Hearing Research 350 (2017) 160–172

Contents lists available at ScienceDirect

Hearing Research

journal homepage: www.elsevier.com/locate/heares

Research Paper

Peripheral hearing loss reduces the ability of children to direct selective attention during multi-talker listening

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ARTICLE INFO

Article history:
Received 31 August 2016
Received in revised form
28 April 2017
Accepted 8 May 2017
Available online 10 May 2017

Keywords:
Hearing loss
Multi-talker listening
Auditory attention
Spatial attention
EEG
CNV

ABSTRACT

Restoring normal hearing requires knowledge of how peripheral and central auditory processes are affected by hearing loss. Previous research has focussed primarily on peripheral changes following sensorineural hearing loss, whereas consequences for central auditory processing have received less attention. We examined the ability of hearing-impaired children to direct auditory attention to a voice of interest (based on the talker's spatial location or gender) in the presence of a common form of background noise: the voices of competing talkers (i.e. during multi-talker, or “Cocktail Party” listening). We measured brain activity using electro-encephalography (EEG) when children prepared to direct attention to the spatial location or gender of an upcoming target talker who spoke in a mixture of three talkers. Compared to normally-hearing children, hearing-impaired children showed significantly less evidence of preparatory brain activity when required to direct spatial attention. This finding is consistent with the idea that hearing-impaired children have a reduced ability to prepare spatial attention for an upcoming talker. Moreover, preparatory brain activity was not restored when hearing-impaired children listened with their acoustic hearing aids. An implication of these findings is that steps to improve auditory attention alongside acoustic hearing aids may be required to improve the ability of hearing-impaired children to understand speech in the presence of competing talkers.

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1. Introduction

Listeners with normal hearing can deploy attention successfully and flexibly to a talker of interest when multiple talkers speak at the same time (Larson and Lee, 2014; O'Sullivan et al., 2014), an ability that is fundamental to successful verbal communication. These multi-talker (or “Cocktail Party”) listening environments are particularly challenging for people with hearing loss, as demonstrated both by accuracy scores and self-report (Dubno et al., 1984; Helfer and Freyman, 2008). As a result of this difficulty, children with hearing loss may be at a particular disadvantage when learning language, because they not only have to do so with distorted representations of the acoustic features of speech, but also frequently hear speech in acoustic environments with multiple competing talkers. At least part of the difficulty in multi-talker listening arises from impairments in peripheral transduction in the ear, including loss of sensitivity to higher frequencies (Hogan and Turner, 1998), impaired frequency selectivity (Gaudrain et al., 2007; Moore, 1998), and impaired ability to interpret temporal fine structure (Lorenzi et al., 2006). However, it is currently unclear to what extent atypical cognitive abilities contribute to the difficulties in multi-talker listening experienced by children with moderate hearing loss (who experience distortions in peripheral processing, although retain residual hearing). The current experiments compared the ability of hearing-impaired and normally-hearing children to direct preparatory attention to the spatial location or gender of a talker during multi-talker listening.

Cognitive abilities have been found to differ between children with normal hearing and children who use cochlear implants (CIs). Children with severe-to-profound hearing loss who use CIs score more poorly on tests of working memory and inhibitory control than normally-hearing children (Beer et al., 2014, 2011). This finding demonstrates that atypical auditory input can potentially affect the development of cognitive abilities. However, the extent to which preserved auditory encoding matters for executive function

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http://dx.doi.org/10.1016/j.heares.2017.05.005
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is currently unclear. Given that children with CIs have minimal residual hearing and may have undergone a period of auditory deprivation in childhood prior to implantation, it is uncertain whether people with less severe hearing losses or adults who acquired hearing loss later in life would also exhibit atypical executive functions.

As a result of the inherent difficulty of separating peripheral from cognitive processes, it remains unclear whether moderate hearing loss has downstream consequences for cognitive auditory abilities. Neher et al. (2009) used the Test of Everyday Attention (Robertson et al., 1996) to measure attention and working memory in adults with moderate hearing loss. Speech reception thresholds in hearing-impaired adults during multi-talker listening were correlated with selective attention, attentional switching, and working memory. However, most of the participants were older adults (mean age of 60 years) and speech reception thresholds were significantly correlated with age; thus, it is possible that declines in cognitive and peripheral auditory processing are unrelated to each other, but both related independently to aging (for example, as a result of decreased cortical volume in older people; e.g. Cardin, 2016).

Instead of using behavioural tests to investigate cognitive function, several studies have measured cortical responses in listeners with moderate hearing loss. For example, Peelle et al. (2011) found that average pure-tone hearing thresholds predicted the extent to which spoken sentences evoked activity in the bilateral superior temporal gyri, thalamus, and brainstem in hearing-impaired adults. Several studies using electro-encephalography (EEG) and magneto-encephalography (MEG) have also shown atypical auditory evoked activity in hearing-impaired adults (Alain et al., 2014; Campbell and Sharma, 2013; Oates et al., 2002) and children (Koravand et al., 2012). However, although these studies measured cortical activity, they do not necessarily indicate atypical cognitive processes in hearing-impaired listeners: differences in neural activity between normally-hearing and hearing-impaired listeners could arise *either* due to impaired cognitive function or because normal cognitive processes are deployed onto a distorted central representation of the acoustic signal. The current experiment avoided this confound by seeking evidence of differences in neural activity when participants prepared to direct attention to speech (i.e. before the speech began) during multi-talker listening.

