spoken stimuli, careful investigators typically take steps to insure that the stimuli (e.g., spoken word lists or sentences) can be correctly identified at the perceptual level. In addition to audiometric screening, having participants "shadow" speech (i.e., repeating each word as it is being heard) can help confirm this ability. Thus, if older adults can successfully shadow speech presented at the same intensity as the to-be-remembered stimuli, it might seem reasonable to exclude differences in hearing acuity as a contributing source of any age-related declines in recall that may be found.

We argue, however, that a consequence of even a mild peripheral or central auditory impairment in older adults may be the need to exert extra effort in order to achieve perceptual success.

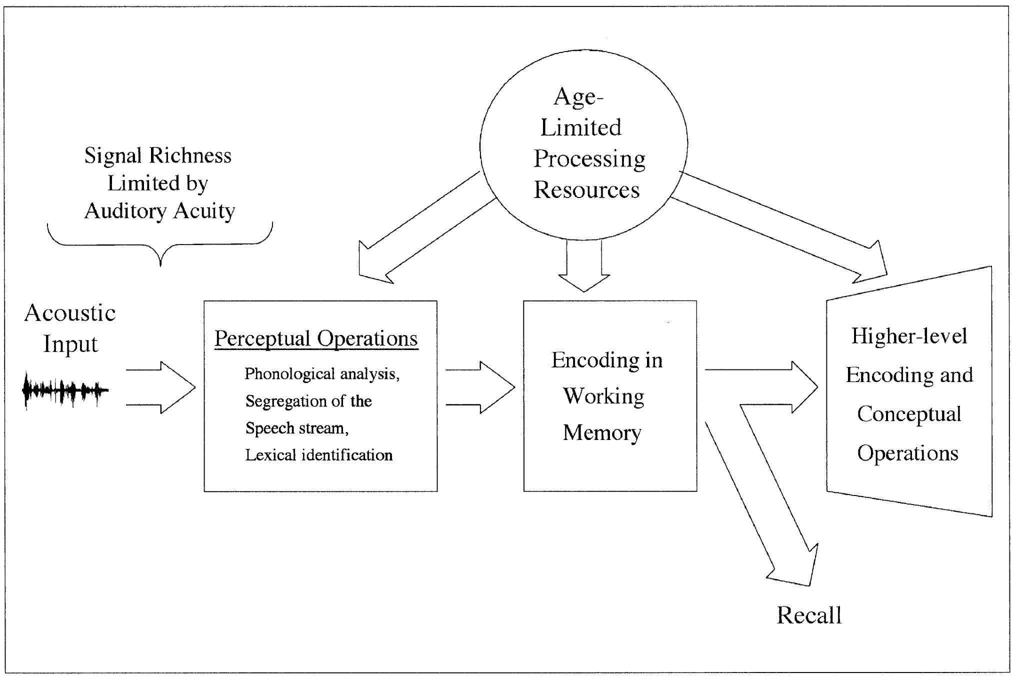


**Fig. 1.** Schematic diagram of the operations required for successful recognition of a speech message, beginning with the perceptual segregation of a continuous speech stream into its constituent words. The product of the perceptual analysis can be encoded in working memory for overt recall as well as serving as input to higher stages, such as understanding the input at the conceptual and discourse levels. Processing at each stage can be facilitated (or on occasion misled) by contextual support, such as the presence of a constraining linguistic context, when available. Age-related factors that may interfere with success include reduced signal richness consequent to peripheral hearing loss (such as a reduced ability to hear the high frequency sounds in speech) and central-auditory-processing deficits (such as reduced ability to discriminate the frequency components of complex auditory signals and to detect and maintain the ordering of rapid arriving sounds).

The concern here is that this more effortful processing in the initial stages of speech perception may come at the cost of processing resources that would otherwise be available for downstream operations, such as effective encoding of the material in memory for recall or performing higher-level comprehension operations. This "effortfulness" hypothesis was well-articulated over 30 years ago (Rabbitt, 1968). It has, however, only recently received renewed attention.

