European Archives of Oto-Rhino-Laryngology (2019) 276:1001–1010
https://doi.org/10.1007/s00405-019-05303-0

OTOLOG

Consequences of hearing aid acclimatization on ALLRs and its relationship with perceived benefit and speech perception abilities

Megha[1] · **Sandeep Maruthy**[1]

Received: 2 November 2018 / Accepted: 17 January 2019 / Published online: 29 January 2019

Abstract

Objective The study aimed to track long latency responses over a period of hearing aid use in naïve hearing aid users, and study its relationship with change in speech perception abilities and perceived benefit.

Methods Thirty adults in the age range of 23–60 years with moderate sensorineural hearing loss participated in the study. Auditory late latency responses (ALLRs), signal-to-noise ratio − 50 (SNR-50), and scores of speech spatial and qualities questionnaire (SSQ) were measured three times over a period of 2 months of hearing aid use.

Results ALLRs showed a significant decrease in the P1 and N1 latency across the three measurements. Significant increase in the scores of SSQ and significant decrease in the SNR-50 were also found. The change in ALLRs did not correlate with change in scores of either SSQ or SNR-50.

Conclusions The study provides evidence for improvements in neural processing of auditory cortical areas with hearing aid acclimatization. The improvements seen in perceived benefit and speech perception are not related to the improvements in ALLRs. This is the first study in the domain with a younger group compared to the previous studies and the results show evidence for neural plasticity influencing hearing aid acclimatization benefits.

Keywords Auditory late latency responses · Hearing aid acclimatization · Speech in noise · Hearing aid use · Neural plasticity · Perceived benefit

Introduction

Over the years, researchers, as well as clinicians, have realized that a single evaluation at the time of hearing aid fitting will not give the complete picture of the total perceptual benefit obtained from the hearing aid [1, 2]. The perceptual benefit obtained from the hearing aid is shown to increase over a period of time as the user gets acclimatized to the output of a new hearing aid [3]. This is particularly true with naïve hearing aid users [4–6].

In the Eriksholm workshop on acclimatization held in the mid-1990s, it was recommended that along with perceptual measures, assessing the electrophysiological measures is important in understanding the changes that occur in the anatomical sites [7]. In view of this recommendation, studies have attempted to track the changes in auditory brainstem responses [8–10], frequency following responses [11] and late latency responses [12–14] over a period of hearing aid use in naïve hearing aid users.

Specifically in cortical auditory potentials, McCullagh [14] showed significant shortening of the N1 latency in adult hearing aid users (49–71 years of age), after 6–8 weeks of hearing aid use. However, there was no change observed in the amplitude of N1 and P2 and the latency of P2 wave. Similarly, there were no significant difference in speech recognition scores with hearing aid use. The change in latency of N1 was attributed to the acclimatization and was considered as the evidence for the physiological change in the higher auditory centers. Rao et al. [15] studied P300a in hearing aid users (experimental group in the age range of 60–85 years and control group in the age range of 49–85 years) and reported that there was a significant reduction in P300a after 4 weeks of hearing aid use. However, there was no significant benefit in the speech perception abilities. The reduction in P300a is reported to be indicative of reduced level of involuntary

✉ Megha
meghajp11@gmail.com

[1] Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysore, Karnataka 570006, India

orientation towards distractors, in turn reflecting improved abilities to suppress distractors.

On the contrary, Dawes et al. [12] did not find any change in auditory late latency responses (ALLRs) in hearing aid users in the range of 69–72 years of age. Dawes et al. [12] compared speech recognition in noise and N1–P2 responses between baseline and 12 weeks of hearing aid use. The results showed a statistically significant 2% improvement in aided speech recognition while there were no improvements in the N1–P2 responses. Similarly, Habicht, Finke, and Neher [13] did not find improvements in ALLRs subsequent to hearing aid use in naïve hearing aid users in the age range of 73–74 years.

Overall, the available evidence in ALLRs lack consensus, and it is not clear whether ALLRs show changes secondary to acclimatization to hearing aids. It is important to note that studies which report lack of significant change in ALLRs also show that speech perception either does not change significantly [11, 13] or changes minimally [12] with hearing aid use. Therefore, one can speculate that lack of change seen in the ALLRs may underlie the lack of improvement in the speech perception abilities. Therefore, it is important to compare the change in ALLRs over a period of hearing aid use, separately in those who show improvements in speech perception and those who do not.

More importantly, the studies in which ALLRs were tracked over a period of hearing aid use, included participants with a mean age of more than 70 years [11–13]. It is well known that the auditory system of older adults have slower neural processing due to prolonged refractory periods, loss of myelin integrity and variability in neural firing [16–20], making it less malleable. Evidence from imaging techniques like magnetoencephalogram and functional magnetic resonance imaging also shows reduced functional neuroplasticity in older adults compared to younger adults [21, 22]. Therefore, one can expect that a similar experimental paradigm of ALLRs tracked over a period of hearing aid use in younger participants will show different findings, owing to better malleability in them. Hence, the present study aimed to track ALLRs over a period of hearing aid use in naïve hearing aid users in the age range of 23–60 years and study its relationship with change in speech in noise perception and change in scores of self-assessment questionnaire. Speech spatial qualities (SSQ) questionnaire was chosen for assessing the perceived benefit, as it probes into a variety of listening environments and provides insight into the corresponding difficulties faced by individuals with hearing impairment. Earlier studies on hearing aid acclimatization have also used SSQ [11, 23] for assessing perceived benefit.

It was hypothesized that the younger group are likely to show benefits of hearing aid acclimatization in ALLRs and such changes in ALLRs are related to their perceived benefit.