Normally-hearing listeners can use between-talker differences in acoustic properties as cues to improve the intelligibility of speech spoken by a target talker during multi-talker listening. For example, normally-hearing listeners show better speech intelligibility when the talkers differ in gender (Brungart, 2001; Brungart et al., 2001; Shafiro and Gygi, 2007), fundamental frequency (Assmann and Summerfield, 1994; Darwin and Hukin, 2000), or spatial location (Bronkhorst and Plomp, 1988; Darwin and Hukin, 1999; Helfer and Freyman, 2005). Normally-hearing listeners can also deploy preparatory attention to these acoustic cues before a target talker starts to speak. First, they achieve better accuracy of speech intelligibility when they know the spatial location (Best et al., 2009, 2007; Ericson et al., 2004; Kidd et al., 2005) or the identity (Freyman et al., 2004; Kitterick et al., 2010) of a target talker before he or she begins to speak. Second, previous experiments using functional magnetic resonance imaging (fMRI; Hill and Miller, 2010) and MEG (Lee et al., 2013) have revealed preparatory brain activity that differs depending on whether normally-hearing adults direct attention to the spatial location or fundamental frequency of the target talker. Normally-hearing adults and children also show preparatory EEG activity when they are cued to the location or gender of a target talker (Holmes et al., 2016). If hearing-impaired children deploy preparatory attention in a similar way as normally-hearing children do, there should be no differences in preparatory EEG activity between normally-hearing and hearing-impaired children.

In the current experiment, we presented an adult male and an adult female voice concurrently from different spatial locations. A third, child's, voice was also presented to increase the difficulty of the task. Prior to the presentation of the voices, a visual stimulus cued attention to either the spatial location or gender of the target talker, who was always one of the two adults. The task was to report key words spoken by the target talker. We recorded brain activity using electro-encephalography (EEG) in children with moderate sensorineural hearing loss of several year's duration (HI children) and in a comparison group of normally-hearing (NH) children. We isolated preparatory EEG activity by comparing event-related potentials (ERPs) between a condition in which the visual cue indicated the location or gender of an upcoming target talker and a control condition in which the same visual cues were presented but did not instruct participants to attend to acoustic stimuli. We hypothesised that we would find less evidence of preparatory EEG activity in hearing-impaired children than in normally-hearing children.

2. Methods

2.1. Participants

Participants were 24 children with normal hearing (9 male), aged 8–15 years (mean [M] = 12.3, standard deviation [SD] = 1.9) and 14 children with sensorineural hearing loss (4 male), aged 7–16 years (M = 11.6, SD = 3.1). All participants were declared by their parents to be native English speakers. The NH children were all also declared by their parents to be right-handed with no history of hearing problems and they had 5-frequency average pure-tone hearing levels of 15 dB HL or better, tested in accordance with BS EN ISO 8253-1 (British Society of Audiology, 2004; Fig. 1). The children with hearing loss had bilateral 5-frequency average pure-tone hearing levels between 42 and 65 dB HL (M = 50.4 dB HL, SD = 7.9; Fig. 1) and the difference in the 5-frequency averages recorded from the left and right ears was less than 12 dB for each participant. Of the fourteen HI children, two were left-handed and one had an additional visual impairment in her left eye. The study was approved by the Research Ethics Committee of the Department of Psychology, University of York, the NHS Research Ethics Committee of Newcastle and North Tyneside, and the Research and Development Departments of York Teaching Hospital NHS

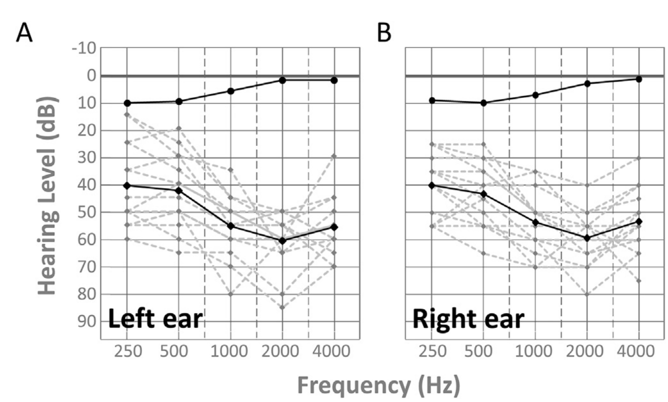

Fig. 1. Average pure-tone audiometric thresholds (dB HL) for hearing-impaired (HI; N = 14) and normally-hearing (NH; N = 24) children, plotted separately for the left (**A**) and right (**B**) ears. Grey dashed lines show thresholds for individual hearing-impaired participants and the black solid lines show mean thresholds across HI (diamonds) and NH (circles) participants.

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