## An Effortfulness Hypothesis

In a recall experiment, Rabbitt (1968, Experiment 2) gave young adults with normal hearing sets of spoken 8-digit lists, each list presented in two halves with a 2-second pause after the first 4 digits. He found that the first half of the list, even when presented clearly and without masking, was less well recalled when the second half of the list was heard in noise rather than in quiet. Rabbitt interpreted these findings as suggesting that the increased effort required to identify the noise-masked digits may have deprived the listeners of processing resources that might have been used to rehearse the previous digits for effective memory.

Rabbitt (1991) later reinforced this interpretation by showing better recall for older adults with good hearing than for those with a mild hearing loss, even when both groups could correctly repeat words heard at the same intensity levels as the to-be-remembered stimuli. Rabbitt argued that the older adults with a mild hearing loss had to allocate more processing resources to identify the spoken stimuli, thus reducing available resources that might otherwise have been deployed to support encoding of the materials in memory (Rabbitt, 1991; see also Dickinson & Rabbitt, 1991, for an analogous argument for degraded vision). Through the recent efforts of such investigators as Murphy, Craik, Li, & Schneider (2000), who studied memory performance with noise masking used to simulate a hearing loss in young and older adults, this effortfulness position has begun to receive considerable attention (Schneider & Pichora-Fuller, 2000; Tun et al., 2002).

How powerful is the effortfulness effect? To explore this question we compared word-list recall in older adults who had good hearing with that in older adults who had mild-to-moderate hearing loss. Participants heard 15-word lists that were stopped at random points, and all that was required of them was to recall just the last three words that they heard. As shown in Figure 2, we found that although both groups showed excellent recall for the final word of the three-word sets, recall of the two words that preceded it was poorer for the hearing-loss group than for the participants with better hearing, even though all three words were delivered at the same amplitude (volume). The data shown in Figure 2, which are taken from McCoy et al., 2005, are for sets of

