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Disregarding hearing loss leads to overestimation of age-related cognitive decline

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A B S T R A C T

Aging is associated with cognitive and sensory decline. While several studies have indicated greater cognitive decline among older adults with hearing loss, the extent to which age-related differences in cognitive processing may have been overestimated due to group differences in sensory processing has remained unclear. We addressed this question by comparing younger adults, older adults with good hearing, and older adults with poor hearing in several cognitive domains: working memory, selective attention, processing speed, inhibitory control, and abstract reasoning. Furthermore, we examined whether sensory-related cognitive decline depends on cognitive demands and on the sensory modality used for assessment. Our results revealed that age-related cognitive deficits in most cognitive domains varied as a function of hearing loss, being more pronounced in older adults with poor hearing. Furthermore, sensory-related cognitive decline was observed across different levels of cognitive demands and independent of the sensory modality used for cognitive assessment, suggesting a generalized effect of age-related hearing loss on cognitive functioning. As most cognitive aging studies have not taken sensory acuity into account, age-related cognitive decline may have been overestimated.

1. Introduction

Aging is associated with deficits in several cognitive functions, including selective attention, working memory, processing speed, and abstract reasoning (e.g., Grady, 2012; Hedden and Gabrieli, 2004; Salthouse, 2004). For example, older adults typically perform worse than younger adults at tasks that require attending to relevant information and ignoring irrelevant information (e.g., Stroop task; Spieler et al., 1996). Similarly, older adults have been shown to perform worse than younger adults in working memory tasks, with age-related differences increasing as a function of memory load (e.g., Mattay et al., 2006; Van Gerven et al., 2007). In addition to cognitive deficits, aging is strongly associated with a decline in sensory functioning. Indeed, age-related hearing loss (i.e., presbycusis) is estimated to affect around 40% of the elderly population (Van Eyken et al., 2007). Visual impairments, such as presbyopia and reduced peripheral vision, are likewise common, affecting nearly all aging individuals (Owsley, 2011).

Over the last decades, a number of studies have shown greater cognitive decline among older individuals with hearing loss (e.g., Dupuis et al., 2015; Lin, 2011; Lin et al., 2011a, 2013; Lindenberger and Baltes, 1994; Moore et al., 2014; Rönnberg et al., 2014; Tay et al., 2006; Uhlmann et al., 1989; Valentijn et al., 2005; but see Anstey et al., 2001; Gennis et al., 1991), as well as among those with visual decline (e.g., Anstey et al., 2001; Dupuis et al., 2015; Elyashiv et al., 2014; Gussekloo et al., 2005; Lin et al., 2004; Tay et al., 2006; Valentijn et al., 2005). Furthermore, age-related hearing loss appears to be not only more prevalent in individuals with dementia than in age-matched controls (Uhlmann et al., 1989), but also independently associated with incident dementia (Lin et al., 2011b; Gallacher et al., 2012; see also Albers et al., 2015).

To account for the link between sensory and cognitive decline in aging, a number of hypotheses have been formulated (for recent reviews, see Roberts and Allen, 2016; Wayne and Johnsrude, 2015). According to the common cause hypothesis (Baltes and Lindenberger, 1997; Lindenberger and Baltes, 1994), a common mechanism (i.e., general neural degeneration) underlies both age-related sensory decline and age-related cognitive decline. According to the cognitive load on perception hypothesis (Lindenberger and Baltes, 1994), cognitive decline places a higher cognitive load on perception, resulting in sensory decline. According to the

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information degradation hypothesis (Schneider and Pichora-Fuller, 2000) and the sensory deprivation hypothesis (Lindenberger and Baltes, 1994),—recently merged into the sensory hypothesis (see Wayne and Johnsrude, 2015)—sensory decline consumes additional cognitive resources, resulting in cognitive decline. However, while the former hypothesis suggests that these effects are short-term and potentially remediable, the latter hypothesis proposes more permanent effects of sensory decline on cognitive function.