Methods

Subjects

Thirty adults in the age range of 23–60 years (mean age = 48 years) participated in the study. The sample size was estimated for an effect size of 0.50 (based on the pilot data), power of 0.80 and significance level of 0.05. All participants had bilateral mild to moderate degree of sensorineural hearing loss in the test ear. In the instance of asymmetric hearing loss, the ear with better word identification scores was preferred for testing. The mean pure tone average (average of the hearing thresholds obtained at 0.5, 1, 2, and 4 kHz) of the test ear was 48.42 dB (SD = 3.87), and the word identification score was more than 75%. Brainstem lesions were ruled out based on auditory brainstem responses.

All the participants were naïve users of hearing aids and were native speakers of Kannada (a regional language spoken in south India). All of them hailed from Mysuru district and spoke the same dialect of Kannada. A written informed consent was obtained from all the participants, and the test procedure conformed to the institutional ethical guidelines for bio-behavioral research in humans.

Procedure

All the participants were aided with a digital behind the ear hearing aid with a minimum of four channels. The hearing aids used had features of gain manipulation for soft, medium and loud sounds. Customized soft ear molds were used to snuggly fit the hearing aids in the ear canal. The hearing aids were programmed with the corresponding software in the NOAH platform. The first-fit based on the NAL–NL2 prescriptive formula was used for gain prescription. The output was then optimized as per the listening needs of the individual based on their direct feedback. The hearing aid prescribed was chosen based on a standard comparative procedure, comparing the performance with at least three hearing aids (belonging to the same category but different manufacturers) in terms of the resultant aided word identification scores in quiet. The hearing aid that provided the maximum aided word identification score (among the three tested) in the audiometric room was prescribed. All the participants were monaurally fitted with hearing aid and the ear in which the hearing aid was used during the study period was considered as the test ear.

Data logging was enabled in the hearing aid to monitor the hours of hearing aid use. The volume control in the hearing aid was disabled to ensure that the output is not manipulated during the 2 months of study period. While twenty-one participants used the same model of hearing aid, the other nine used an equivalent (having same technical features but belonging to a different manufacturer) hearing aid.

Following the hearing aid fitting, SNR-50, ALLRs and SSQ questionnaire were administered three times (M1, M2 & M3) during the study period. M1 referred to the measurement immediately after hearing aid fitting, whereas M2 and M3 referred to measurements after 1 and 2 months of hearing aid use, respectively. SNR-50 was measured in the aided condition while ALLRs were recorded in the unaided condition. These were measured on the day of hearing aid fitting for M1. As an exception, SSQ was administered after 1 week of hearing aid use for M1, to ensure that they had sufficient listening experience with the hearing aid before answering the SSQ.

Administration of questionnaire

The original SSQ questionnaire given by Gatehouse and Noble [24] was adapted to Kannada language. The questionnaire probed into the abilities and experiences of hearing and listening in different situations. The questionnaire was translated to Kannada by an experienced Audiologist, who was a native speaker of Kannada. The translated questionnaire was then reverse translated to English by a linguist and four other Audiologists, to ensure that the meaning conveyed is same as that of the original questions. The questions that did not convey the original meaning were modified suitably and ensured that the original meaning is conveyed. The questionnaire had three sub-sections; speech hearing, spatial hearing and qualities of hearing. Participants were instructed to rate each question in the three sub-sections on a ten-point rating scale which ranged between 0 (not at all) and 10 (perfect). The total score was calculated for each sub-section, and the scores of all the three sub-sections were added to obtain the total SSQ score.

Measurement of SNR-50

SNR-50 was estimated based on the identification of Kannada bi-syllabic words [25] presented in the presence of speech spectrum shaped noise, at different SNRs, generated using a MATLAB code [26]. The stimuli was presented through a customized software [27]. The stimuli presented in the software were routed through an audiometer and delivered through a loudspeaker kept at 45° azimuth (towards the side of the ear with hearing aid). The stimulus level was calibrated by adjusting the VU meter to zero while a calibration tone was generated by the software. The participants were instructed to repeat the words heard in the presence of the competing noise. Based on the response, the tester provided an input to the software about the correctness of the response. The SNR was varied accordingly. To begin with, the words were presented at 45 dB HL at +8 dB SNR. The level of the noise was varied in steps of 2 dB automatically by the software, based on the response of the participants. That is, in instances of correct response, SNR was decreased by 2 dB and it was increased by 2 dB if the response was incorrect. One word was presented at each SNR. A minimum of eight reversal points were obtained and the average of the last five reversals was taken as the threshold. SNR-50 (in dB) was estimated in the aided, sound-field condition. Different word lists were used in each session to avoid practice effects.

Recording of ALLRs

ALLRs were recorded for syllable |da| of 40 ms, using a Biologic Navigator Pro EP system (version 7.2.1). The stimulus was delivered through insert receivers at a rate of 1.1/s, and at 80 dBnHL. Using a single channel, the EEG was picked up from scalp electrodes placed in the vertical montage (positive at Fpz, negative at test ear mastoid and ground at non-test ear mastoid). The EEG picked-up was band-pass filtered between 0.1 and 30 Hz, in the acquisition window of − 81 to 800 ms. Only the sweep with EEG amplitude within ± 25 µV was considered for averaging and the responses were averaged across 150 such stimulus sweeps. The resultant averaged waveforms were visually analysed by 3 experienced Audiologists to mark the peak of P1, N1 and P2 waves. The latency of P1, N1 and P2 along with amplitudes of P1–N1 and N1–P2 complexes were noted down from each waveform.

Results

The data were tabulated and was tested for its distribution using the Shapiro–Wilk test of normality using Statistical Package for Social Sciences (version 21). The results showed that the data were not normally distributed in many of the dependent variables. Hence, non-parametric tests were used for within- and between-group comparisons. The scores of SSQ and SNR-50 presented in this article are the same as that presented in another article by the authors (accepted for publication). However, the focus of the earlier article was different compared to this article and the results of the earlier article was derived from the data of 26 participants.

