Brainstem processing following unilateral and bilateral hearing-aid amplification

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Running head: "ABR following hearing aid amplification"

24 **Abstract**

25 Following previous research suggesting hearing aid experience may induce functional
26 plasticity at the peripheral level of the auditory system, click-evoked auditory brain stem
27 response (ABR) was recorded at first fitting and following 12 weeks hearing aid use by
28 unilateral and bilateral hearing aid users. A control group of experienced hearing aid users
29 was tested over a similar time scale. No significant alterations in ABR latency or amplitude
30 were identified in any group. This does not support a hypothesis of plastic changes in the
31 peripheral auditory system induced by hearing aid use by 12 weeks use.

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33 Key words: Auditory brainstem response, Hearing aids, Auditory acclimatization,
34 Rehabilitation

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36 Abbreviations: ABR, auditory brainstem response; LDL, loudness discomfort level; NAL-NL1,
37 National Acoustic Laboratories Non-linear 1; nHL, normal hearing level; REIG, real ear
38 insertion gain; SII, speech intelligibility index; SPL, sound pressure level

Introduction

Hearing aids selectively amplify acoustic input so that previously inaudible acoustic cues become audible to hearing impaired listeners. When hearing aids are first provided, there is immediate benefit due to increased speech intelligibility. Additionally, performance may improve further over time; this is termed “auditory acclimatization”, a type of perceptual learning [1]. This additional improvement is not due to task, procedural or training effects, but rather increased efficiency of utilisation of newly available auditory cues. There is evidence of selective changes on performance of behavioural tests of auditory function such as speech perception, loudness perception and intensity discrimination [2].

Cortical alterations are generally noted in sensory learning [3], for example expanded auditory cortical representations of behaviourally trained frequencies [4]. There is some electrophysiological evidence for alterations in cortical processing in relation to hearing aid use [5,6]. There is also evidence that hearing aids may induce physiological changes in the brainstem, and this is in line with recent research suggesting that experience may alter processing at the level of the brain stem, for example musical [7] and language experience [8]. It is currently uncertain how brainstem processing is affected by experience, though it may be that efferent pathways have a top-down effect on peripheral processing, or alternatively that changes cascade from the peripheral to the central auditory system. The purpose of the current study was to determine if experience-related changes of performance with hearing-aid use are reflected in changes of brainstem processing. To date two studies suggest alterations in brain stem processing related to hearing aid use based on alterations in click-evoked Auditory Brainstem Responses (ABR).

First, Munro and colleagues measured ABR in each ear of 8 adult unilateral hearing aid users with a minimum of 2 years experience with hearing aids and 9 non-hearing aid using controls [9]. ABR responses were symmetrical between the right and left ear in controls, while wave V amplitude¹ was significantly larger for the fitted ear of the experienced hearing aid users. However, this study was cross-sectional, so the observed asymmetries may have been due to idiosyncrasies within participant groups unrelated to hearing aid use.

Second, Philibert and colleagues measured click-evoked ABR in 5 novice adult bilateral hearing aid users before first fitting of hearing aids and at 1, 3 and 6 months after fitting [10]. After 6 months hearing aid use, significant reduction of wave V latency was observed, though only for the right ear. The authors suggested that this asymmetry may have been due to slight asymmetries in hearing loss between ears, or due to inherent asymmetry in the functional auditory pathway favouring the right ear. Participants also completed behavioural intensity discrimination and loudness scaling at low and high frequencies (500 Hz and 2000 Hz). 2000 Hz tones (but not 500 Hz tones) of the same intensity were perceived as being less loud over time, and intensity discrimination improved particularly for higher frequency and higher intensity stimuli. This was interpreted as consistent with acclimatization to frequency-dependent gain provided by hearing aids. The weaknesses of this are rather small participant numbers (5), a wide range of hearing loss severity, asymmetries of hearing loss up to 20 dB at individual frequencies, and a lack of a control group; differences may be related to chance oddities within the small group of participants, to retest effects, or both.

¹ Measured as the difference in amplitude between the peak of wave V to the trough of the slow negative deflection (SN10) that followed it.

The authors of both studies suggested that the apparent alterations in ABR may be due to hearing aid use and might be caused by better neural synchronisation and/or greater neural activation. However, results are inconsistent; Munro et al. observed increases in wave V amplitude but no change in latency while Philibert et al. observed reduction in latency (for right ear only) but no change in amplitude. One significant difference between the studies is that Munro et al. focused on unilateral hearing aid users, while Philibert et al.'s study involved bilateral users. Perhaps the discrepancy between studies is related to differences in acclimatization to unilateral versus bilateral aids. However, taking the two studies together, there is evidence that hearing aid use may be associated with changes in brain stem processing of sound.