The association between sensory and cognitive decline among older adults—allied to the fact that the vast majority of cognitive aging studies have confounded age and sensory decline by comparing sensory-intact younger adults to sensory-impaired older adults (see Roberts and Allen, 2016)—raises the question of whether previously reported age-related cognitive deficits may, in fact, have been overestimated due to age-related sensory decline. Some studies have started to investigate the role of sensory decline on age-related differences in cognitive functions, using one of two approaches. In the perceptual matching approach, sensory stimulation can be adjusted to compensate for sensory decline in older individuals (e.g., Heinrich and Schneider, 2011; Murphy et al., 1999; Schneider et al., 2000) or sensory deficits can be simulated in younger adults (e.g., Ben-David and Schneider, 2010; Brown and Pichora-Fuller, 2000; Jorgensen et al., 2016; Mund et al., 2010; Pichora-Fuller et al., 2007; Wood et al., 2009). Such studies have shown that compensating for age-related sensory decline leads to improvements in performance (e.g., Murphy et al., 1999; Schneider et al., 2000), and that reducing the sensory acuity of younger adults leads to cognitive deficits that emulate, at least to some extent, age-related effects (Ben-David and Schneider, 2010; Brown and Pichora-Fuller, 2000; Mund et al., 2010; Pichora-Fuller et al., 2007; Wood et al., 2009; see also Jorgensen et al., 2016). In the group matching approach, younger and older adults are matched with respect to their sensory acuity (e.g., Baldwin and Ash, 2011; Dubno et al., 1984; Dupuis et al., 2016; Füllgrabe et al., 2015; Hopkins and Moore, 2011; Pichora-Fuller et al., 1995; Smith et al., 2016; Stewart and Wingfield, 2009; Verhaegen et al., 2014). So far, these studies have focused almost exclusively on the impact of hearing status on age-related differences in speech perception and auditory short-term memory, revealing that they are reduced (Pichora-Fuller et al., 1995; Smith et al., 2016) or even abolished (Verhaegen et al., 2014; see also Füllgrabe et al., 2015) when older adults are compared with hearing-matched younger adults. Finally, a recent study has shown that—while age, sensory processing, and cognitive processing are all significantly correlated—the correlation between age and cognitive processing disappears when global sensory processing is controlled for, suggesting that age-related cognitive decline is entirely mediated by sensory deficits (Humes et al., 2013). Taken together, these studies raise the compelling possibility that cognitive deficits that have been typically ascribed to aging—and often proposed as mechanistic explanations of cognitive aging itself (e.g., processing speed, working memory, inhibitory control)— may have been greatly overestimated in previous research, if not actually result from age-related sensory decline.

The overarching goal of this study was to investigate the effect of age-related hearing loss on age-related differences in cognitive processing. To this end, we have re-analyzed the data of studies in which we had previously found age-related differences in performance (see section 2.1), while taking into account the hearing status of the older sample. Specifically, older adults were classified into those with good hearing and those with poor hearing. The comparison between younger adults and older adults with good hearing reveals differences that can be primarily attributed to age-related cognitive decline, whereas the comparison between older adults with good hearing and older adults with poor hearing indicates differences in cognitive function that can be primarily attributed to age-related hearing loss. If age-related differences are mainly driven by hearing loss,—rather than by true cognitive decline—then they should be reduced or abolished when comparing younger adults and older adults with good hearing. If, however, age-related differences remain when comparing younger adults and older adults with good hearing, then they can be mainly attributed to true age-related cognitive decline.

A secondary goal of this study was to examine the role of cognitive demands on sensory-related cognitive decline. If the effects of hearing loss on cognitive processing are due to increased cognitive demands (as resources that would be available for cognitive processing are deployed for sensory processing; Schneider and Pichora-Fuller, 2000; Pichora-Fuller et al., 1995), then they should be modulated by cognitive load. In other words, sensory-related cognitive decline may not be visible at low cognitive load levels (when older adults with poor hearing may still be able to compensate for hearing decline), but may become particularly prominent in tasks imposing greater cognitive demands (and, thus, leaving fewer resources available to compensate for hearing decline). If, however, the effect of hearing loss on cognitive processing is independent of cognitive demands, then sensory-related cognitive decline may be expected regardless of cognitive load.

Finally, we deemed it crucial to determine whether sensory-related cognitive decline depends on the sensory modality used for cognitive assessment. If age-related hearing loss primarily affects performance on the auditory modality, then sensory-related cognitive decline should be predominantly observed in auditory tasks, but not necessarily in visual tasks. If, however, age-related hearing loss has a generalized impact on cognitive performance, then sensory-related cognitive decline should be observed across sensory modalities.

2. General methods

2.1. Participants

Participants were 103 younger adults and 92 older adults recruited in the context of a research project investigating the role of sensory modality in age-related differences in selective attention (Guerreiro and Van Gerven, 2011; Guerreiro et al., 2012, 2013, 2014, 2015; for a review Van Gerven and Guerreiro, 2016), conducted at Maastricht University[1]. Here, we exclusively focus on those tasks where age-related differences were observed and in which a sufficiently large number of participants took part (i.e., *n*-back task, Guerreiro and Van Gerven, 2011; Guerreiro et al., 2013; Stroop task, Guerreiro et al., 2013, 2014, 2015; Raven's Standard Progressive Matrices, Guerreiro and Van Gerven, 2011; Guerreiro et al., 2012, 2013, 2014, 2015) to investigate the effect of age-related hearing loss on age-related differences in cognitive processing.

2.2. Materials

2.2.1. Audiometric assessment

Hearing sensitivity was assessed with a screening audiometer (Voyager 522, Madsen Electronics, Taastrup, Denmark) in a dedicated sound-isolated room, by measuring pure-tone detection thresholds (in dB HL) in each ear at 0.5, 1, 2, and 4 kHz. The overall hearing acuity was expressed as the average hearing thresholds at 1,

[1] Because in the original research project we were interested in minimizing the potential influence of sensory deficits on age-related differences in selective attention, only participants who reported normal hearing (i.e., no hearing aids), as well as normal or corrected-to-normal vision, were included. Moreover, the testing protocol did not allow for the use of hearing aids.