Comparison of scores of SSQ questionnaire across the three sessions

Figure 1 gives the median and 95% confidence interval of scores of SSQ in the three sessions (M1, M2 and M3). It was observed that the median SSQ scores increased from M1 through M3 session.

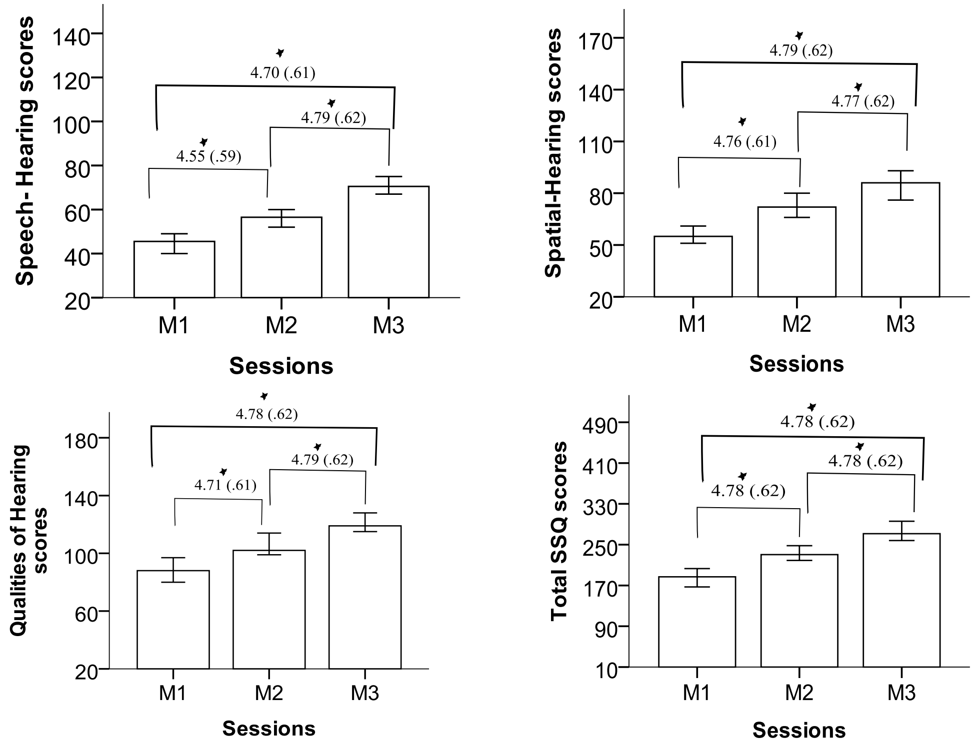

Fig. 1 Median and 95% confidence interval of scores of SSQ questionnaire. Wilcoxon Z values and effect size (in parentheses) are provided whenever the scores were significantly different between the sessions. *Indicates significant difference ($p<.01$)

The effect of session on SSQ scores (speech, spatial & qualities sub-sections & total scores) was tested using the Friedman's test. Friedman's test showed a significant main effect of session on speech hearing [χ^2 (2, 30) = 56.58, $p<.001$], spatial hearing [χ^2 (2, 30) = 56.06, $p<.001$], qualities of hearing [χ^2 (2, 30) = 59.51, $p<.001$] and the total scores [χ^2 (2, 30) = 60.00, $p<.001$]. Further, pair-wise comparisons using Wilcoxon's signed rank test (Fig. 1) showed a significant difference across the three sessions in each of the three sub-sections and the total SSQ scores.

Comparison of SNR-50 across the three sessions

The median and 95% confidence interval of SNR-50 obtained in the three sessions is given in Fig. 2. The median SNR-50 scores showed a decreasing trend from M1 through M3.

The results of Friedman's test showed a significant main effect of session on SNR-50 [χ^2 (2, 30) = 56.53, $p<.001$]. Subsequent pair-wise comparisons using Wilcoxon signed rank test revealed a significant difference in SNR-50 across the three sessions (Fig. 2).

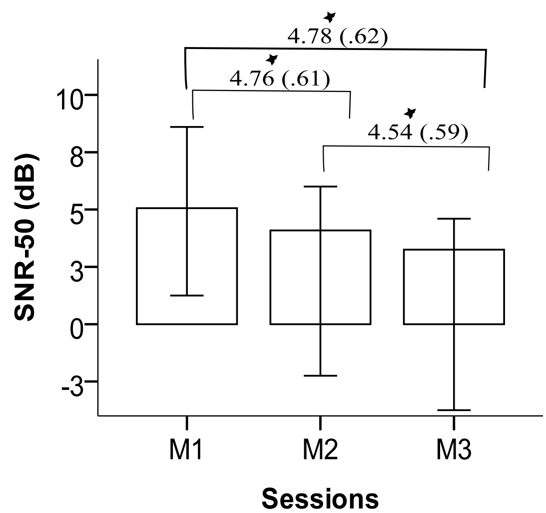

Fig. 2 Median and 95% confidence interval of SNR-50 obtained in the three sessions. Wilcoxon Z values and effect size (in parentheses) are provided whenever the scores were significantly different between the sessions. *Indicates significant difference ($p<.01$)

Comparison of ALLRs across the three sessions

The median and 95% confidence interval of peak latency of P1, N1 and P2 in the three sessions (M1, M2 and M3) are shown in Figs. 3 and 4. It can be noted that the median latency decreased from M1 through M3 for P1 and N1 but not for P2. In P2, the median latency increased from M1 through M3.

