COGNITIVE CONTRIBUTIONS TO HEARING IN OLDER PEOPLE

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Abstract

Background: Hearing necessarily involves top-down influences on the sensory signals provided by bottom-up information from the ear. The top-down influences include elements of attention, memory, motivation, emotion, and learning, deriving from many regions of the cerebral cortex. They exert their influence via intra-cortical networks and auditory efferent pathways that extend back down the auditory system, right out to the ear. These 'cognitive' contributions to hearing affect sound detection, hearing-in-noise, and short- and long-term experiential modulation. Difficulty in speech perception in noisy environments (SiN) is the most common complaint that people of all ages and hearing levels make about their hearing. We review here aspects of those difficulties.

Methods: Studies considered recruited children and older adults with normal audiograms. Tests included speech-in-noise, cognition, and remote delivery via the internet. Interventions included wireless devices and training.

Results: For those with cochlear hearing loss, reduced sensitivity and broadened spectral and temporal processing contribute to poor speech perception in quiet and in noise. But for SiN, the nature of the noise is also important. Typically, able young adults can benefit from amplitude-modulated noise as it enables them to listen into the dips of the noise. They also benefit from a spatial separation between the target speech and the noise. However, those with reduced cognitive capabilities, notably children (especially those with learning difficulties), receive less benefit in these conditions. Older people have a high prevalence of both cochlear hearing loss and cognitive impairment. While these problems often occur together, and may be supra-additive and causally connected, they can also occur independently. We review studies showing that those (rare) older people with normal hearing sensitivity nevertheless have impaired SiN for both modulated and unmodulated noises, but older listeners show normal benefit from listening into the energetic minima of a fluctuating noise.

Discussion: Effective interventions to improve SiN in older people are likely to include reduction of room reverberation, instruction on viewing important sound sources, improved signal to noise (e.g. Bluetooth, FM), onset enhancement, directional microphones on hearing devices, and auditory training. Training should emphasise engagement with the target sound and is best achieved through the use of highly motivating exercises. These may involve the use of social engagement and salient signals (e.g. talk radio) that are also likely to enhance general cognitive well-being.

Conclusions: The reviewed studies – of development of hearing in children, of SiN perception in older adults, and of intervention – emphasise the role of top-down, cognitive factors in hearing, hearing impairment, and rehabilitation.

Background

The audiogram is currently still considered the 'gold standard' index of a person's hearing abilities. However, it has been known for at least 50 years that pure-tone sensitivity only partially predicts other forms of hearing commonly used outside the sound chamber. In addition, the audiogram of any given individual is subject to significant variability depending on, for example, practice (Zwislocki et al., 1958) and assessment method (Marshall and Jesteadt, 1986). Hearing abilities also vary across individuals with similar audiograms and can deviate considerably from predictions based on audibility. For example, despite having normal hearing sensitivity, some middle-aged listeners experience difficulties understanding speech in noisy restaurants and bars in which younger people still seem to communicate quite happily (Leigh-Pfaffenroth and Elangovan, 2011).

While much work has been done on the perceptual consequences of peripheral hearing loss (for an overview, see Moore, 1995), our research has primarily focused on auditory processing deficits and listening difficulties in young and older listeners with normal or near-normal audiograms (i.e. < 20–25 dB HL). We (Moore et al., 2010; 2011) showed that many typically developing, normal-hearing children (≤12 y.o.) have poorer performance and/or sensitivity and greater variability on a variety of noise-masked detection and supra-threshold tests of hearing, compared both to adult controls and to what would be expected based on their audiograms. Many of those with learning difficulties (e.g. language and reading impairment, attention deficits, and autistic disorders) but normal audiograms, have additional auditory perception problems – for example, impaired pure-tone frequency discrimination. In adults, processing and listening difficulties probably also contribute to the subjectively reported reduction with age in speech-in-noise intelligibility, but are generally difficult to study due to the simultaneously occurring progressive age-dependent loss in audibility (Davis, 1995). Controlling for peripheral factors by recruiting only older listeners (>60 y.o.) with normal audiograms (i.e. ≤20 dB HL for frequencies ≤6 kHz), we (Füllgrabe et al., 2011) recently showed more difficulties with speech-in-noise

(SiN) perception in these listeners than in younger controls (<30 y.o.) with matched average thresholds. These results are discussed in more detail in the following sections, but first we consider briefly the potential underlying mechanisms of these difficulties.

Successful auditory perception depends on the sensory processing of sounds in the ear and 'conventional' central auditory nervous system (CANS; auditory nerve to auditory cortex), and the interpretation and modulation of those sensations by the auditory cortex and higher cortical areas (Moore, 2012). A specific feature of the CANS is the dense and extensive descending projection pathway, extending from the cortex right out to the cochlea and the middle ear. In children, accumulating evidence suggests that the sensory processing of sounds matures early in life (<2 y.o.), more than a decade before mature perception is achieved. We and others have argued that this mismatch between the maturation of sensation and perception is due to the later development of cognitive processing underlying auditory cognition. In adults, possibly as early as 40–50 years, when hearing sensitivity is generally still normal, there are the first signs of a decline in supra-threshold auditory processing (Füllgrabe, 2012) and cognitive (Singh-Manoux et al., 2012) abilities. Hearing loss in older persons has also been associated with cognitive decline and neurodegenerative disorders (Lin et al., 2011).

