Effects of auditory acclimatization to bilateral amplification on audio-visual sentence-in-noise processing and speech-evoked potentials

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Recently, Wendt *et al.* (2014) developed an eye-tracking paradigm for estimating *how quickly* a participant can grasp the meaning of audio-visual sentence-in-noise stimuli (the 'processing time'). Using this paradigm, Wendt *et al.* (2015) and Habicht *et al.* (2015) found that hearing-impaired listeners with prior hearing aid (HA) experience performed faster on this task than hearing-impaired listeners without any HA experience, despite comparable speech recognition performance. To better understand this finding the current study investigated the effects of auditory acclimatization to bilateral amplification on this task using a longitudinal study design. Groups of novice and experienced HA users took part. The novice users were tested before and after 12 weeks of acclimatization to bilateral HAs. The experienced users were tested with their own devices over the same time period. In addition to the processing time measurements, speech-evoked potentials were measured. Initial results show a tendency for shorter processing times for linguistically complex sentences and no changes in speech-evoked potentials. Additional analyses based on a set of measurements collected after another 12 weeks of acclimatization will make it possible to scrutinize the variables of interest further.

INTRODUCTION

Although a number of studies have investigated the effects of auditory acclimatization to hearing aids (HAs; see reviews by Turner *et al.*, 1996; Palmer *et al.*, 1998; Munro, 2008), the results of these studies are not consistent. Some studies found acclimatization effects (e.g., Munro and Lutman, 2003) while others did not (e.g., Humes and Wilson, 2003). Furthermore, these studies often used outcome measures which are not necessarily indicative of real-world communication abilities (e.g., loudness perception). Therefore, we wanted to investigate the potential effects of HA use on speech comprehension in complex listening situations. To that end, we used a recently developed audio-visual test paradigm for the assessment of speech comprehension in noise (Wendt *et al.*, 2014). This paradigm allows estimating *how quickly* a participant can grasp the meaning of sentence-in-noise stimuli (the

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'processing time'). Using this method, we previously obtained results suggesting that HA experience leads to better performance on this task, irrespective of the amplification characteristics (Habicht *et al.*, 2015). Because these results were obtained using an across-group design, it is unclear whether they were due to a lack of auditory stimulation for the hearing-impaired listeners without prior HA experience. Here, we therefore investigated the effects of auditory acclimatization to bilateral amplification on processing times using a longitudinal study design. Furthermore, we measured speech-evoked potentials using a test paradigm of Finke *et al.* (2014) that allowed us to explore any higher-level neurophysiological changes due to HA provision.

Our hypotheses were as follows:

1. Acclimatization to bilateral amplification will lead to improved (i.e., shorter) processing times.
2. Bilateral amplification will also result in larger amplitudes and shorter latencies of late auditory potentials.
3. For experienced users, no such changes will be apparent.

METHODS

Participants

We recruited 15 habitual HA users with at least one year of HA experience ('eHA group') and 18 novice HA users ('nHA group'). The nHA users were acclimatized to bilateral HAs for 12 weeks. The eHA users continued to wear their own HAs for the same period. Inclusion criteria were (1) age from 60 to 80 yr, (2) bilateral, sloping, sensorineural hearing loss ranging from 40 to 80 dB hearing level (HL) at 3-8 kHz, and (3) self-reported normal or corrected-to-normal vision. The two groups were matched closely (see Table 1) in terms of age and pure-tone average hearing loss from 500 Hz to 4 kHz (PTA). Furthermore, their speech reception thresholds corresponding to 80%-correct speech intelligibility for the speech stimuli used here (SRT_{80}) were very similar. All participants were required to wear their HAs for at least six hours per day. In this contribution, we show results from 22 participants who at the time of writing had completed all measurements.

Hearing aids and amplification

At the beginning of the study, the nHA users were fitted with Sivantos pure micon 7mi receiver-in-the-canal devices. These HAs are equipped with 20-channel dynamic range compression and active noise management. Acoustic coupling was achieved via standard double click domes or, if ear canals were too small, closed click domes. The HAs were fitted according to NAL-NL1 prescription targets (Byrne *et al.*, 2001). Target gains were verified with real-ear insertion gain measurements. The nHA users were given up to three days to get used to their devices, and gains were adjusted only if participants felt that they could not tolerate the prescribed amplification for the duration of the study. Two nHA users were satisfied with the prescribed amplification, whereas for the other 16 nHA users gains had to be reduced for frequencies above 4 kHz. Following fine-tuning, no further adjustments were made, and the participants were not able to alter the amplification themselves. The eHA participants, who were all users of receiver-in-the-canal devices (various brands), were tested with their own HA fittings. Figure 1 shows mean prescription targets and user gains for a 65 dB input signal level for the two groups of participants.