Comparison of peak latency across the three sessions using Friedman's test revealed a significant main effect of session in P1 [χ^2(2, 30) = 41.21, $p<.001$] and N1[χ^2(2, 30) = 21.59, $p<.001$] but not in P2 [χ^2(2, 30) = 0.76, $p>.05$]. Pair-wise comparisons showed a significant

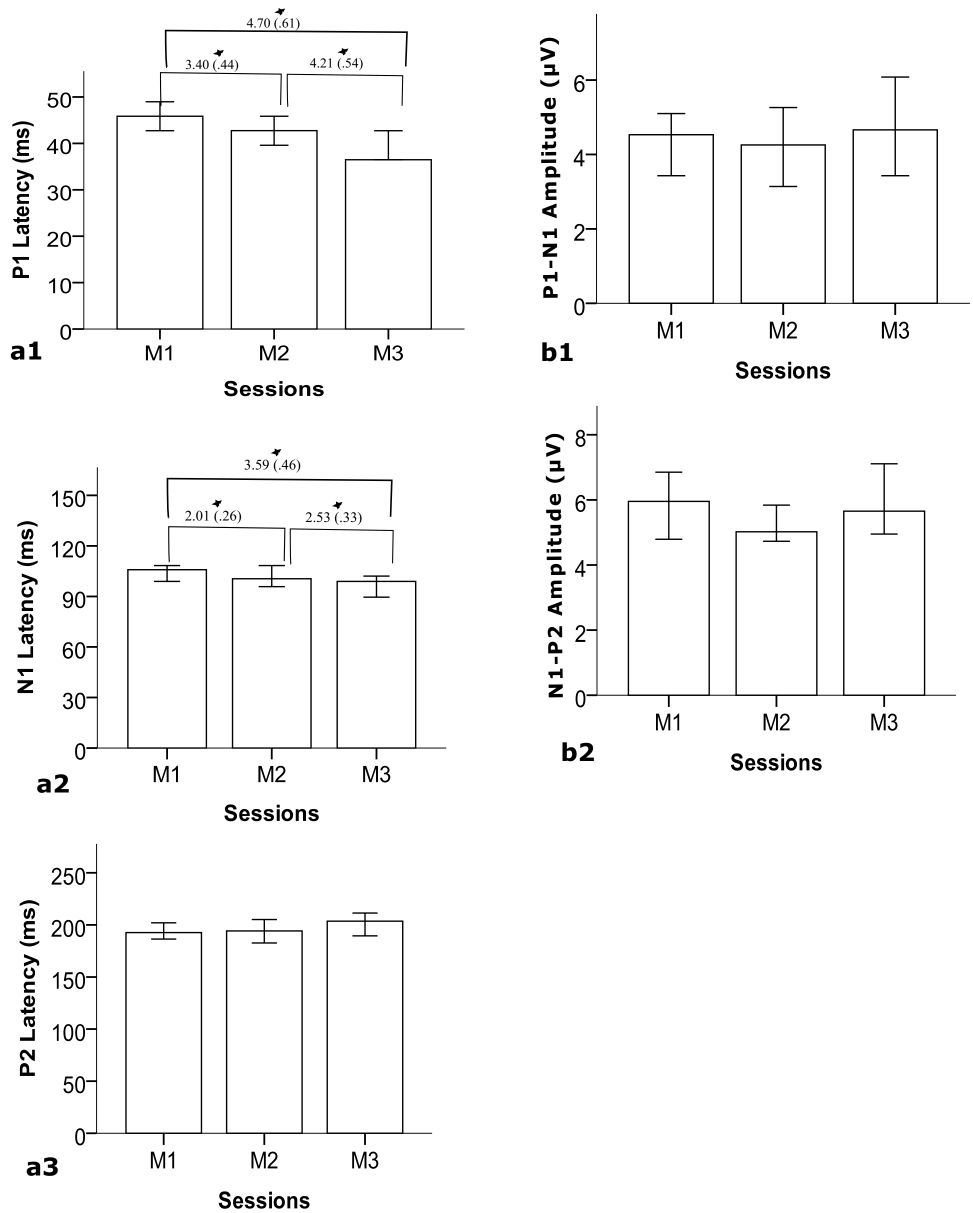

Fig. 3 **a1**–**a3**. Median and 95% confidence interval of latency of ALLRs. Wilcoxon *Z* values and effect size (in parentheses) are provided whenever the scores were significantly different between the sessions. *Indicates significant difference ($p < .01$). **b1, b2** Median and 95% confidence interval for P1–N1 and N1–P2 amplitude of ALLRs

difference across the three sessions in the latency of P1 and N1 (Fig. 3a1–a3).

The median amplitude of ALLR recorded in M1, M2, and M3 are provided in Fig. 3b1 and b2. It was noted that the median amplitude showed minimal change from M1 through M3. To study the main effect of sessions on ALLR amplitude, Friedman's test was done. The test results did not show a significant main effect of the session on P1–N1 and N1–P2 amplitude of ALLRs ($p > .05$).

