Audiovisual speech processing and listening effort in untreated age-related hearing loss: evidence from functional magnetic resonance imaging

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ABSTRACT

Functional magnetic resonance imaging (fMRI) enables objective measurement of central auditory processing. We used fMRI to investigate neural processing of audiovisual speech in hearing impaired unaided and non-hearing impaired elderly subjects. Speech stimuli were used under four different conditions, visual only, auditory only and two audio-visual conditions, in which subjects could see the speakers face, one with congruent auditory and visual information and a second with incongruent information. While performance in this task did not differ between hearing impaired and non-hearing impaired participants, task-related neural activity differed. Hearing impaired participants showed higher neural activity in medial and lateral prefrontal cortex which correlated with the amount of high-frequency hearing loss. We suggest that the additional recruitment of frontal brain regions may relate to increased effort, which was supported by reports of increased daily listening effort in the hearing impaired group. An additional data analysis on resting state fMRI data in the same group of subjects, showed that this increased listening effort relates to decreased functional connectivity between inferior frontal and auditory cortex. Task and resting state fMRI data therefore provide valuable measures of central auditory processing of speech and increases in listening effort in the hearing impaired.

Keywords: age-related hearing loss, functional neuroimaging, audiovisual speech, listening effort

1. INTRODUCTION

Age-related hearing loss affects a large proportion of the elderly but often stays untreated for several years (1). The loss of hearing abilities at high frequencies leads to difficulties in understanding speech and increased listening effort, especially in multispeaker situations. The effects of reduced sensory input on the brain are well investigated in the congenitally deaf and those with profound hearing loss and demonstrate that the loss of auditory input induces changes in neural processing in and beyond the auditory cortex (2). A well-investigated phenomenon is crossmodal plasticity, evident as increased responses in auditory cortex to visual stimuli. Recently, evidence for crossmodal plasticity has also been found in mild to moderate age-related hearing loss (3, 4). For example, in a functional magnetic resonance imaging (fMRI) study in elderly subjects with varying degree of high frequency hearing loss, increased functional connectivity between auditory cortex and motion-related brain regions was found when subjects had to categorize frequency-modulated tones presented alone or in the context of non-matching versus matching visual motion (3). Together with a prior behavioural finding that hearing impaired listeners are more distracted by incongruent visual input (5) the results

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compellingly demonstrate that untreated age-related hearing-loss impacts brain connectivity and audiovisual integration. Behaviourally, increased audiovisual integration in elderly hearing impaired listeners has also been described for speech stimuli using the McGurk effect, an illusion that can occur if incongruent auditory and visual syllables are presented which lead to a fused third percept (6, 7). An increased sensitivity for processing lip movements in the hearing impaired, which convey visual information that may aid speech understanding, may explain these findings (8). The brain mechanisms related to processing audiovisual speech in the hearing impaired are however unclear.

2. METHODS AND RESULTS

To investigate audiovisual processing of speech in age-related hearing impairment we performed a functional neuroimaging study in in a sample of subjects with untreated mild to moderate hearing loss and an age-matched control group. Magnetic resonance imaging methods enable the measurement of brain function and structure with high spatial precision. FMRI was introduced in humans in 1991 and measures brain activity via the so-called blood oxygen level dependent (BOLD) contrast, which exploits the different magnetic properties of oxygenated and deoxygenated blood (9). Even though this measure is an indirect measure of neuronal activity that relies on neurovascular coupling, it is strongly correlated with the local field potential of neurons (10). The method can be used to investigate the strength of activation in different brain regions during different task conditions or the coupling of brain regions during task conditions or at rest. They therefore provide an objective measure of changes in neural activity and functional connectivity. In contrast to electrophysiological methods such as electro- or magnetoencephalography, fMRI provides better spatial resolution and also enables tracking of neural activity in subcortical regions. The disadvantage is however the high levels of noise produced during measurement which can only partly be reduced by active noise cancellation.

We will here report on a previously published dataset that was acquired in normal hearing (n=19; mean age 63.2) and hearing impaired participants (n=20; mean age 63.5) who performed an audio-visual sentence detection task inside the MRI scanner (3T Prisma with 20 channel headcoil) as well as a so-called resting state scan. In addition, subjects performed the McGurk task outside the scanner and filled in a questionnaire on daily listening effort. Hearing status was assessed with pure tone audiometry. Mean values for high frequencies (2-8kHz) were 39.5 dB for the hearing impaired and 18.9 dB for normal hearing subjects.

Analysis of the behavioral data acquired outside the scanner indicated significantly higher daily listening effort and stronger audio-visual integration (increased McGurk effect) in hearing impaired compared to normal hearing subjects. Furthermore, hearing-loss was highly correlated with audio-visual integration with higher hearing-loss leading to a higher amount of McGurk illusions. These results confirm prior findings that mild to moderate hearing impaired subjects are more prone to the McGurk illusion than normal hearing subjects. Behavioural data in the MRI showed best performance for congruent audiovisual sentences but no differences between hearing impaired and normal hearing subjects, which may have been due to the scanner noise. Neural activity during sentence processing differed however significantly between both groups. Increased activation was found in the hearing impaired in frontal areas for unimodal visual, unimodal auditory and incongruent audio-visual sentences (see Figure 1, for further results see (11)). Our results indicate a hearing-loss induced modulation of the BOLD response in frontal areas during unimodal auditory, visual and incongruent audio-visual input, but not for congruent audio-visual input. This effect may be related to an increased listening effort in those conditions in the hearing impaired.