	eHA group	**nHA group**
N	10	12
Age (yr)	73.7 (3.7)	73.2 (5.0)
PTA (dB HL)	42.4 (4.2)	38.2 (6.0)
SRT_{80} (dB SNR)	−1.6 (1.6)	−1.6 (0.8)
HA use (hr/day)	11.1 (4.5)	8.1 (3.5)

Table 1: Means (and standard deviations) for the age, PTA, SRT_{80} and HA use data for the two groups of participants.

During the measurements (see below), all stimuli were amplified in accordance with the measured individual insertion gains using the Master Hearing Aid research platform (Grimm *et al.*, 2006).

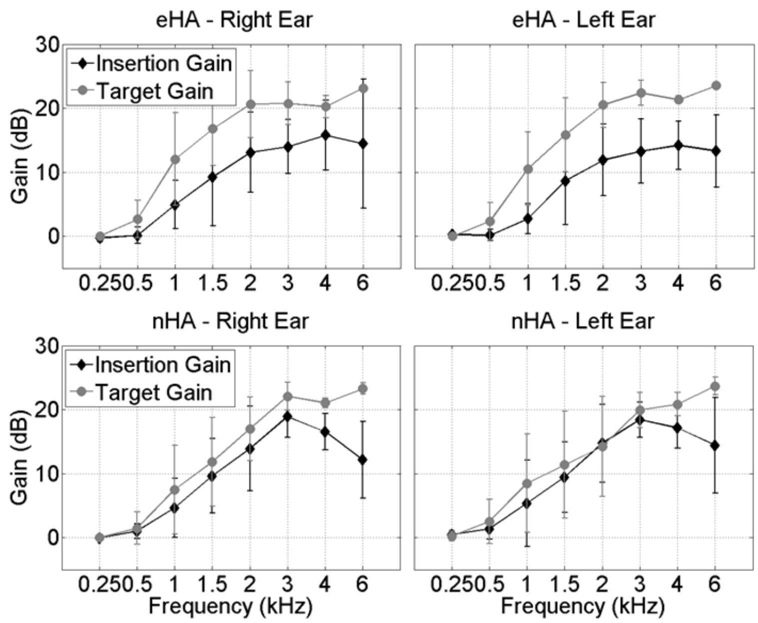

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Fig. 1: Mean insertion gains and target gains (based on NAL-NL1) for the eHA (top, N = 10) and nHA (bottom, N = 12) groups.

Eye-tracking measurements

The eye-tracking measurements were based on sentences from the "Oldenburg corpus of Linguistically and Audiologically Controlled Sentences" (Uslar *et al.*, 2013). This corpus consists of (grammatically correct) sentence structures that vary in linguistic complexity. For our measurements, we used two sentence structures with either low or high linguistic complexity. In the German language, the linguistic complexity of these sentences is determined by relatively subtle grammatical or acoustic cues (see Table 2). In each sentence, there are two characters (e.g., a dragon and a panda), one of which (the subject) performs a given action with the other (the object).

Sentences were presented in stationary speech-shaped noise at individual SRT_{80}'s via closed headphones (Sennheiser HDA 200). On each trial, two similar pictures (one target, one competitor) were displayed on a monitor positioned in front of the participant. In the target picture, the subject and object matched those conveyed by the corresponding acoustic sentence; in the competitor picture, the roles of the subject and object were interchanged so that there was a cross-modal mismatch. The task of the participant was to select the picture that matched the sentence by pressing a button on a hardware controller as quickly as possible after the acoustic presentation. During the stimulus presentation, the eye movements of the participant were recorded. If a participant has understood the meaning of a sentence, (s)he will automatically start fixating the corresponding (target) picture. In the following, the time elapsed for this to occur will be referred to as the "processing time".

A total of four test blocks were performed per participant and visit. Within a test block there were 30 trials based on 15 sentences with low linguistic complexity and 15 sentences with high linguistic complexity plus seven catch trials. The different blocks were presented in randomized order across the different participants.