In the present study, click-evoked ABR was measured in novice unilateral and bilateral hearing aid users at the time of first hearing aid fitting and after 3 months hearing aid use. A control group of experienced hearing aid users was tested over a similar time frame. A retest interval of 3 months was chosen following several studies showing behavioural changes consistent with acclimatization after 3 months hearing aid use [2]. It was expected that electrophysiological changes may also be apparent in this time scale. Both new unilateral and bilateral hearing aid users were tested to establish whether there are differences in the acclimatization process between unilateral versus bilateral fits. The hypothesis was that over time either increased amplitude or reduced latency (or both) of wave V would be observed in ears fitted with hearing aids, while no changes would be observed in a control group.

Method

Based on previously reported latency and amplitude differences [9,10], statistical power calculations suggested a minimum of 8 participants to detect changes in amplitude and 4 participants to detect changes in latency, with 80% power and alpha level of .05 on a paired t-test. Minimum group sizes were met or exceeded for new user groups.

Fifty-six participants (17 experienced hearing aid users and 39 new users) were recruited from local audiology clinics. For all participants, inclusion criterion was symmetrical, mild-to-moderate, sloping high frequency sensorineural hearing loss of at least 40 dB HL at 2-6 kHz. Exclusion criteria were i) asymmetry in air conduction thresholds greater than 15 dB at two or more frequencies, ii) fluctuating or recent changes in hearing, iii) an air-bone gap greater than 15 dB at any test frequency, iv) abnormal middle ear function assessed using oto-admittance audiometry. Additional inclusion criteria for new users was no hearing aid experience prior to the study and average daily hearing aid use of at least 6 hours per day during the study period (based on data logging information provided by the hearing aid). Additional inclusion criteria for experienced hearing aid users were at least one year's hearing aid use and self-reported daily hearing aid use of at least 6 hours per day. Further, participants' data was included for analysis if reliable wave V could be identified for both ears at both time points (see ABR recordings below). If wave V could not be reliably identified at any point, the participant was excluded from analysis. Reasons for unreliable wave V identification centred on poor quality of recordings, for example due to muscle artefact contamination.

For new users, bilateral or unilateral fitting was assigned as participants were recruited to the study, alternating between unilateral or bilateral fit. No participant expressed a strong

preference for unilateral or bilateral aiding, and unilaterally fit participants had the option of bilateral amplification on completion of the study (and vice versa). For unilateral fit, ear of fitting alternated between left and right. Hearing aid use was monitored during the study via hearing aid data logging, and some participants were excluded from further analysis having failed to wear hearing aids at least 6 hours per day, per selection criterion. Additional participants were recruited until sufficient participant numbers were achieved. In total, 24 unilateral users were recruited; 12 were excluded due to hearing aid use less than 6 hours per day, 1 excluded due to illness and 3 excluded due to unreliable identification of wave V. The remaining 8 new unilateral users were included in the analysis below (4 fit in right ear, 4 left). 15 bilateral users were recruited; 2 excluded due to low hearing aid use, 3 excluded due to unreliable ABR. 10 new bilateral users were included for analysis. 17 experienced hearing aid users were recruited; 11 were excluded from further analysis due to unreliable ABR, leaving 6 for analysis. Experienced hearing aid users included 3 unilateral users (all fit in right ear) and 3 bilateral users.

Mean pure tone hearing thresholds for new hearing aid users were 25 dB HL (SD 12) at .5 kHz and 58 dB HL (SD 10) at 4 kHz, comparable with those in Munro et al's study [9]. Philibert et al. [10] included participants with a wide range of hearing loss (35 to 80 dB HL at 4 kHz); average hearing loss in this study is within that range. Experienced users tended to have poorer thresholds (39 dB HL (SD 23) at .5 kHz and 64 dB HL (SD 11) at 4 kHz), although this difference was not statistically significant. Mean difference in hearing threshold between the two ears was less than 5 dB for each group at every frequency, and this difference was not statistically significant. Hearing thresholds were retested at the end of the study (T2); Mean change in hearing threshold (initial minus final) was 0.75 dB (SD 2.57).

Over 90% of thresholds changed by less than 5 dB at each audiometric frequency, and 99% changed by less than 10 dB. This compares favourably with audiometric test-retest differences as have previously been reported [11]. Mean age of participants was 69 years (SD 9).