Correlation between change index of SSQ questionnaire and change index of ALLR

The index of the change in the scores of SSQ questionnaire was derived by subtracting the individual scores in M1 from that of M3. The change index was derived only for the total score of SSQ. Similar change index was also calculated for the latency of P1 and N1. The change index

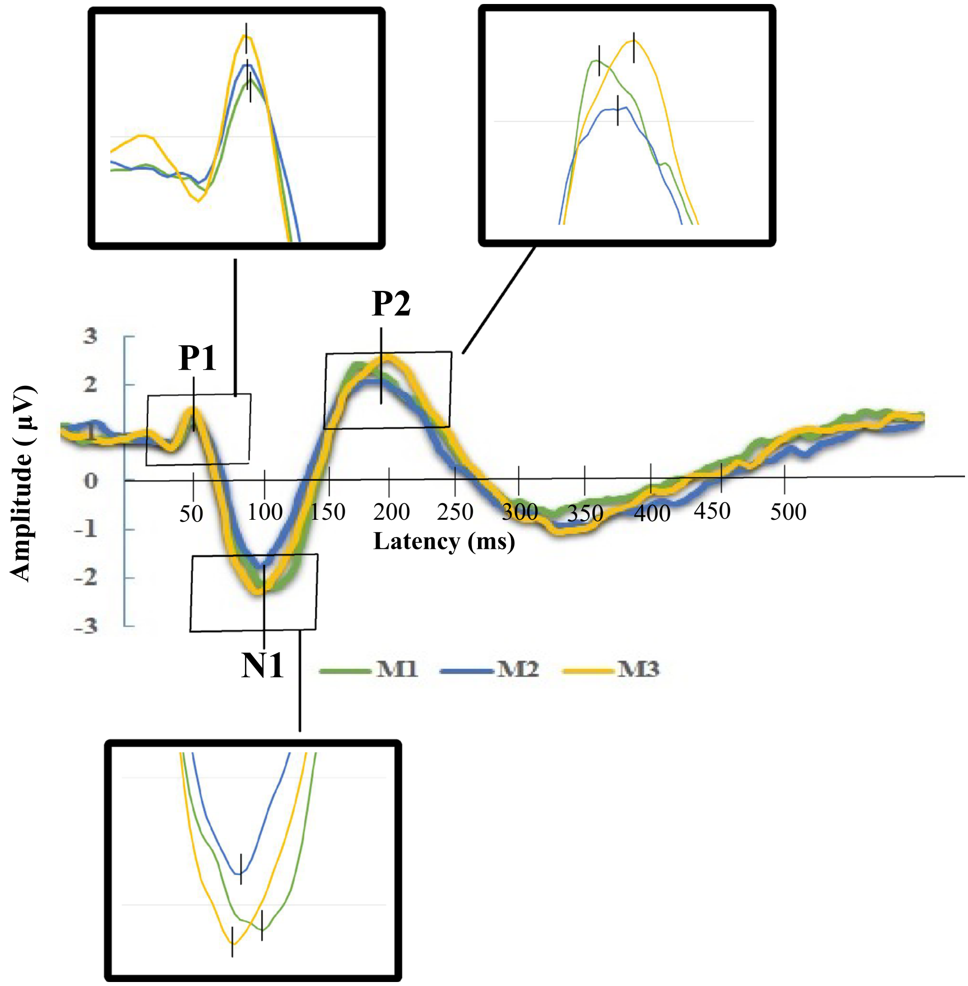

Fig. 4 Grand averaged waveforms of ALLR recorded in M1, M2, and M3. In the inset are the zoomed portions of the ALLR components

of SSQ was tested for its correlation with change index of latency of P1 and N1. The results of Spearman correlation showed that there was no significant correlation of change index of total scores of SSQ either with that of latency of P1 ($r_s = 0.009$, $p > .05$) or N1 ($r_s = -0.28$, $p > .05$).

Correlation between change index of SNR-50 and change index of ALLRs

The index of the change in SNR-50 scores was derived by subtracting the individual SNR-50 in M1 from that of M3. The change index of SNR-50 was tested for its correlation with change index of latency of P1 and N1. The results showed that there is no significant correlation of change index of SNR-50 either with that of latency of P1 ($r_s = 0.18$, $p > .05$) or N1 ($r_s = 0.05$, $p > .05$).

Comparison of change index of ALLRs between good and poor performers

The relationship of SSQ scores with ALLRs was explored further by dividing the participants into two groups based on their change index of total SSQ scores and SNR-50.

Comparison of change index of ALLRs between good and poor performers, based on change index of total scores in SSQ

Based on the 95% confidence interval of change index of SSQ scores, participants were divided into good performers and poor performers. The derived upper bound was

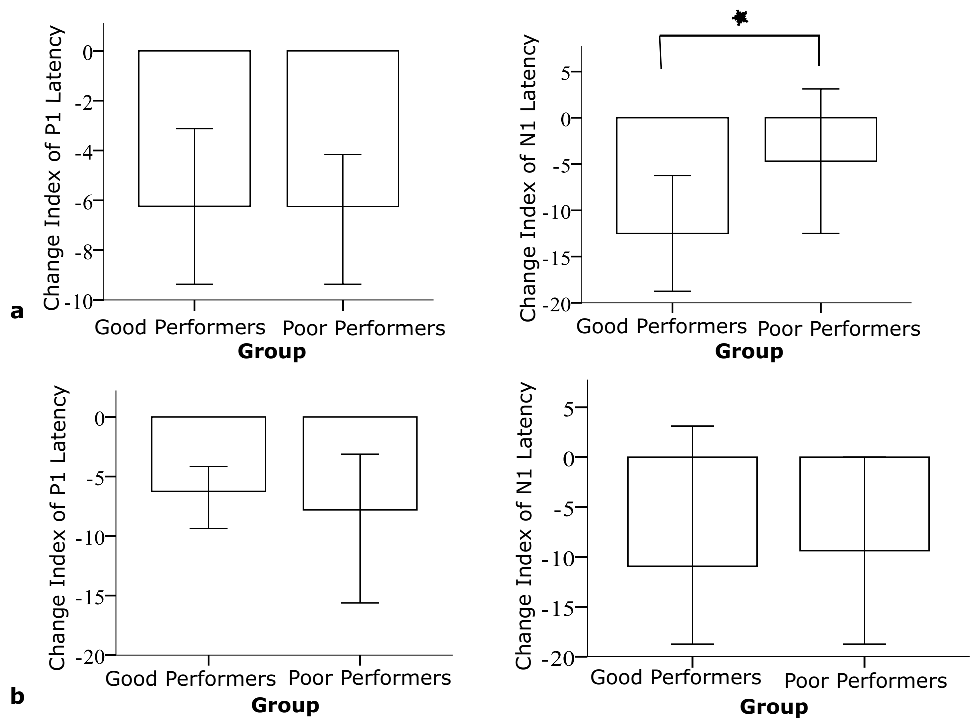

Fig. 5 **a** Median and 95% confidence interval of change index of P1 and N1 between the good and poor performers based on change index of total scores in SSQ. **b** Median and 95% confidence interval of change index of P1 and N1 between the good and poor performers based on change index of total scores SNR-50