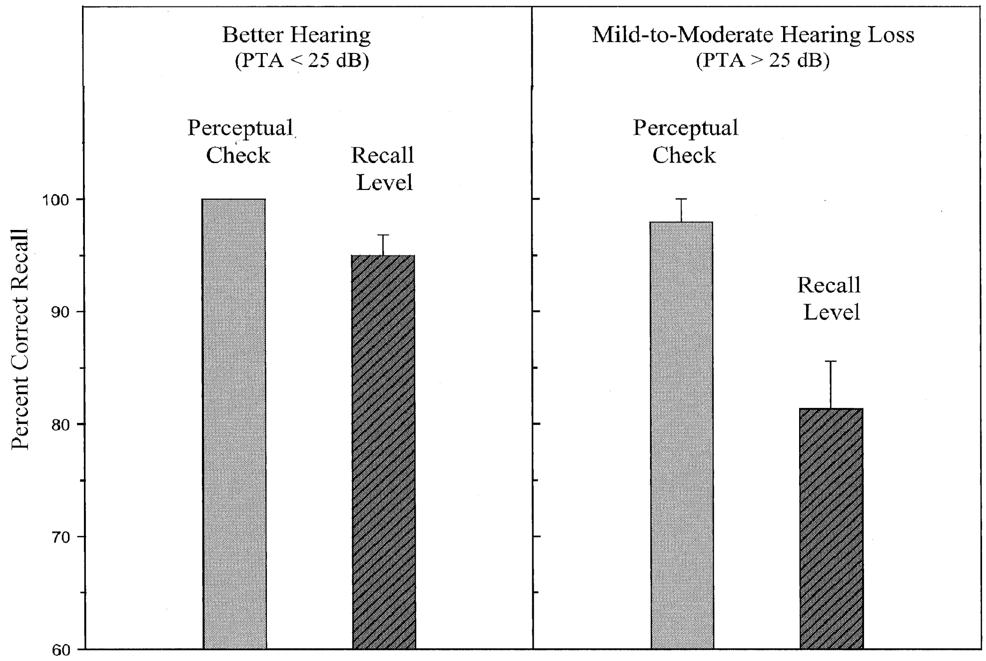


**Fig. 2.** Effect of hearing loss on word-list recall for two groups of older adults. Left panel shows percent correct recall for participants with better hearing, defined as a pure-tone average (PTA) of less than 25 dB (the ability to hear pure tones averaged across frequencies of 1000, 2000, and 4000 Hz for the better ear). The right panel shows corresponding data for age-matched participants with a mild-to-moderate hearing loss (PTA greater than 25 dB). The left bar in each panel shows recall accuracy for the final word of the three-word recall sets as a perceptual check to insure that the stimulus words could be correctly identified at the intensities at which they were heard. The right bars in each panel show mean recall for the first two words of the three-word recall sets. To support the position that the greater number of errors in the poorer hearing group was due not to a failure of perceptual identification of the words but to a detrimental effect on memory encoding due to increased effort in processing the stimulus words, we show recall only for cases where the final words of the sets were recalled correctly (100% of the cases for the better hearing group; 97.0 % of the cases for the hearing loss group).

unrelated words unsupported by the constraints of context that are found in meaningful connected speech such as sentences or passages. In this same experiment we also showed that contextual constraints can significantly ameliorate this diminished recall among hearing-impaired participants (McCoy et al., 2005).

Because both of the groups could correctly report the final word of the three-word sets, we concluded that the reason for the hearing-loss group's failure to recall the previous two words was not that they had failed to correctly identify them. Consistent with Rabbitt's effortfulness hypothesis, we interpreted our results as showing that the extra effort the older adults with hearing loss had to expend to achieve their perceptual success came at the cost of processing resources that would otherwise have been available for encoding the words in memory. It is especially noteworthy that this effect was so powerful as to influence memory performance for just a three-word memory set.

## CAUTIONS, CONCLUSIONS, AND FUTURE DIRECTIONS

Results such as these suggest that the question of age differences in comprehension or memory for speech should not necessarily be framed simply in terms of whether poor performance on a test of memory or comprehension is due to poor hearing or to declines at the cognitive level. Certainly, sufficiently sensitive test procedures need to be developed to determine contributions at all three levels: peripheral, central, and cognitive. We have suggested, however, that these levels should not be seen as independent, but rather that the theoretical question that should engage researchers is one of how these levels interact. On the one hand, hearing scientists must determine the extent to which markers of central auditory decline such as declines in frequency- or temporal resolution are independent of, or may be related to, peripheral hearing loss (e.g., Humes et al.,1992). On the other hand, we need also to pursue the apparent paradox implied by the effortfulness notion: that hearing loss can contribute to memory failure even when it can be demonstrated that all of the to-be-recalled stimuli could be correctly identified. In making this argument, we would not wish to imply that perceptual effortfulness is the only way in which poor hearing could affect recall of correctly identified spoken words. For example, poor hearing might strip the memory representation of extra-lexical features such as voice quality that might add distinctiveness to the memory trace.

As we caution against framing the sensory-cognitive interaction in either–or terms, we would also caution against rushing to conclude that sensory declines, whether visual or auditory, underlie all of the many cognitive, memory, and attentional declines that can accompany the aging process. That is, recognizing the importance of age-related sensory changes should not be seen as an argument against the existence of working-memory or other cognitive declines over and above these input limitations. Indeed, to the extent that older adults begin with more limited resources, the extra effort required at the sensory level could further add to the differential memory effects often seen in older adults' verbal recall.

In calling for a more comprehensive approach to broadening our understanding of sensory and cognitive declines in adult aging we would also encourage greater attention to individual-difference factors ordinarily associated with social and personality psychology, such as the potential effects of perceived self-efficacy on the degree of effort a person gives to a task. This broadening of the research scope could add further insight to the increasing evidence that cognitive performance may be reduced by perceptual effort even when, paradoxically, it can be shown that the to-be-remembered stimuli were correctly identified. These and related findings point to the need for awareness of the importance of sensory ability in studies of cognitive function in adult aging, as well as emphasizing the need for research that may better inform our understanding of the dynamics of sensory–cognitive interactions.

**Recommended Reading**

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