

Research Article



Relationship between Auditory Processing Abilities and Hearing Aid Benefit in Elderly Individuals with Hearing Impairment

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Highlights

- Auditory processing abilities and HAB in naïve and experienced HA users was studied
- Auditory closure and binaural integration correlated with HAB in experienced users

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ABSTRACT

Background and Aim: Cognitive and auditory processing deficits are seen in older individuals with normal hearing sensitivity. Studies on older individuals with hearing impairment have assessed the cognitive function and correlated with hearing devices benefit. Since auditory processing can also affect speech perception abilities, and there is a possible relationship between cognition and some of the auditory processing abilities, it is essential to assess the relationship between auditory processing abilities and hearing aid benefit in naïve and experienced hearing aid users in older adults.

Methods: Fifty individuals in the age range of 51 to 70 years with mild to moderate hearing loss participated in the study. There were 30 participants without any hearing aid experience and 20 participants with hearing aid experience for at least six weeks. Their auditory processing abilities were tested using gap detection test, duration pattern test, speech perception in noise, dichotic consonant-vowel test, masking level difference, forward and backward span tests. The hearing aid benefit was assessed using aided speech perception in noise measures and International Outcome Inventory-Hearing Aids questionnaire in Kannada.

Results: Spearman's correlation showed only correlation between auditory closure ability and binaural integration abilities with hearing aid benefit in experienced users. There was no correlation between any other auditory processing abilities and hearing aid benefit.

Conclusion: There is a correlation between a few auditory processes and hearing aid use in elderly individuals with mild to moderate hearing loss.

Keywords: Auditory processing abilities; hearing aid benefit; hearing aid users; working memory



Introduction

Age-related hearing loss (Presbycusis) is a common cause of hearing impairment. Approximately 25% to 40% of individuals between the ages of 65 and 74 years and about 90% over 80 years of age have hearing loss [1-3]. The hearing problem in older adults is complex as there are age-related physiological changes in the peripheral auditory system and central mechanisms [4]. Hence, in the recent past, there has been a lot of interest in cognition and its effect on hearing and hearing aid benefit in elderly individuals [5-9].

However, the role of changes in auditory processing abilities in elderly individuals has not been studied extensively. Though there are a handful of studies on auditory processing abilities in elderly individuals, they are staggered and assessed only one or a few of the auditory processes. The available evidence shows that auditory processing abilities tend to decline with age [10], and younger listeners outperform older individuals on most of the auditory-related tasks [11]. Hearing loss is another significant factor that can affect auditory processing abilities. Studies have been done in the past to assess the effect of hearing loss and age on auditory processing.

Roeser et al., [12], studied the effect of hearing loss on dichotic listening performance and found that the dichotic scores were reduced in individuals with hearing loss. As the severity of hearing loss increased, the dichotic scores decreased. Similarly, Cañete et al., [13], evaluated the relationship between age, hearing loss and binaural integration ability using staggered spondaic word Spanish Version. They reported a correlation between raw and corrected staggered spondaic word error scores and hearing loss. They also found that the performance significantly differed between younger and older adults aged above 70 years.

Fitzgibbons and Wightman [14] studied the effect of hearing loss on temporal resolution by comparing gap detection thresholds (GDT) in individuals with normal hearing sensitivity and individuals with hearing loss. They found the temporal resolution was significantly lower in individuals with hearing loss compared to normal listeners. Even age and hearing loss affect temporal resolution [15].

Whereas, Kelly-Ballweber and Dobie [16], studied the effect of hearing loss on binaural interaction by comparing younger and older adults with mild sloping sensorineural hearing loss (SNHL). Binaural interac-

tion abilities were measured using electrophysiological and behavioral measures. The results showed that younger adults performed better than older adults on all the tests though the difference was not statistically significant. Humes et al. [17] assessed auditory closure abilities using speech recognition in noise in 13 young adults with normal hearing, ten elderly adults with normal hearing, and 16 elderly individuals with hearing impairment. The results showed that individuals with hearing impairment performed lower than the other two groups. Hence, they concluded that age and hearing loss affect auditory closure abilities.

Sanchez et al., [18] also reported that sentence identification in the presence of ipsilateral competing signals was lower in older individuals with normal hearing than adults with normal hearing sensitivity. Sandeep and Yathiraj [19], studied the effect of age on speech in noise test, GDT, duration pattern test (DPT), and dichotic consonant vowel (CV) test in younger and older adults with normal hearing sensitivity. The results showed that older individuals performed lower in all four auditory processing tests than the younger group. Among the two older groups, participants in the age range of 55 to 65 years of age performed significantly better than participants in the age range of 65 to 75 years of age.