96.29 and the lower bound was 78.56. Accordingly, there were 12 participants in each group (with change index of total score of SSQ being above the upper bound or below the lower bound). The change index of latency of P1 and N1 were compared between these two groups using Mann–Whitney *U* test. Figure 5 shows the median of the change index of latency of P1 and N1 in the two groups. It can be noted that, statistically, the median change in ALLR latency was more in the group of good performers compared to poor performers in N1 but not in P1. Comparison between the two groups showed that change in N1 latency was significantly higher in good performers compared to that of poor performers ($U=35.50$, $p<.05$, $r=.43$).

Comparison of change index of ALLRs between good and poor performers based on change index of SNR-50

The 95% confidence interval of the change index of SNR-50 was derived and the participants were divided into good performers and poor performers. The upper bound thus derived was −3.01 and the lower bound was −4.45. Accordingly, there were 10 participants in the good performers group (with change index of SNR-50 being more than −4.45) and 13 in the poor performers group (with change index of SNR-50 being less than −3.01). The corresponding change index of ALLRs of these two groups were compared. Figure 5 shows the median of the change index of ALLRs in these two groups. Mann–Whitney *U* test showed no significant difference in the change in the latency of P1 and N1 between the two groups ($p>.05$).

Discussion

The study aimed to track the changes if any in ALLRs over a period of hearing aid use, in naïve hearing aid users. The presence of acclimatization was inferred from the change in SSQ scores during the study period. In the study, total SSQ scores, as well as the scores of the three sub-sections of the questionnaire (speech hearing, spatial hearing & quality of hearing), showed significant improvement with hearing aid use, thus suggesting improvement in the perceived benefit. In the 2 months of the study period, the participants had not undergone any kind of training and their lifestyle remained same as in the pre-hearing aid fitting times. However, they had used the hearing aids continuously throughout the day with mean usage being 8.1 hours. Therefore, the improvement seen in the perceived benefit during the 2 months of study period is attributable to benefits secondary to the acclimatization to their hearing aids. This result is in consensus with earlier literature reporting perceptual benefit with the hearing aid use [11, 23, 28–33]. From a clinical point of view, it is important to note that every participant of the study showed improvement in the perceived benefit.

The acclimatization related benefits were also seen in SNR-50 and the mean SNR gain by 2 months of hearing aid use was 3.73 dB. Earlier studies have also shown improvement in speech perception abilities with the hearing aid use

[34–36] and the improvement in perceived benefit was found to be related to the SNR gain. However, there are few studies which did not witness any change in the speech perception abilities with the use of hearing aid over a period of time [1, 5, 23, 24, 30, 37].

Dawes and Munro [34] attributed the differences in the findings to the differences in the degree of hearing loss, method of testing and the type of noise used across studies. The methodology used in the present study is similar to that of Dawes and Munro [34], in terms of degree of hearing loss of the participants (moderate hearing loss) and the method used to obtain the speech scores (adaptive SNR changes). The resultant mean improvement in SNR-50 obtained in the present study is comparable to that observed in Dawes and Munro [34].

ALLRs also showed a significant improvement with the hearing aid use. Specifically, the improvement was seen in the peak latency of P1 and N1 waves. This is supported by the findings of McCullagh [14] who reported improvement in the latency of N1 in new hearing aid users by 8 weeks of hearing aid use. P1 is known to have contributions from primary auditory cortex, hippocampus, planum temporale and lateral temporal cortex [38, 39], whereas N1 is generated from auditory cortex on the supratemporal lobe [40]. The findings of the current study suggest that the regular use of hearing aids in naïve hearing aid users results in physiological changes at these sub-cortical and cortical areas. The improvement in the latency of ALLRs indicates that the processing in these cortical areas become faster with acclimatization to hearing aid.

McCullagh [14] reported improvement only in the latency of N1, whereas the current study evidenced improvements in the latencies of both P1 and N1. The differences in the findings between the two studies could be attributed partly to the difference in the age of the participants. While the participants in McCullagh [14] were in the age range of 49–71 years, the current study included younger participants (23–60 years, mean = 48 years). The decrease in neural plasticity with advancing age, could be the probable reason for the differences between the two studies.

Contrary to the current findings, some of the earlier studies have not reported changes in ALLRs with hearing aid use [12, 13]. Although the exact reason for the difference in the findings is not clear, the difference in the age of the participants could be one of the significant contributing factor. The mean age of the participants of the current study is 48 years, while in the earlier studies it was more than 70 years. The support for differences in the malleability across age groups can be drawn from the evoked potential, neurophysiological and imaging studies [21, 22, 41–45].

Another important difference between the current study and the earlier studies that have not shown improvement in ALLRs with hearing aid use is in the change in speech perception abilities. While the earlier studies have shown absent [11, 13] or negligible improvements [12] in speech perception abilities, the current study showed a significant improvement of 3.73 dB. Therefore, one can speculate the presence of a relationship between improvements in speech perception abilities and improvements in ALLR.

