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Review

A review of causal mechanisms underlying the link between age-related hearing loss and cognitive decline

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ABSTRACT

Accumulating evidence points to a link between age-related hearing loss and cognitive decline, but their relationship is not clear. Does one cause the other, or does some third factor produce both? The answer has critical implications for prevention, rehabilitation, and health policy but has been difficult to establish for several reasons. First, determining a causal relationship in natural, correlational samples is problematic, and hearing and cognition are difficult to measure independently. Here, we critically review the evidence for a link between hearing loss and cognitive decline. We conclude that the evidence is convincing, but that the effects are small when hearing is measured audiometrically. We review four different directional hypotheses that have been offered as explanations for such a link, and conclude that no single hypothesis is sufficient. We introduce a framework that highlights that hearing and cognition rely on shared neurocognitive resources, and relate to each other in several different ways. We also discuss interventions for sensory and cognitive decline that may permit more causal inferences.

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1. A consideration of causal mechanisms underlying the link between age-related hearing loss and cognitive decline

Age-related changes in sensory sensitivity and acuity, and in cognitive processing, are among the most robust findings in psychology. Such declines will become more common as the world's population shifts towards a greater number of older adults (Mathers et al., 2000; World Health Organization, 2012). Declines in hearing and cognition are functionally interdependent, since there is no sharp division between sensation and perception, and cognition. A growing body of research highlights the role of cognitive abilities in supporting speech comprehension, particularly when the speech signal is ambiguous due to background noise, semantic ambiguity, or unusual talker characteristics (e.g., accents; see Akeroyd, 2008; Heald and Nusbaum, 2014; Wingfield and Tun, 2007 for reviews). The mapping of ambiguous speech sounds onto the corresponding linguistic representations is a knowledge-guided process, and probably depends on working memory, executive functioning, and processing speed for efficient operation. Although cognitive contributions to everyday speech comprehension are well-established, whether peripheral hearing level, and general (i.e., not specifically auditory) cognitive function are somehow linked in old age is not clear.

Both age-related hearing loss and cognitive decline are associated with communication difficulties, isolation, decreased quality of life, and depression (Bozeat et al., 2000; Cacciatore et al., 1999; Carabellese et al., 1993; Comijs et al., 2004; Holmen et al., 2000; Mulrow et al., 1990). Recently, Lin et al., have suggested that hearing loss may play a causal role in precipitating cognitive decline (Lin et al., 2013; Lin et al., 2011a,c), and the relationship between hearing loss and cognitive decline has attracted increased attention in recent months (Albers et al., 2015; Panza et al., 2015; Barnabei et al., 2014). A clearer understanding of the nature of the relationship between hearing loss and cognitive decline is critical if we are to minimize their impact, either in isolation or together, on quality of life, and to develop effective prevention and rehabilitation strategies (Lin et al., 2013; Pichora-Fuller, 2003). If hearing loss does contribute to cognitive decline, a case may be made to offer hearing aids or other rehabilitative strategies much earlier in the course of auditory decline, and to promote their use more aggressively; this has important health care and public policy implications. Further, the degree to which such interventions are effective will depend on the size of the effect for the relationship between age-related hearing loss and cognitive decline; a larger effect size makes it more likely that such interventions will have a clinically significant impact.

In this paper, we critically examine the evidence for a link between hearing loss and cognitive decline. We begin by explaining what we (and most others, in our opinion) mean by "hearing loss" and "cognitive decline." Then, we assess empirical support for a link, taking effect sizes into account. We follow this with a discussion of the evidence for and against several different possible causal relationships. Overall, we conclude that evidence supports a significant, but reliable relationship between age-related hearing loss and cognitive decline. In addition, we conclude that the link cannot be satisfactorily explained by any single mechanism; we end with an alternative view that incorporates multiple possible mechanisms, taking the strengths of each.

2. Operational definitions of hearing loss and cognitive function, and their limitations

The ways in which hearing and cognition are operationally defined and assessed will influence the nature of the apparent relationship between them. Hearing loss in studies that have evaluated links with cognitive function has almost exclusively been measured using pure-tone audiometry (PTA), in which detection thresholds for pure tones across a range of frequencies are measured monaurally, yielding indices of hearing sensitivity (e.g., Anstey et al., 2001a,b; Gennis et al., 1991; Kiely et al., 2012; Lin et al., 2013; Lin, 2011 Lin et al., 2011a,c; see Akeroyd, 2008 for a review). Hearing loss is typically defined as at least an average 25-dB HL elevation in detection thresholds across frequency regions necessary for speech comprehension (0.5–4 kHz; note that selected frequency regions vary between studies), and less typically as thresholds at the worst measured frequency.

Older adults commonly complain of difficulty understanding speech in noise, although audiometric measurements are often normal. Indeed, functionally relevant loss can occur in the absence of elevation of pure-tone thresholds (Frisina et al., 1997; He et al., 1998; Hopkins and Moore, 2011; Schneider, 1997; Snell and Frisina, 2000; Kujawa and Lieberman, 2009). In fact, peripheral hearing ability encompasses a number of factors other than pure-tone sensitivity, including frequency selectivity, temporal coding fidelity, intensity resolution and loudness, among others, which are not commonly measured.

Auditory filters appear to broaden with age, reducing frequency selectivity such that sounds that are cleanly resolved in the young, normally hearing ear are 'blurred together' in older adults with hearing loss (Glasberg et al.,1984; He et al., 2007; Patterson et al., 1982). Reduction in frequency selectivity is thought in part to reflect a loss of the frequency-specific gain generated by the outer hair cells, which are vulnerable to damage from noise exposure (e.g., Fernandez et al., 2015; Liberman et al., 2014; see also Stamper and Johnson, 2015). High-threshold auditory-nerve fibers (medium- and low-spontaneous rate fibers), which are thought to be important for temporal coding fidelity (and hence representation of precise frequency information), also appear to be disproportionately damaged by noise (compared to high spontaneous-rate fibers and hair cells; Kujawa and Liberman, 2009; Ruggles et al., 2012; Plack et al., 2014). This cochlear synaptopathy, undetectable using conventional audiometry, would particularly degrade transmission of moderate to intense sounds and may underlie the speech in noise difficulties experienced by older listeners. Although age-related deficits in suprathreshold processing and cochlear synaptopathy appear to precede threshold elevations (e.g., Sergeyenko et al., 2013; Kujawa and Liberman, 2015), pure-tone audiometry remains the gold standard for clinical assessment of hearing loss.

Non-audiometric measurements of hearing loss are relatively rare in the literature relating it to cognitive decline, but include speech-in noise-performance (Gennis et al., 1991, Gates et al., 1996; Wong et al., 2014) and psychophysical measures of temporal resolution, including temporal gap detection, temporal order identification, and temporal masking (Humes et al., 2013a see also, Humes et al., 2013b. Such measures may well pick up deficits that correlate with cognitive decline and a focus on audiometric measures may therefore underestimate the relationship with cognitive function (Humes et al., 2013a).

Different cognitive processes are differentially affected by aging (Jagust, 2013), with domains such as processing speed and memory more subject to decline, compared to language and general reasoning (Salthouse, 1996). Studies have generally employed inconsistent definitional criteria for cognitive decline. Some studies operationalize cognitive decline (usually dementia) as a clinical impairment relative to a normal control group through clinical consensus and the criteria of the Diagnostic and Statistical Manual of Mental Disorders (DSM; American Psychiatric Association, 2000). Other studies index cognitive decline through change in performance on tests of cognition. Note that these may not reflect only clinical declines, as the distinction between normative and clinical declines in cognition (i.e., dementia) is based on functional