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## How does hearing loss affect the brain?

“There is ample evidence linking hearing loss to changes in cognitive ability, particularly when listeners are faced with the task of understanding speech that is acoustically or linguistically challenging.”

Ageing  
HEALTH

Although estimates vary, some 40–50% of adults over the age of 65 years have a measurable hearing impairment, with this figure rising to 83% of those over the age of 70 years [1]. These data make hearing loss the third most prevalent chronic medical condition among older adults, after arthritis and hypertension [2]. Beyond the obvious impediment to spoken communication, we have come to realize that there are also hidden effects of hearing loss that may have significant consequences for both cognitive function and neural integrity.

Of special concern when considering hearing in aging is the loss of hair cells located on the basilar membrane in the cochlea in the inner ear: some 12,000–15,000 outer hair cells whose movement serves as a cochlear amplifier, and 3000 inner hair cells that transduce the mechanical vibrations into neural impulses that reach the primary auditory cortex via the eighth cranial nerve. Most notable in age-related hearing loss (presbycusis) is a loss of hair cells in the region of the basilar membrane that is responsive to the high-frequency sounds that are critically important for the perception of speech. As many older adults know only too well, over and above the attenuation of high-frequency sounds also comes an increased difficulty in hearing speech in the presence of background noise. Common instances of this include the din of traffic, the babble of overlaid conversations in a crowded restaurant, and situations when the acoustic ‘noise’ consists of two people talking at once [3].

In addition to the more obvious effects of reduced hearing acuity is a subtle, often unnoticed, effect of hearing impairment. This is the finding that successful perception of speech that is degraded by hearing loss can draw cognitive resources that might otherwise be available for encoding what has been heard in memory [4], or for the comprehension of rapid, informationally complex speech as often occurs in everyday life [5]. Our emphasis here is not on failures of perception, but rather, the effect on cognitive performance even when it can be shown that the speech itself has been successfully recognized.

This type of ‘effortful listening’ is associated with increased stress responses, changes in pupil dilation, and poorer behavioral performance (e.g., on memory tests for degraded speech). It is thus possible that even a mild-to-moderate hearing loss can inflate the appearance of cognitive decline in the older adult – a cautionary note for the geriatric clinician/diagnostician and family members alike. This sensory–cognitive interaction is a reminder that the auditory system may be the conduit to the brain, but it is the brain that ‘hears’ [6].

The connection between hearing acuity and cognition, however, may go beyond the effects of competition for limited resources under conditions of effortful listening. A striking finding from a recent large-scale population study has revealed a strong statistical connection between the appearance and degree of hearing loss and all-cause dementia [7]. Indeed, as Lin and colleagues have shown, this relationship persists even when adjusted for sex, age, race, education, diabetes, smoking history and hypertension [8]. This statistical relationship does not in itself establish causation, such as whether continuous perceptual effort with hearing loss takes a cumulative toll on cognitive reserves, whether the cognitive decline is consequent to depression and social isolation that can often accompany a serious hearing loss, or whether the parallel incidence of reduced hearing acuity and the appearance of dementia are independent reflections of an aging nervous system. It is also possible that all of these factors may be contributing to the relationship between hearing acuity and dementia to some degree. It is the case, however, that these findings join others that have begun to show a statistically reliable association between auditory processing deficits and the appearance of cognitive decline [9]. Although the relationship between hearing loss and cognitive ability must be rooted in the brain, only recently have cognitive neuroscientists begun to explicitly examine the neurobiological bases for these effects.

A recent pair of studies using MRI were aimed at precisely examining this link [10]. All



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of the participants in these studies were between the ages of 60 and 77 years, and reported themselves to have good hearing. Nevertheless, audiometric testing with pure-tone audiometry revealed a significant amount of variability in their hearing levels. This allowed examination of the effect of subtle individual differences in hearing ability and the function and structure of brain regions supporting speech comprehension.

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The first study used functional MRI to examine brain activity while participants listened to sentences that varied in their grammatical complexity, as it is well established that linguistically complex sentences rely on increased neural activity. The listeners with poorer hearing showed a smaller degree of change in their neural activity for the more complex sentences relative to the less complex ones in brain regions including the auditory cortex, which is the first cortical waystation for acoustic information processing in the brain. It would not be surprising if hearing acuity impacted low-level acoustic processing of speech, particularly in sensory regions of the brain. However, the presence of a significant interaction between hearing ability and linguistic difficulty in the functional MRI data suggests that listeners' hearing ability does not only impact their sensory processing of auditory information, but also impacts higher-level linguistic processes [10].