New users were fit with Radius behind-the-ear ($n = 2$) or Destiny completely-in-the-canal ($n = 16$) aids, manufactured by Starkey, USA with similar levels of technology. New users were fit according to National Acoustic Laboratories Non-linear 1 (NAL-NL1) prescription targets and verified with real ear insertion gain (REIG; the difference between aided and unaided ear canal sound pressure level) measurement. REIG measures were carried out with a Siemens Unity hearing aid analyser and followed recommended procedure [12]. No gain adjustments were made during the study period and hearing aids did not have volume controls; participants were not able to adjust gain themselves. Experienced users continued to use their hearing aids as usual, and no alterations to hearing aid gain were made during the study period. Experienced users' hearing aids were Danalogic 6070 ($n = 3$), Oticon Spirit Zest ($n = 1$), Oticon Spirit 3 ($n = 1$) and Siemens Reflex 1012 ($n = 1$); all non-linear hearing aids.

For new hearing aid users, REIG was around 17 dB at high frequencies, where hearing impairment was most severe (0.5 kHz; 4 ± 2 , 1 kHz; 11 ± 5 , 2 kHz; 17 ± 5 , 4 kHz 18 ± 3); similar levels to those reported by Munro et al. (2007). Average REIG was within 2 dB of prescribed targets across frequencies. Mean Speech Intelligibility Index [13] for single words presented at a level of 65 dB SPL in quiet was 0.54 for unaided and 0.84 for aided listening. Therefore, audibility was significantly improved by aiding. User gain was measured at the

end of the study in order to check the stability of gain. Mean change in gain was 0.0 dB (SD 3.5), with the size of absolute changes in gain ranging from 0.00 to 6.5 dB across groups and across frequencies. Variation in gain is consistent with that reported by a previous acclimatization study where REIG was retested over a similar period [14] as well as short-term test-retest REIG data [15]. Participants experienced relatively stable gain.

New hearing aid users were tested at the time of first fitting (T1), ranging from 8 days before to 7 days after fit (median; 1 day before fit). All participants were retested after 3 months (T2), with the exact retest interval varying depending on participant availability. Mean retest interval was 103 days (SD 14). Participants were seated in a reclining chair in a sound-proofed booth and encouraged to relax. Silver/silver chloride recording electrodes were applied to the scalp at the vertex (Cz), left and right ear lobes and a ground electrode on the high forehead. Stimulus generation, presentation and acquisition were performed with a Neuroscan STIM and SCAN evoked potential system. Stimuli were 0.1 ms rarefaction rectangular clicks at a presentation rate of 20.1 Hz (49 ms ISI) via insert earphone (etymotic EAR 3A). Monaural stimuli were presented at 80 dB nHL (with reference to the average threshold of a group of normally hearing adults). Three runs of 1000 presentations were acquired using a balanced design for ear of presentation and recorded with open filters at a sampling rate of 20 kHz. Off-line analysis consisted of +/- 30 uV artefact rejection, baseline correction and digital filtering from 90 to 2500 Hz with a slope of 96 dB/octave and re-windowed from -5 to 20 ms relative to stimulus onset. Three runs were combined to provide a maximum of 3000 sweeps for each condition. As well as a grand average waveform, average waveforms were generated for each run separately. Wave V amplitude and latency was determined automatically from the grand mean waveform, based on the

peak amplitude between 6 and 8 ms latency (allowing for a ~0.9 ms delay for sound propagation between the earphone transducer and arrival in the ear canal). Waveforms were visually inspected by the first author, and the automatically detected peak latency and amplitude accepted only if wave V could be reliably identified in three separate runs. The second author independently inspected 10% of recordings, and no discrepancies were identified.

Results

For the New bilateral (NB) and Experienced (E) user groups, wave V latency and amplitude are reported according to left and right ears. For the New unilateral (NU) group, results are reported according to the fitted and non-fitted ear. Non-parametric tests were applied where appropriate. Figure 1 shows mean ABR wave V latency and amplitude across groups, for each ear and each time point.

There was no significant difference in latency across groups at T1 (left ear: $F(1,21) = 0.51$, $p = .61$, right ear: Kruskal-Wallis $\chi^2(2) = 1.23$, $p = .54$). Small asymmetries in latency are apparent for the NU and the E group, perhaps due to small differences in threshold between the ears, although this difference is also not significant (New unilateral group: paired $t(7) = 0.9$, $p = .39$, E group: paired $t(5) = 0.89$, $p = .41$). Non-normal distributions for T1 right ear NB group and T2 right ear E group precluded the use of repeated measures ANOVA. Instead, paired comparisons with T1 and T2 latency were carried out for each ear and for each group. Any significant changes identified in the new user groups could then be compared against the experienced user group. Type 1 error was controlled by adjusting the value for p for multiple comparisons (so that $p = .05/6 = .008$). There was no significant difference in mean latency between T1 and T2 for the NU group (fitted ear: $t(7) = 0.19$, $p = .85$; not-fitted

ear $t(7) = 0.31$, $p = .77$). There was no statistically significant difference in mean latency between the two time points in the NB group (Left ear: $t(9) = 0.30$, $p = .77$; Right ear: Wilcoxon $Z = 0.74$, $p = .46$) or in the control group of E users (Left ear: $t(5) = 0.29$, $p = .79$; Right ear: Wilcoxon $Z = 1.09$, $p = .28$). There was no evidence for changes in latency for aided ears of the new user groups over time. Correlation between T1 and T2 latency was .86 and .85 ($p < .001$) for left and right ears respectively; reliability of latency measures was high.

