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Research report

Changed crossmodal functional connectivity in older adults with hearing loss

Sebastian Puschmann [a,*] *and Christiane M. Thiel* [a,b]

[a] *Biological Psychology Lab, Department of Psychology, Cluster of Excellence "Hearing4all", European Medical School, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany*

[b] *Research Center Neurosensory Science, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany*

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ABSTRACT

Previous work compellingly demonstrates a crossmodal plastic reorganization of auditory cortex in deaf individuals, leading to increased neural responses to non-auditory sensory input. Recent data indicate that crossmodal adaptive plasticity is not restricted to severe hearing impairments, but may also occur as a result of high-frequency hearing loss in older adults and affect audiovisual processing in these subjects. We here used functional magnetic resonance imaging (fMRI) to study the effect of hearing loss in older adults on auditory cortex response patterns as well as on functional connectivity between auditory and visual cortex during audiovisual processing. Older participants with a varying degree of high frequency hearing loss performed an auditory stimulus categorization task, in which they had to categorize frequency-modulated (FM) tones presented alone or in the context of matching or non-matching visual motion. A motion only condition served as control for a visual take-over of auditory cortex. While the individual hearing status did not affect auditory cortex responses to auditory, visual, or audiovisual stimuli, we observed a significant hearing loss-related increase in functional connectivity between auditory cortex and the right motion-sensitive visual area MT+ when processing matching audiovisual input. Hearing loss also modulated resting state connectivity between right area MT+ and parts of the left auditory cortex, suggesting the existence of permanent, task-independent changes in coupling between visual and auditory sensory areas with an increasing degree of hearing loss. Our data thus indicate that hearing loss impacts on functional connectivity between sensory cortices in older adults.

1. Introduction

Previous research provides compelling evidence that a lasting loss of input from one sensory modality, for example caused by a disease of a sensory organ, results in a recruitment of the deprived sensory cortex by the intact sensory modalities (Bavelier & Neville, 2002; Butler & Lomber, 2013; Kral, 2007; Merabet & Pascual-Leone, 2010). This crossmodal plasticity

* *Corresponding author*. Carl von Ossietzky Universität Oldenburg, Department für Psychologie, 26111 Oldenburg, Germany.
E-mail address: sebastian.puschmann@uni-oldenburg.de (S. Puschmann).
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is commonly thought to reflect compensatory changes in the intact sensory modalities, for example leading to the changed perceptual abilities observed in deaf or blind individuals (Hötting & Röder, 2009; Kupers & Ptito, 2014; Lomber, Meredith, & Kral, 2010; Shiell, Champoux, & Zatorre, 2014; Stropahl et al., 2015). In the auditory domain, studies in deaf and severely hearing-impaired populations demonstrated auditory cortex activity in response to non-auditory sensory input, in particular to visual motion and vibrotactile stimulation, as well as during speechreading and while processing sign language (Auer Jr., Bernstein, Sungkarat, & Singh, 2007; Finney, Fine, & Dobkins, 2001; Sadato et al., 2005). Complementing this work, several recent animal studies aimed to investigate whether the changed auditory cortex activation patterns are related to changes in crossmodal connectivity between auditory and visual or somatosensory cortex. The experimental findings suggest that, for most auditory cortical regions, the general pattern of crossmodal connectivity is not significantly altered in hearing-impaired as compared to normal-hearing animals (Barone, Lacassagne, & Kral, 2013; Kok, Chabot, & Lomber, 2014; Meredith, Clemo, Corley, Chabot, & Lomber, 2016). Meredith et al. (2016) therefore suggested that changes in auditory cortex firing patterns following hearing loss may not be related to an increased number of projections from other sensory cortices but rather to changes in the local branching of existing projection terminals in auditory cortex. Other studies however observed increased visual and somatosensory projections into specific fields of cat auditory cortex, indicating that crossmodal plasticity in hearing loss may still to some extend rely on a rewiring of crossmodal connections (Kok et al., 2014; Wong, Chabot, Kok, & Lomber, 2015). For example, Kok et al. (2014) reported that the dorsal zone, which has been shown to be involved in processing visual motion in deaf cats, receives increased projections form parts of visual cortex involved in motion processing in deaf as compared to hearing animals.

