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Research Paper

The impact of hearing aids and age-related hearing loss on auditory plasticity across three months – An electrical neuroimaging study

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A B S T R A C T

The present study investigates behavioral and electrophysiological auditory and cognitive-related plasticity in three groups of healthy older adults (60–77 years). Group 1 was moderately hearing-impaired, experienced hearing aid users, and fitted with new hearing aids using non-linear frequency compression (NLFC on); Group 2, also moderately hearing-impaired, used the same type of hearing aids but NLFC was switched off during the entire period of study duration (NLFC off); Group 3 represented individuals with age-appropriate hearing (NHO) as controls, who were not different in IQ, gender, or age from Group 1 and 2. At five measurement time points (M1-M5) across three months, a series of active oddball tasks were administered while EEG was recorded. The stimuli comprised syllables consisting of naturally high-pitched fricatives (/sh/, /s/, and /f/), which are hard to distinguish for individuals with presbycusis. By applying a data-driven microstate approach to obtain global field power (GFP) as a measure of processing effort, the modulations of perceptual (P50, N1, P2) and cognitive-related (N2b, P3b) auditory evoked potentials were calculated and subsequently related to behavioral changes (accuracy and reaction time) across time.

All groups improved their performance across time, but NHO showed consistently higher accuracy and faster reaction times than the hearing-impaired groups, especially under difficult conditions. Electrophysiological results complemented this finding by demonstrating longer latencies in the P50 and the N1 peak in hearing aid users. Furthermore, the GFP of cognitive-related evoked potentials decreased from M1 to M2 in the NHO group, while a comparable decrease in the hearing-impaired group was only evident at M5. After twelve weeks of hearing aid use of eight hours each day, we found a significantly lower GFP in the P3b of the group with NLFC on as compared to the group with NLFC off.

These findings suggest higher processing effort, as evidenced by higher GFP, in hearing-impaired individuals when compared to those with normal hearing, although the hearing-impaired show a decrease of processing effort after repeated stimulus exposure. In addition, our findings indicate that the acclimatization to a new hearing aid algorithm may take several weeks.

1. Introduction

Peripheral age-related hearing loss (presbycusis) caused by damage to the cochlea or the auditory nerve (Chertoff and Jacobsen, 2012) challenges the central auditory system by delivering a disrupted acoustic signal to the cortex. Hearing aids (HA), the most common treatment for presbycusis, have been developed to restore the signal by amplifying sounds in order to improve audibility.

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Furthermore, intelligibility of spoken utterances can be supported by applying noise reduction algorithms in HA. Although improvement in speech intelligibility has been shown in aided compared to unaided listening conditions (Coez et al., 2010), it remains unclear if and how central auditory processing changes as a function of HAs.

To date, only a handful of studies have examined early auditory evoked potentials (AEP) such as the P50, the N1, and the P2, and this while young, normal-hearing listeners were fitted with hearing aids for the first time. Comparing aided with unaided listening conditions, some studies reported increases in the peak amplitude of AEPs (Miller and Zhang, 2014; Tremblay et al., 2006a) while others reported a decrease of amplitudes (Billings et al., 2011), delayed latencies (Marynewich et al., 2012; Miller and Zhang, 2014), or no significant differences (Billings et al., 2007; Marynewich et al., 2012). Thus, these results remain difficult to interpret for two reasons. First, these studies applied passive paradigms that do not allow for the direct relation of neurophysiological data to behavior, which would have made less ambiguous interpretations of the decreases and increases in amplitudes and latencies possible. Second, it remains unclear to what extent these results apply to older adults, the group which typically suffers from presbycusis.

Nevertheless, two feasibility studies showed that the acoustic change complex (ACC) (Tremblay et al., 2006b) and the speech-evoked envelope following response (EFR) (Easwar et al., 2015) can be reliably recorded in older hearing aid users. The ACC is a cortical auditory evoked potential elicited in response to an acoustic change (Kim, 2015) and the EFR is a phase locked response to the stimulus envelope frequency (Picton et al., 2003), both of which are measurable with scalp EEG. Furthermore, one other study reported an increase of the P2 amplitude in response to passively presented lower tones and a P2 amplitude decrease in response to passively presented higher tones for aided compared to unaided listening in older adults with age-related hearing loss (Bertoli et al., 2011).