Speech-in-Noise (SiN) Perception

The greatest challenge that people report with their hearing is listening in noise, and this is exacerbated for those with hearing loss. SiN identification is more cognitively demanding than tone detection, since it involves decoding a complex acoustic signal that must then be subject to further linguistic and language reconstruction. A feature of recent auditory research using SiN has been manipulations of the masking noise. The simplest masker is unmodulated flat-spectrum or speech-shaped Gaussian noise. When combined with simple words (e.g. the monosyllabic digits 0–9), speech detection thresholds (SDTs) for these SiN tests correlate highly with audiogram pure-tone averages. Maskers such as modulated noise or multi-talker speech (e.g. 'babble') provide a greater cognitive challenge, as they more closely resemble the target speech, leading to 'informational' masking. On the other hand, these maskers also provide an opportunity for the listener to 'glimpse' the target speech during the amplitude minima ('dips') in the masker (Füllgrabe et al., 2006).

It is surprising that, unlike the audiogram, there are no universally agreed measures of SiN identification. Obviously, such measures pose challenges across different languages and accents. Even cultural groupings could pose difficulties, for example, where nuanced use of certain words or phrases occurs. Nevertheless, closed-set lists of simple, commonly used ('high frequency' or 'high redundancy') individual words or syntactically legal sentences can address most of these challenges within a language or at a national level. In fact, with the advent of high-throughput SiN testing via the telephone and internet (Vlaming et al., 2011), there are now large corpora of data on two tests developed as part of the Hearcom EU project (www.hearcom.org), the Digit Triplets Test (Smits and Houtgast, 2005; Nachtegaal et al., 2012), and the Sentence Matrix Test (Hagerman and Kinnefors, 1995; Holube et al., 2010).

Latest Findings

Several laboratory studies have recently attempted to investigate systematically the distinctive effect of age on speech identification in clinically normal hearing using various types of speech materials and interfering maskers (e.g. Füllgrabe et al., 2011). Based on the above considerations, we might predict that, with declining supra-threshold sensory processing *and* cognitive function, older listeners would have more difficulty with SiN than predicted based on pure-tone audiometry. This should be reflected in greater age-related decline in speech identification than in audiometric threshold. Indeed, while identification of speech-in-quiet did not differ across age groups, consonant identification in both stationary and amplitude-modulated speech-shaped noise, and sentence identification in interfering speech babble, were impaired in older listeners. Moreover, there was a strong positive correlation between speech identification in noise and performance on a variety of cognitive tasks (notably fluid intelligence and verbal working memory). While the poorer performance of the older listeners in the stationary noise supports the prediction, the finding that those same listeners benefitted as much as the younger listeners from modulation of the masker suggests that they did not experience additional informational masking and could receive as much benefit from the amplitude dips in the masker as the younger listeners. It is possible that undiagnosed or high frequency hearing loss, exacerbated at higher (supra-threshold) levels, influenced speech-identification performance in the older listeners in all masking conditions. However, the relation between speech identification and cognitive performance is more difficult to explain. For example, children with mild–moderate hearing loss tend not to show impairment on tests of non-verbal cognition (Briscoe et al., 2001).

Implications for Rehabilitation

Borrowing again from our work with children, we (BSA, 2011; Moore et al., 2013) have recommended two primary forms of rehabilitation for impaired auditory perception. One is to increase signal-to-noise levels. This could involve very simple steps, improved listening strategies and environments, and wider use of the mushrooming number of wireless, remote microphone devices (e.g. ReSound Unite, Phonak iSense). Alternatively, training has shown convincing, clinically significant benefit in vision (acuity; Levi and Li, 2009) and memory (Holmes et al., 2009) studies. On the premise that perceptual learning is also closely related to, or primarily dependent on higher-order cognition (Amitay et al., 2006; Xiao et al., 2008), these results strongly suggest that a variety of forms of training could improve auditory perception and cognition. A number of computer-based training programs have been developed for the rehabilitation of hearing loss (e.g. 'LACE': Henderson-Sabes and Sweetow, 2007; Oba et al., 2011) or to improve listening skills (e.g. 'Phonomena': Moore et al., 2005; Halliday et al., 2012). However, while generally positive, the improvements achieved through training have been modest. There are many possible reasons for this, but much more extensive research in visual training (Li et al., 2011) suggests that the duration of auditory training needs to be extended by an order of magnitude or more (i.e. to 100+ hours), relative to that used thus far, to achieve substantial and lasting impact. To effect this, it may be preferable to adapt everyday listening tasks that are especially engaging for different demographic groups than to rely solely on computer games.

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