Although crossmodal plasticity has been observed most prominently in severe congenital or early-onset hearing loss, there is increasing evidence coming from animal data that crossmodal neuroplastic changes in auditory cortex can also emerge at adult age and following partial hearing impairments (Allman, Keniston, & Meredith, 2009; Meredith, Keniston, & Allman, 2012). Complementing this animal research, there have been a few studies investigating crossmodal plasticity in older human subjects with an early stage of high frequency hearing loss (*presbycusis*). Using electroencephalography (EEG) it was demonstrated that such participants show changed visual and audiovisual evoked-potentials as compared to age-matched controls with normal hearing (Campbell & Sharma, 2014; Musacchia, Arum, Nicol, Garstecki, & Kraus, 2009). Applying an EEG source localization approach, Campbell and Sharma (2014) further provided evidence for a shift of visually-evoked activity into more temporal regions, providing a first indication for a crossmodal reorganization of human auditory cortex in older adults with hearing loss.

We were previously interested in the perceptual consequences of such possible crossmodal reorganization on audiovisual processing in older adults with hearing loss. Using an auditory stimulus categorization task with crossmodal visual distraction, we found a positive correlation between the degree of high-frequency hearing loss and the amount of categorization errors made in rarely presented trials containing incongruent audiovisual information (Puschmann, Sandmann, Bendixen, & Thiel, 2014). These findings indicated that, with increasing degree of hearing loss, subjects relied more on additional visual information to support auditory processing, making them more prone to crossmodal visual distraction by incongruent audiovisual information. Due to the lack of additional neural data, it remained however open whether this effect was indeed related to crossmodal neuroplastic changes in older hearing-impaired subjects.

To investigate this question, we here used functional magnetic resonance imaging (fMRI) to study changes in the auditory cortex processing of audiovisual information in older adults related to the degree of high-frequency hearing loss. Similar to our previous behavioral study, we applied an auditory stimulus categorization paradigm in which subjects had to categorize rising versus falling frequency-modulated (FM) tones. The FM tones were presented in blocks of four stimuli, either without additional visual input or in combination with matching (i.e., the visual motion direction always corresponded to the FM direction) or non-matching visual motion cues (i.e., the visual motion direction was independent of the FM direction). Stimulus blocks containing only visual motion but no auditory stimulation served to control for a visual recruitment of auditory cortex. We hypothesized that hearing loss in older adults could modulate auditory cortex responses to auditory, visual, or audiovisual input, but may also affect the crossmodal connectivity between auditory and visual cortices when processing matching audiovisual information. To investigate this second hypothesis, we applied a psycho-physiological interaction (PPI) analysis, aiming to reveal hearing loss-related changes in functional connectivity between both sensory cortices when processing matching as compared to non-matching audiovisual input. Given that hearing-impaired subjects were thought to rely on the additional visual motion information when performing the stimulus categorization task, we hypothesized that hearing loss may most likely affect crossmodal connectivity between visual areas involved in motion processing and auditory cortex. Therefore, the motion-sensitive visual area MT+ served as primary seed region for this analysis (Born & Bradley, 2005; Zimmermann et al., 2011). The earlier visual areas V1 and V2 served as additional region of interest to control for hearing loss-related changes in crossmodal connectivity to visual areas not specifically involved in motion processing.

2. Material and methods

2.1. Subjects

We recruited a group of twenty older volunteers (9 female, mean age: 61 ± 5 years, age range: 52–67 years) with a uniformly varying degree of bilateral sloping high-frequency hearing, ranging from normal-hearing to a moderate to severe degree of high frequency hearing loss. This parametric approach was chosen instead of a between-group design to study the modulatory influence of increasing degrees of hearing loss on audiovisual processing. Fig. 1 depicts