Thus, it can be concluded that age and hearing loss are potential contributors to the decline in auditory processing abilities. While age as a factor influencing auditory processing skills is well established [20-23], peripheral hearing loss could, to some extent, affect specific central auditory function [7]. If hearing loss affects specific auditory processes, fitting hearing aids might lead to positive changes in auditory processes. Hence, researchers have been interested in studying the relationship between hearing aid benefit, age, hearing loss, and cognitive abilities. Humes et al. [17] measured aided and unaided speech recognition scores on 171 elderly participants using a hearing aid. Auditory discrimination ability of participants was assessed using the Test of Basic Auditory Capabilities at 30 dB SL. Cognitive assessment was done through Wechsler Adult Intelligence Scale- Revised [22]. There was an age-related difference in scores, which could be attributed to cognitive factors. Lunner [23] studied the relation between cognitive abilities and hearing aid benefit in 72 hearing aid users. Hearing aid benefit was assessed using speech recognition in noise tests along with reading span test and verbal information processing speed to evaluate cognitive abilities. Results showed a significant correlation between cognitive skills and speech recognition in noise with and without hearing

aids. Individuals having high cognitive abilities had high performance in speech recognition.

From the above review, one can deduce that there are cognitive and auditory processing deficits in older individuals with normal hearing sensitivity. There is a shortage of research on older individuals with hearing impairment. The limited studies on individuals with hearing impairment have mostly assessed only the cognitive function and correlated with hearing devices' benefit. Since auditory processing can also affect speech perception abilities, and there is a possible relationship between cognition and some of the auditory processing abilities, it is essential to assess the relationship between auditory processing abilities and hearing aid benefit. Some studies have individually evaluated the effect of age and hearing loss on some of the auditory processes [5, 11, 12, 14, 15, 19].

There is no research, to our knowledge, that incorporated a correlation study using all the auditory processing abilities in naïve and experienced hearing aid users. Since hearing aid usage facilitates neural plasticity by sensory input sounds, it is essential to measure auditory processing abilities in naïve and experienced hearing aid users. Such a study will help modify the protocol of hearing aid fitting, counseling, and planning an effective rehabilitation program based on the clients' needs. Hence, the present study aimed to evaluate the relationship between different auditory processing abilities, working memory, and hearing aid benefit of elder naïve and experienced hearing aid users.

Methods

Participants

The present study included two groups of native speakers of Kannada: Group I comprised of 30 participants in the age range of 51 to 70 years (Mean age=60.5; SD=5.48) with mild to moderate SNHL. Group I had no hearing aid experience. Group II included 20 hearing aid users in the age range of 54 to 70 years (Mean age=64; SD=5.66) with mild to moderate SNHL. Figure 1 shows the mean pure-tone air conduction and bone conduction thresholds of both the groups.

Routine audiological evaluation was carried out in an acoustically treated air-conditioned room. A calibrated dual-channel audiometer Inventis Piano Plus Clinical Audiometer (Italy) with TDH-39 headphones and the B-71 bone vibrator was used to determine air and bone conduction thresholds, respectively. All the

participants had Speech Identification Scores of more than or equal to 60%. A calibrated immittance meter Grason-Stadler Inc. Tymptstar (GSI- Tymptstar version 2 middle ear analyzer, Denmark) was used to assess the middle ear status.

All the participants had A type of tympanogram with acoustic reflex thresholds appropriate to the degree of hearing loss. Mini-mental status examination [24] was carried out to rule out cognitive issues. Individuals having a score of more than 24 in mini-mental status examination [25] were considered for the study. Participants with any history or presence of any middle ear disorders, neurological involvement, and psychological problems or any combination of these problems were excluded from the study.

The pure tone average for right and left ears were compared between the two groups using independent sample t-test and the results showed no significant difference for the right ear [$t(48)=-1.734$; $p>0.05$] and for the left ear [$t(48)=-1.352$; $p>0.05$]. Taylor [26] reported that, on average, approximately 30 days are sufficient for hearing aid users to get accustomed to hearing aids. All the participants in Group II wore their own binaural digital wide dynamic range compression hearing aids with noise reduction algorithms. They were daily users of hearing aids with at least six weeks of hearing aid experience, and they wore the hearing aid for at least six hours a day. The usage of hearing aid was ensured using self-reports of patients. The hearing aids were matched between the two groups. The processing schemes and the number of channels of hearing aids worn by participants in Group II were similar.

Procedure

All the audiological tests were carried out in a well-illuminated acoustically and electrically shielded rooms with ambient noise levels well within the permissible limits. All the participants were informed about the objectives and the procedure of the study, and informed consent was taken from them. The participants were assessed individually for all the central auditory processing skills and working memory.

Assessment of central auditory processing skills

Auditory closure

Auditory closure was assessed using speech perception in noise test (SPIN). The phonemically balanced Kannada word lists developed by Manjula et al., [27] were

used as the stimuli to assess auditory closure. The sentences were presented along with the speech noise ipsilaterally at 0 dB signal to noise ratio (SNR) to both the ears separately. The participants repeated the words. 25 words were presented to each ear at 40 dBSL (re: SRT), and percent correct scores were calculated for both the ears.

Binaural interaction

Binaural interaction was assessed using masking level difference (MLD) test. This test was assessed using calibrated Inventis Piano Audiometer, where the signal and the masker were presented in homophasic and antiphasic conditions bilaterally, and the masked thresholds were obtained. MLD was performed for 500 Hz at 40 dBSL (re: PTA). The masking level difference was calculated as the difference in threshold between homophasic (SoNo) and antiphasic (S π No) conditions.