Overall, the findings of the current study provide evidence for improvement in the neural processing of signals in the auditory cortical areas with regular use of hearing aids in adult users. Considering that most of the participants used hearing aids monaurally, the findings may be restricted to the monaural hearing aid use. Use of hearing aids binaurally may yield different results, which needs to be probed in future studies.

Relationship between improvement in ALLRs and improvement in the perceived benefit

The current study showed that there is no significant correlation between improvement in scores of SSQ and improvement in ALLRs. This suggests that the improvement seen in the perceived benefit is not influenced by the improvement in neural processing as evidenced through ALLRs. However, when the participants were grouped based on the improvement seen in the perceived benefit, it was found that those with higher perceived benefit (good performers) had greater improvements in the N1 latency than those with lesser perceived benefit. These findings suggest the presence of a relationship between N1 latency and perceived benefit. Nonetheless, the absence of correlation indicates that there is no one-to-one relationship between the two.

Relationship between improvement in ALLRs and improvement in the SNR-50

Similar to the SSQ scores, the improvement in speech perception in noise was not found to relate with improvements in ALLRs. This was true even after the participants were divided into good and poor performers based on their scores in SNR-50. This suggests that acclimatization related improvements seen in ALLRs and SNR-50 are independent of each other and also improvements seen in speech perception abilities are not influenced by improvements in neural processing time. Therefore, from a clinical point of view, it is important to note that the improvements in ALLRs does not assure improvements in speech perception in noise. Considering that the improvements with hearing aid use were seen in both ALLRs and speech perception in noise, a relationship between the two was speculated. The absence of evidence of such a relationship suggests that the absence of improvement of speech perception abilities in the earlier studies [11–13] could be due to poor malleability attributable to the age of the participants.

The inferences drawn in the current study could have been strengthened with multiple baselines or by having a control group. However, none of the potential participants of the study were ready to delay the hearing aid use, due to which it was not practical to recruit a control group or take multiple baseline measurements.

Conclusions

The findings of the present study show evidence for improvements in ALLRs secondary to hearing aid acclimatization in naïve hearing aid users. However, the improvements evidenced in ALLRs are not related to the improvements in their speech perception abilities. Nonetheless, the improvements seen in N1 latency appears to be related to the improvements in perceived benefit. This relationship, however, warrants further exploration in future studies.

Acknowledgements We would like to acknowledge All India Institute of Speech and Hearing for providing the resources and infrastructure to carry out this research. The co-operation rendered by the participants for multiple evaluations is extremely appreciated.

Funding No funding was received.

Compliance with ethical standards

Conflict of interest None of the authors have potential conflicts of interest to be disclosed.

Informed consent Informed consent was obtained from all individual participants included in the study. The test procedure conformed to the institutional ethical guidelines for bio-behavioral research in humans.

References

1. Cox RM, Alexander GC (1992) Maturation of hearing aid benefit: objective and subjective measurements. Ear Hear 13:131–141
2. Gatehouse S (1992) The time course and magnitude of perceptual acclimatization to frequency responses: evidence from monaural fitting of hearing aids. J Acoust Soc Am 92:1258–1268
3. Taylor B (2007) Changes in hearing aid benefit over time: An evidence-based Review. Audiology Online. Retrieved from http://www.audiologyonline.com/articles/article_detail.asp?article_id=1853. Accessed 5 April 2012
4. Horwitz AR, Turner CW (1997) The time course of hearing aid benefit. Ear Hear 18:1–11
5. Kuk FK, Potts L, Valente M, Lee L, Picirrillo J (2003) Evidence of acclimatization in persons with severe-to-profound hearing loss. J Am Acad Audiol 14:84–99
6. Munro KJ, Lutman ME (2003) The effect of speech presentation level on measurement of auditory acclimatization to amplified speech. J Acoust Soc Am 114:484–495
7. Arlinger S, Gatehouse S, Bentler RA, Byrne D, Cox RM, Dirks DD, Humes L, Neuman A, Ponton C, Robinson K, Silman S (1996) Report of the Eriksholm Workshop on auditory deprivation and acclimatization. Ear Hear 17:87S
8. Dawes P, Munro KJ, Kalluri S, Edwards B (2013) Brainstem processing following unilateral and bilateral hearing-aid amplification. Neuroreport 24(6):271–275
9. Munro KJ, Pisareva NY, Parker DJ, Purdy SC (2007) Asymmetry in the auditory brainstem response following experience of monaural amplification. Neuroreport 18:1871–1874
10. Philibert B, Collet L, Vesson JF, Veuillet E (2005) The auditory acclimatization effect in sensorineural hearing-impaired listeners: evidence for functional plasticity. Hear Res 205:131–142
11. Karawani H, Jenkins KA, Anderson S (2018) Neural and behavioral changes after the use of hearing aids. Clin Neurophysiol 129:1254–1267
12. Dawes P, Munro KJ, Kalluri S, Edwards B (2014) Auditory acclimatization and hearing aids: late auditory evoked potentials and speech recognition following unilateral and bilateral amplification. J Acoust Soc Am 135:3560–3869
13. Habicht J, Finke M, Neher T (2018) Auditory acclimatization to bilateral hearing aids: effects on sentence-in-noise processing times and speech-evoked potentials. Ear Hear 39:161–171
14. McCullagh JP (2009) An investigation of central auditory nervous system plasticity following amplification. University of Connecticut, Connecticut
15. Rao A, Rishiq D, Yu L, Zhang Y, Abrams H (2017) Neural correlates of selective attention with hearing aid use followed by ReadMyQuips auditory training program. Ear Hear 38:28–41
16. Anderson S, Kraus N (2013) Auditory training: evidence for neural plasticity in older adults. SIG 6 Perspect Hear Hear Dis Res Diag 17:37–57
17. Anderson S, Parbery-Clark A, White-Schwoch T, Kraus N (2012) Aging affects neural precision of speech encoding. J Neurosci 32:14156–14164
18. Lu PH, Lee GJ, Raven EP, Tingus K, Khoo T, Thompson PM, Bartzokis G (2011) Age-related slowing in cognitive processing speed is associated with myelin integrity in a very healthy elderly sample. J Clin Exp Neuropsychol 33:1059–1068
19. Parthasarathy A, Bartlett EL (2011) Age-related auditory deficits in temporal processing in F-344 rats. Neurosci 192:619–630
20. Recanzone GH, Engle JR, Juarez-Salinas DL (2011) Spatial and temporal processing of single auditory cortical neurons and populations of neurons in the macaque monkey. Hear Res 271:115–122
21. Heinzel S, Lorenz RC, Brockhaus WR, Wüstenberg T, Kathmann N, Heinz A, Rapp MA (2014) Working memory load-dependent brain response predicts behavioral training gains in older adults. J Neurosci 34:1224–1233. https://doi.org/10.1523/JNEUROSCI.2463-13.2014
22. Mary A, Bourguignon M, Wens V, de Beeck MO, Leproult R, De Tiège X, Peigneux P (2015) Aging reduces experience-induced sensorimotor plasticity. A magnetoencephalographic study. NeuroImage 104:59–68. https://doi.org/10.1016/j.neuroimage.2014.10.010
23. Dawes P, Munro KJ, Kalluri S, Edwards B (2014) Acclimatization to hearing aids. Ear Hear 35(2):203–212
24. Gatehouse S, Noble W (2004) The speech, spatial and qualities of hearing Scale (SSQ). Int J Audiol 43:85–99
25. Puttabasappa M, Periannan JA, Kumar SKS, Chinnaraj C (2015) Development of phonemically balanced word lists for adults in the Kannada language. J Hear Sci 5:22–30
26. Gnanateja N (2016) Speech Spectrum shaped noise. MathLab file retrieved from https://in.mathworks.com/matlabcentral/fileexchange/55701-speech-spectrum-shaped-noise. Accessed on 12 Dec 2016
27. Uppunda A, Maruthy S (2014) Effect of Auditory-cognitive training on some auditory and speech reception on skills in individuals with sensorineural hearing loss. DST Project, AIISH, Mysuru