There was a possible trend for lower mean amplitude in the E group, which is consistent with poorer hearing thresholds in this group. At T1, there was no significant difference in amplitude between groups for the fitted/left ear ($F(2,21) = 1.77$, $p = .20$), though there was significantly higher mean amplitude for the not-fitted ear of the NU group compared to left ear of the NB and E groups ($F(2,21) = 3.74$, $p = .04$; Fisher LSD post hoc comparisons; $p = .03$, $p = .02$, respectively). Possible asymmetries between ears for the NB and NU groups were not statistically significant (paired $t(9) = 1.07$, $p = .31$, $t(7) = 0.91$, $p = .39$, respectively). Non-normal distributions for T2 right ear E user group precluded the use of repeated measures ANOVA, so change in amplitude over time was analysed similarly to latency. There was no significant difference in mean amplitude between T1 and T2 for the fitted ear of the NU group ($t(7) = 1.68$, $p = .14$) or not-fitted ear of the NU group ($t(7) = 0.64$, $p = .54$). There was no significant difference between T1 and T2 in mean amplitude for the NB group (Left ear: $t(9) = 1.40$, $p = .19$; Right ear: $t(9) = -0.08$, $p = .93$), or for the E user group (Left ear: Wilcoxon $Z = -1.15$, $p = .25$; Right ear: $t(5) = -1.22$, $p = .28$). Correlations between T1 and T2 amplitude were .61 ($p = .00$) and .29 ($p = .16$) for left and right ear, respectively; reliability of amplitude measures was low.

Discussion

The hypothesis was that either increased amplitude or reduced latency (or both) of wave V of the ABR would be observed in the aided ears of unilaterally and bilaterally fit new hearing aid users following 3 months hearing aid use, while no changes would be observed in a control group of experienced hearing aid users. However, there was no evidence for changes in either latency or amplitude in either unilateral or bilateral new user groups. This contrasts with two previous studies that suggested alterations in ABR following hearing aid use. Munro et al. [9] found higher amplitude wave V for the fitted ear of long-term unilateral hearing aid users, while Philibert et al. [10] reported reduced wave V latency in the right ear of newly fit bilateral hearing aid users after 6 months hearing aid use.

Differences between the studies may be accounted for by differences in design. Munro et al.'s study was cross sectional, so the observed amplitude asymmetry between ears may have been pre-existing, unrelated to hearing aid use and an artefact of group composition. In contrast, the current study examined changes in amplitude longitudinally from the time of first fitting. Philibert et al. studied a rather small sample of new hearing aid users (n=5) and no control group was included; differences in latency detected in this study may have been spurious. The current study utilised larger samples and included a control group to account for any systematic changes in ABR related to procedure rather than hearing aid use.

However, a potentially significant difference between the current study and previous ones is duration of hearing aid use. In the current study, ABR was retested after ~3 months hearing aid use (following behavioural evidence that acclimatization is observable after about this time [2]). In contrast, Philibert et al. found significant changes in ABR latency after 6 months

use, while Munro et al. tested those with at least 2 years experience with hearing aids. It is possible that acclimatization effects in ABR associated with hearing aid use only become apparent after longer than the 3 months experience with hearing aids used in this study.

A possible weakness of the current study is that several participants, both experienced users and new hearing aid users, had to be excluded from further analysis because of unreliable ABR recordings, and this may be a potential source of bias. The difficulty in obtaining reliable ABR recordings with elderly hearing impaired participants may be a significant limitation for future research in this area. In this study, ABR latency was a more reliable index than amplitude, possibly because of fluctuations in SNR of recordings between sessions impacting on ABR amplitude.

In summary, no changes in ABR wave V amplitude or latency were detected in the aided ears of new hearing aid users after 3 months hearing aid use, despite careful attention to a range of design variables. Productive questions for future research may address the impact of longer term changes in brainstem processing in hearing aid users, and how any changes might be linked to alterations in cortical processing as well as behavioural measures of aided listening and hearing aid benefit.

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Figure 1. ABR wave V latency and amplitude

Notes: Error bars show one standard error. For the New unilateral group, bars are arranged according to the fitted and not-fitted ear. Mean latency has been corrected to account for ~0.9 ms delay for sound propagation between the earphone transducer and arrival in the ear canal.

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