In this paper we systematically addressed the shortcomings of the previous research outlined above by using an active oddball paradigm to assess accuracy and reaction time of oddball detection and by comparing the latencies and global field power (GFP), used here as a correlate for processing effort (Lemke and Besser, 2016), of early perceptual AEPs (P50, N1, P2) and also later cognitive-related AEPs (N2b, P3b) in older adults with moderate presbycusis who were experienced hearing aid users and an age matched control group without hearing loss. Here we define processing effort as the additional resources allocated to a listening task in order to meet the task goal under adverse listening conditions (Lemke and Besser, 2016) and we consider the GFP[1] of the AEPs to be its neurophysiological marker (Pichora-Fuller et al., 2016). The use of GFP as obtained by a topographical microstate approach has several advantages when compared to classic one-electrode or one-electrode-pool analyses: First, single electrodes do not have to be chosen manually. Second, topographical measures are reference independent (Koenig et al., 2014; Lehmann and Skrandies, 1980, 1984). Third, topographical dissimilarities between conditions or groups can be interpreted directly, as they reflect differences in the configuration of the underlying neural networks (Murray et al., 2008; Vaughan, 1982). Fourth, the use of a temporal filter when applying the microstate approach (Koenig et al., 2014; Murray et al., 2008) allows for the identification of temporally stable topographical configurations, which can then be analyzed in a data-driven manner, and thus forgoing the need to define arbitrary time windows of interest in an ERP time course a priori (Giroud et al., 2017; Kühnis et al., 2013; Michel et al., 2009; Murray et al., 2008; Pascual-Marqui et al., 1995). Also, GFP of the N2b and the P3b has previously been shown to reflect longitudinal auditory plasticity in younger adults (Giroud et al., 2017).

Investigating the longitudinal modulations of cognitive-related AEPs is crucial, as several behavioral studies have found facilitating effects of hearing aids on cognitive-related auditory processes (Doherty and Desjardins, 2015; Lavie et al., 2015). In addition, we followed the two groups for three months (measurement time points M1-M5) in order to study central auditory plasticity as a function of the HA time of usage. Longitudinal research to investigate within-group changes across time is much needed in this field, but still rare. Previous longitudinal research on older hearing aid users mainly focused on the predictive value of individual working memory capacity on behavioral speech understanding in different aided conditions (Cox and Xu, 2010; Ng et al., 2014; Rudner et al., 2011). Moreover, in our study, the hearing-impaired group was further divided into two subgroups, one of which was provided with traditional amplification hearing aids, while the other was equipped with a specific hearing aid feature, namely nonlinear frequency compression (NLFC).

NLFC is a common hearing aid feature in which the high-frequency signal, typically no longer accessible to the older hearing-impaired, is compressed into a lower frequency range. It only compresses the signal above a certain threshold which is determined individually (McDermott and Henshall, 2010). NLFC does not compress lower frequencies in order to avoid artifacts in vowels and it has been reported to improve the recognition of high-frequency consonants, such as fricatives and monosyllabic words (Alexander, 2016; McCreery et al., 2014; Wolfe et al., 2010, 2011, 2015), although not all study participants benefit from NLFC to the same extent (Bohnert et al., 2010; Ching et al., 2013; Hillock-Dunn et al., 2014; Simpson et al., 2005, 2006).

At M1, we predicted longer latencies in P50, N1, and P2 in hearing aid users compared to those with age-appropriate hearing as has been shown in within-subject designs in younger adults (Korczak et al., 2005; Marynewich et al., 2012; Miller and Zhang, 2014) and in studies comparing CI users to those with normal hearing (Finke et al., 2016). Further, for all groups, we expected to find increases of oddball detection accuracy, decreases of reaction time and decreases in AEP latencies across the measurement time points as was shown in a similar experiment with younger adults (Giroud et al., 2017). Importantly, we also expected to find group * M interactions from M2 to M3 revealing stronger increases of accuracy and stronger decreases of reaction time and AEP latencies for normal-hearing participants as compared to the hearing impaired. This is because the central auditory system of hearing aid users is presumed to adapt to hearing aid use for several weeks. This adaption is necessary to appropriately process the auditory stimulus material altered by the hearing aid (Wolfe et al., 2011, 2015). We further predicted that the group with NLFC on would show stronger increases in detection accuracy and decreases in reaction time and AEP latencies compared to the group with pure amplification (Alexander, 2016; Wolfe et al., 2011, 2015). Moreover, we expected that usage of NLFC would lead to stronger decreases in processing effort, measured by the GFP of the N2b and P3b, when compared to the group without NLFC (Hällgren et al., 2005; Hornsby, 2013; Rudner, 2016; Tremblay and Backer, 2016).

2. Materials and methods

2.1. Participants

Thirty older adults with moderate age-related hearing loss were

[1] We compare the mean GFP and the latency of the peak GFP of the AEPs from the current study with the peak amplitude and peak latency respectively from previous studies.