<table>
<tr><td rowspan="2">Low</td><td>Der$_{nom}$</td><td>müde$_{nom}$</td><td>Drache</td><td>fesselt</td><td>den$_{acc}$</td><td>großen$_{acc}$</td><td>Panda.</td></tr>
<tr><td colspan="7">Meaning: "The tired dragon ties up the big panda."</td></tr>
<tr><td rowspan="2">High</td><td>Den$_{acc}$</td><td>müden$_{acc}$</td><td>Drachen</td><td>fesselt</td><td>der$_{nom}$</td><td>große$_{nom}$</td><td>Panda.</td></tr>
<tr><td colspan="7">Meaning: "The big panda ties up the tired dragon."</td></tr>
</table>

Table 2: Examples of sentences from the "Oldenburg corpus of Linguistically and Audiologically Controlled Sentences" (Uslar *et al.*, 2013) with two levels of linguistic complexity (low and high). In each case, the grammatically salient ***word endings*** and corresponding cases (nom = nominative; acc = accusative) are indicated, as are the English meanings.

Event-related potentials

In addition to the eye-tracking measurements, we measured event-related potentials (ERPs) to also investigate potential acclimatization effects based on the latencies and amplitudes of the P3 response, which is known to reflect post-perceptual processing. For that purpose, we used an active oddball paradigm of Finke *et al.* (2014) with stimuli from Rufener *et al.* (2014). Standards were spoken words describing non-living objects (e.g., invoice or window). Deviants described living beings (e.g., mother or eagle). The participants were seated in a comfortable chair in an electrically shielded booth and looked at a visual marker. Their task was to press a button whenever they heard a deviant. The stimuli were presented diotically in quiet via insert earphones (Etymotic EAR 3A). The length of all stimuli was 800 ms with an inter-stimulus interval of 1.5 s and a jitter of maximally 50 ms. We presented 350 trials (270 standards and 80 deviants) in three blocks (1 × 140 trials, 2 × 105 trials). The block order was randomized across participants. At least two standard stimuli were presented in-between two deviant stimuli. The duration of the blocks was 4 to 5 min. The ERPs were recorded from 66 active scalp electrodes according to the International 10-20 system. Additionally, we placed two reference electrodes at the earlobes. To analyze P3 amplitudes and latencies we averaged the ERPs from the electrodes Pz, P1, P2, P3, and P4.

Test protocol

Each nHA participant attended four visits. At the first visit, the HAs were fitted. At the second visit, individual insertion gains and SRT_{80}'s were measured. At the third and fourth visit, the eye-tracking and ERP measurements were carried out. Between the second and third visit, participants used their HAs for about 12 weeks. The first and second visit took 1 hr each, whereas the third and fourth visit took 2 hr each. The eHA participants only attended visits 2 to 4.

RESULTS

Eye-tracking measurements

Mean processing times with 95% confidence intervals are shown in Fig. 2. To analyze these data we performed a mixed-model analysis of variance (ANOVA) with listener group (eHA, nHA) as between-subject factor and linguistic complexity (low, high) and time point (baseline, 12 weeks) as within-subject factors. This revealed significant effects of linguistic complexity ($F_{1,20}$ = 35.4, p < 0.00001, η_p^2 = 0.64) and listener group [$F_{1,20}$ = 15.6, p < 0.001, η_p^2 = 0.44], but not of time point [p > 0.2]. Interestingly, however, there was a tendency for the processing times for sentences with high linguistic complexity to decrease following 12 weeks of acclimatization.

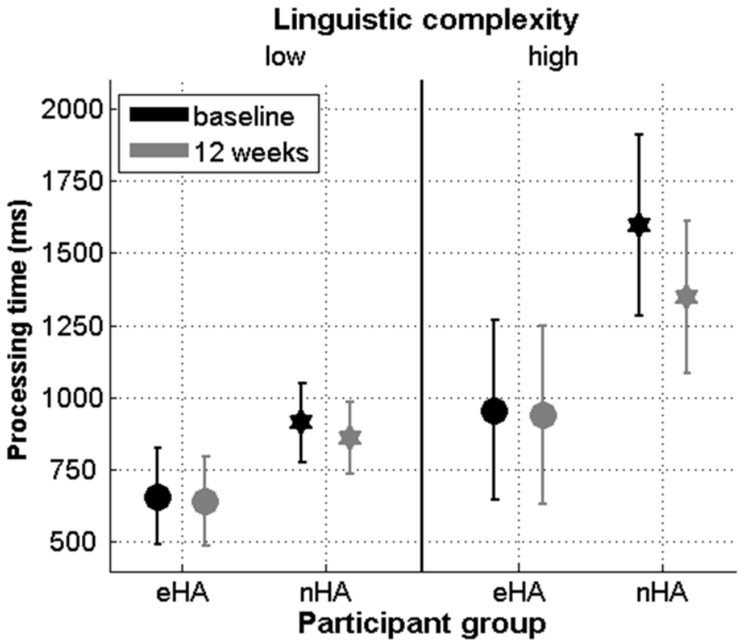

Fig. 2: Mean processing times for the eHA (circles, *N* = 10) and nHA (stars, *N* = 12) groups before ('baseline', black) and after 12 weeks (gray) of HA use for sentences with low (left) and high (right) linguistic complexity.