A second, related study, used structural MRI images to investigate the relationship between hearing ability and regional gray matter volume [10]. Intriguingly, the results revealed a significant correlation between individual differences in hearing ability and gray matter volume in the auditory cortex, such that people with poorer hearing also had a lower gray matter volume in that region. This relationship was spatially restricted, and not evident anywhere else in the brain. These findings suggest a possible biological link between sensory stimulation and cortical integrity, consistent with many animal models demonstrating cortical reorganization when sensory input is disrupted. In general, this

line of research suggests that decreased hearing ability has cascading consequences for the neural processes supporting both perception and cognition.

Given this discovered relationship between hearing ability and regional brain volume, one is bound to ask whether improving hearing ability through the use of hearing aids might help in preserving either cortical health or cognitive ability. Although this is an appealing suggestion, at this point it is too early to draw any firm conclusions. One reason for this is that the relationship between hearing ability and gray matter volume is correlational, without direct evidence as to its causality. As noted above, the same is true for the relationship between hearing loss and dementia.

With respect to the effect of hearing aids on cognitive function, the results of studies conducted to date have been mixed [11,12]. Although costly and time-consuming, large-scale, long-term, prospective longitudinal studies are likely needed to clarify the potential benefit of hearing aids for maintaining cognitive function. Such work should have a broad focus, as peripheral hearing loss influences the brain within a wide context of biological, social and emotional health. For example, people with hearing loss are more likely to avoid social situations, which may impact both physical activity and emotional well being, any of which may mediate the relationship between hearing ability and brain health [13].

In conclusion, there is ample evidence linking hearing loss to changes in cognitive ability, particularly when listeners are faced with the task of understanding speech that is acoustically or linguistically challenging. Recent studies have gone even further, suggesting a potential link between hearing loss and dementia [7–9]. Although more research is needed, the link between hearing ability and neural health is clearly a critical issue in public health that will benefit from increased awareness, resources and study.

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## References

1. Cruickshanks KJ, Wiley TL, Tweed TS *et al.* Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin. The Epidemiology of Hearing Loss Study. *Am. J. Epidemiol.* 148, 879–886 (1998).
2. Lethbridge-Cejku M, Schiller JS, Bernadel L. Summary health statistics for U.S. adults: National Health Interview Survey, 2002. *Vital Health Stat.* 10, 1–151 (2004).
3. Tun PA, O’Kane G, Wingfield A. Distraction by competing speech in young and older adult listeners. *Psychol. Aging* 17, 453–467 (2002).
4. Wingfield A, Tun PA, McCoy SL. Hearing loss in older adulthood: what it is and how it interacts with cognitive performance. *Curr. Dir. Psychol. Sci.* 14, 144–148 (2005).
5. Wingfield A, McCoy SL, Peelle JE, Tun PA, Cox LC. Effects of adult aging and hearing loss on comprehension of rapid speech varying in syntactic complexity. *J. Am. Acad. Audiol.* 17, 487–497 (2006).
6. Rönnerberg J, Rudner M, Lunner T. Cognitive hearing science: the legacy of Stuart Gatehouse. *Trends Amplif.* 20, 1–9 (2011).
7. Lin FR. Hearing loss and cognition among older adults in the United States. *J. Gerontol. Med. Sci.* 66A, 1131–1136 (2011).
8. Lin FR, Metter EJ, O’Brien RJ, Resnick SM, Zonderman AB, Ferrucci L. Hearing loss and incident dementia. *Arch. Neurol.* 68, 214–220 (2011).
9. Gates GA, Anderson ML, McCurry SM, Feeney MP, Larson EB. Central auditory dysfunction as a harbinger of Alzheimer dementia. *Arch. Otolaryngol. Head Neck Surg.* 137, 390–395 (2011).
10. Peelle JE, Troiani V, Grossman M, Wingfield A. Hearing loss in older adults affects neural systems supporting speech comprehension. *J. Neurosci.* 31, 12638–12643 (2011).
11. Mulrow CD, Aguilar C, Endicott JE *et al.* Quality-of-life changes and hearing impairment. A randomized trial. *Ann. Intern. Med.* 113, 188–194 (1990).
12. van Hooren SAH, Anteunis LJC, Valentijn SAM, Bosma H, Ponds RW, van Boxtel MPJ. Does cognitive function in older adults with hearing impairment improve by hearing aid use? *Int. J. Audiol.* 44, 265–271 (2005).
13. Gopinath B, Schneider J, McMahon CM, Teber E, Leeder SR, Mitchell P. Severity of age-related hearing loss is associated with impaired activities of daily living. *Age Ageing* 41, 195–200 (2012).