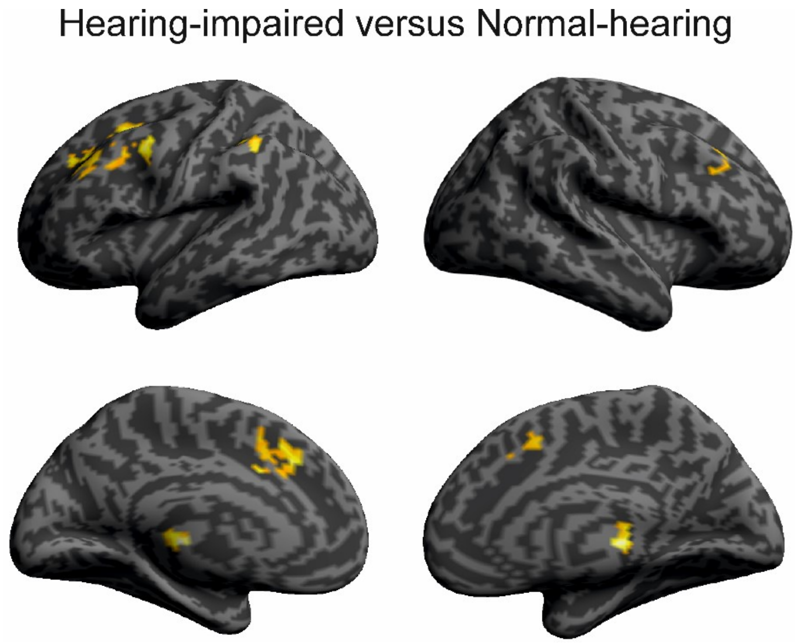

Figure 1 – Higher neural activity in hearing impaired vs. normal hearing subjects showing increased BOLD signal in medial, middle and inferior frontal gyri (side view upper row), as well as cingulate cortex (medial view, lower row) with incongruent audio-visual speech [$p<0.05$; FWE corrected on the cluster level]. Similar activation differences were found for the unimodal auditory and visual conditions (not shown). No differences between hearing impaired and normal hearing subjects were seen with congruent audio-visual speech. Figure adapted from (11).

To further investigate long-term effects of increased daily listening effort in the study population the subjectively reported questionnaire data was related to resting state functional connectivity. Resting state functional connectivity measures coherent fluctuations of BOLD signal between brain regions. Several resting state networks, such as the default mode, the dorsal attention and the salience network, have been identified (12). Changes in these networks have been related to various disease states, two recent studies also report changes in relation to age-related hearing loss (13, 14) but the relation to daily listening effort is unclear. Our data provide evidence for lower functional connectivity with increased listening effort. This effect was present in the dorsal attention network and in a connection from auditory cortex to inferior frontal gyrus (for further results see (15)). Note that these changes in functional connectivity were not dependent on hearing loss, which suggests that increased listening effort experienced in everyday life rather than the hearing loss itself has a significant influence on resting state connectivity.

3. CONCLUSIONS

The data presented here suggest that mild to moderate untreated hearing-loss and even increased daily listening effort can lead to compensatory changes in brain activity and connectivity. Whether these changes are beneficial or maleficial will need to be determined in future studies.

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REFERENCES

1. Davis A, Smith P, Ferguson M, Stephens D, Gianopoulos I. Acceptability, benefit and costs of early screening for hearing disability: a study of potential screening tests and models. Health Technol Assess. 2007;11(42):1-294.
2. Kral A, Kronenberger WG, Pisoni DB, O'Donoghue GM. Neurocognitive factors in sensory restoration of early deafness: a connectome model. Lancet Neurol. 2016;15(6):610-21.
3. Puschmann S, Thiel CM. Changed crossmodal functional connectivity in older adults with hearing loss. Cortex. 2017;86:109-22.
4. Campbell J, Sharma A. Cross-modal re-organization in adults with early stage hearing loss. PloS one. 2014;9(2):e90594.
5. Puschmann S, Sandmann P, Bendixen A, Thiel CM. Age-related hearing loss increases cross-modal distractibility. Hear Res. 2014;316:28-36.
6. Stropahl M, Chen LC, Debener S. Cortical reorganization in postlingually deaf cochlear implant users: Intra-modal and cross-modal considerations. Hear Res. 2017;343:128-37.
7. MacDonald J, McGurk H. Visual influences on speech perception processes. Percept Psychophys. 1978;24(3):253-7.
8. Brown VA, Hedayati M, Zanger A, Mayn S, Ray L, Dillman-Hasso N, et al. What accounts for individual differences in susceptibility to the McGurk effect? PloS one. 2018;13(11):e0207160.
9. Belliveau JW, Kennedy DN, Jr., McKinstry RC, Buchbinder BR, Weisskoff RM, Cohen MS, et al. Functional mapping of the human visual cortex by magnetic resonance imaging. Science. 1991;254(5032):716-9.
10. Logothetis NK. What we can do and what we cannot do with fMRI. Nature. 2008;453(7197):869-78.
11. Rosemann S, Thiel CM. Audio-visual speech processing in age-related hearing loss: Stronger integration and increased frontal lobe recruitment. Neuroimage. 2018;175:425-37.
12. Beckmann CF, DeLuca M, Devlin JT, Smith SM. Investigations into resting-state connectivity using independent component analysis. Philos Trans R Soc Lond B Biol Sci. 2005;360(1457):1001-13.
13. Husain FT, Carpenter-Thompson JR, Schmidt SA. The effect of mild-to-moderate hearing loss on auditory and emotion processing networks. Frontiers in systems neuroscience. 2014;8:10.
14. Schmidt SA, Akrofi K, Carpenter-Thompson JR, Husain FT. Default mode, dorsal attention and auditory resting state networks exhibit differential functional connectivity in tinnitus and hearing loss. PloS one. 2013;8(10):e76488.
15. Rosemann S, Thiel CM. The effect of age-related hearing loss and listening effort on resting state connectivity. Sci Rep. 2019;9(1):2337.