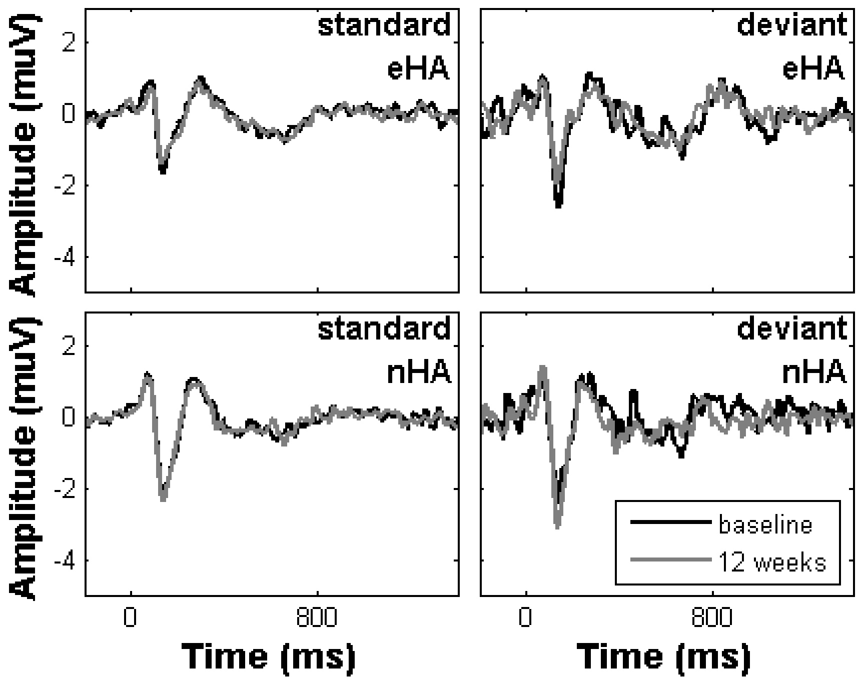

Fig. 3: Averaged speech-evoked potentials with standard (left) and deviant (right) stimuli before ('baseline', black) and after 12 weeks (gray) of HA use for the eHA (top, *N* = 10) and nHA (bottom, *N* = 12) participants.

Event-related potentials

Figure 3 shows averaged speech-evoked potentials for the two groups of participants, the two stimulus types, and the two time points. To analyze the ERPs we performed two mixed-model ANOVAs, one on the latencies and one on the amplitudes of the P3 response (which occurs around 800 ms after stimulus onset; see Finke *et al.*, 2014), with listener group (eHA, nHA) as between-subject factor, and stimulus type (standard, deviant) and time point (baseline, 12 weeks) as within-subject factors. The ANOVA performed on the amplitude data revealed significant effects for stimulus type [$F_{1,17} = 48.6$, $p < 0.00001$, $\eta_p^2 = 0.74$], but neither for listener group nor time point [both $p > 0.4$]. The ANOVA performed on the latency data revealed no significant effects [all $p > 0.05$].

SUMMARY AND CONCLUSIONS

In this contribution, we presented initial data from a longitudinal investigation into the effects of auditory acclimatization to bilateral amplification on audio-visual sentence-in-noise processing times and speech-evoked potentials. For this, we acclimatized a group of hearing-impaired listeners without HA experience to bilateral amplification for 12 weeks. In addition, we tested a group of experienced users with their own HA fittings over the same time period. As expected, the analysis of the processing time data showed significant effects of linguistic complexity and listener group. However, the effect of acclimatization was non-significant. Nevertheless, we observed a tendency for shorter processing times for sentences with high linguistic complexity following 12 weeks of acclimatization. Preliminary analyses of the measured P3 responses revealed larger amplitudes for deviant stimuli, but no effects of acclimatization.

Follow-up analyses based on the data from a total of 30 participants and an additional set of processing time and ERP measurements following 24 weeks of HA use will allow for more comprehensive analyses of the effects of HA use on the (neuro)physiological outcomes investigated here.

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