28. Amorim RMC, de Almeida K (2007) Study of benefit and of acclimatization in recent users of hearing aids. Pro Fono J Sci Update Barueri (SP) 19:39–48
29. Humes LE, Humes LE (2004) Factors affecting long-term hearing aid success. Semin Hear 25:63–72
30. Humes LE, Halling D, Coughlin M (1996) Reliability and stability of various hearing-aid outcome measures in a group of elderly hearing-aid wearers. J Sp Lang Hear Res 39:923–935
31. Takahashi et al (2007) Subjective measures of hearing aid benefit and satisfaction in the NIDCD/VA follow-up study. J Am Acad Audiol 18:323–349
32. Vestergaard MD (2006) Self-report outcome in new hearing-aid users with ski-slope hearing loss: Longitudinal trends and relationships between subjective measures of benefit and satisfaction. Int J Audiol 45:382–392
33. Verma L et al (2017) A comparative study on hearing aid benefits of digital hearing aid use (BTE) from 6 months to 2 years. Int Arch of Otorhinolaryngol 21:224–231
34. Dawes P, Munro KJ (2017) Auditory distraction and acclimatization to hearing aids. Ear Hear 38:174–183
35. Ng EHN, Classon E, Larsby B, Arlinger S, Lunner T, Rudner M, Ronnberg J (2014) Dynamic relation between working memory capacity and speech recognition in noise during the first 6 months of hearing aid use. Trends Hear 18:1–10
36. Prates LPCP, Iorio MCM (2006) Acclimatization: speech recognition in hearing aid users. Pró-Fono Revista de Atualização Científica 18:259–266
37. Munro KJ, Lutman ME (2004) Self-reported outcome in new hearing aid users over a 24-week post-fitting period. Int J Audiol 43:555–562
38. Howard MA et al (2000) Auditory cortex on the human posterior superior temporal gyrus. J Compar Neurol 416:79–92
39. Billings CJ, Tremblay KL, Souza PE, Binns MA (2007) Effects of hearing aid amplification and stimulus intensity on cortical auditory evoked potentials. Audiol Neurotol 12:234–246
40. Näätänen R, Picton T (1987) The N1 wave of the human electric and magnetic response to sound: a review and an analysis of the component structure. Psychophysiol 24:375–425
41. Burki CN, Ludwig C, Chicherio C, de Ribaupierre A (2014) Individual differences in cognitive plasticity: AN investigation of training curves in younger and older adults. Psychol Res 78:821–835
42. Daselaar SM, Veltman DJ, Rombouts SARB, Raaijmakers JGW, Jonker C (2003) Neuroanatomical correlates of episodic encoding and retrieval in young and elderly subjects. Brain 126:43–56. https://doi.org/10.1093/brain/awg005
43. de Lange AG, Brathen ACS, Rohani DA, Grydeland H, Fjell AM, Walhovd KB (2017) The effects of memory training on behavioral and microstructural plasticity in young and older adults. Hum Brain Map 38:5666–5680
44. Friedman D, Trott C (2000) An event-related potential study of encoding in young and older adults. Neuropsychology 38:542–557
45. Nyberg L, Sandblom J, Jones S, Neely AS, Petersson KM, Ingvar M, Backman L (2003) Neural correlates of training-related memory improvement in adulthood and aging. Proc Natl Aca Sci USA 100:13728–13733