Binaural integration

The dichotic CV test [28] was used to assess binaural integration. Stimuli consists of six syllables /pa/, /ta/, /ka/, /ba/, /da/ and /ga/ which were presented five times randomly to make it a total of 30 presentations. There are five lists with 0 ms, 30 ms, and 90 ms lag either in the right or left ear track. Only 0 ms lag was utilized for the present experiment, and two syllables were presented at a time. The stimuli were presented at 40 dB SL (Ref speech recognition thresholds), and participants had to write down/repeat the stimuli heard in both right and left ear. Single correct and double correct scores were calculated for all the participants. A score of 'one' was given for the correct response and 'zero' for an incorrect response.

Temporal processing

GDT and DPT were utilized to assess temporal processing. The procedure for the same is explained below:

GDT. The participant's ability to detect a temporal gap in the center of 500 ms broadband noise was measured [29]. The noise with 0.5 ms cosine ramps at the beginning and the end of the gap was used for the estimation of GDT. In a three-block alternate forced-choice task, the standard stimulus was always a 500 ms broadband noise with no gap, whereas the variable stimulus contained the gap. The participant's task was to identify which stimulus among the three stimuli had a gap. GDT was estimated using mlp employed in MATLAB software version 7.10.0 (R2010a, California, USA). The minimum and maximum duration of the gap used was 0.1 ms and 64 ms, respectively.

DPT. The test consists of three 1000 Hz tones with 300 ms inter-tone intervals. Tones in each pattern were either of 250 ms or 500 ms duration and were designated as short duration (S) and long duration (L), respectively. Six combinations (LLS, LSL, LSS, SLS, SLL, SSL) are presented five times to make it a total of 30 duration patterns (6 combinations*5 randomizations) with 6 sec inter pattern interval. The participants were asked to repeat the pattern verbally, and a total number of correct responses were noted down.

Working memory

The individuals' auditory working memory was assessed using the auditory digit span, which was administered in two phases; forward and backward phase. This was done through the Auditory cognitive training module (Smriti Shravan) software developed by Kumar and Sandeep [30]. The stimuli consisted of Kannada digits from one to nine. A minimum number of digits that the participant could recall was assessed using a staircase procedure (three-alternate forced choice method). The numbers were presented in random order with an increasing level of difficulty with a minimum of three digits and a maximum of ten digits with 250 ms of inter-stimulus interval. Group of digits was presented, and participants were asked to repeat them in the same order for the forward digit span and reverse order for backward digit span.

The participants were expected to repeat the digits in the same order in the forward span (FW). For example, if the stimuli were 'four, nine, six, eight,' the response expected was 'four, nine, six, and eight' in the same order. The complexity of the test was increased when the participant correctly repeated the sequence, and the complexity was reduced for every repetition of the wrong sequence by reducing a digit. Similarly, the participants were instructed to repeat the digits in reverse order in the backward digit span (BW). Thus, for the same stimuli, the expected response was "eight, six, nine, and four".

Hearing aid programming

The participants in the naïve hearing aid group were fitted with the hearing aid that was connected to a personal computer with NOAH-3 software connected through Noah link with appropriate programming cable. The programming was done based on the NAL-NL1 formula and optimization level set to '2'. The gain was optimized till all the ling's six sounds were identified correctly. The compression settings were kept at default. Routing hearing aid evaluation was carried out by asking five ques-

tions and speech intelligibility score for words at 40 dB HL. All the noise reduction features such as digital noise reduction and directionality were enabled. Experienced hearing aid users also underwent routine hearing aid evaluation using the above procedure to ensure that the gain-frequency response of their hearing aids was sufficient. Hearing aid verification was assessed using real ear measurement. Otoscopy examination was carried out prior to the real ear measurement to ensure all participants are free from cerumen or wax. Individual's audiogram was loaded in to the Fonix 7000 system. Real ear SPL measurement option was selected in order to find the SPL in the ear canal. Participants were made to sit at 45 (degree) azimuths with respect to the loudspeaker and at a distance of 12 inches from the loud speaker. The probe microphone was inserted into the ear canal of the participant. The marker was used to mark the appropriate depth that can be inserted inside the participant's ear canal. The participants were instructed to maintain the same position during the recording and they were asked to inform in case of any discomfort during the procedure. Levelling procedure was carried out after the probe tube was inserted into individual's ear canal. Gain in the hearing aid was adjusted till the SPL in the ear canal reached the target gain measurement.

Assessment of hearing aid benefit

Hearing aid benefit was measured using speech intelligibility in noise test and International Outcome Inventory for Hearing Aids (IOI-HA) hearing aid benefit questionnaire.

Speech intelligibility in noise

A computer with Cubase 6 software connected with eight speakers (Genelec 8020B, Thomann GmbH, Burgebrach, Germany) covering 0o to 360°, kept at a distance of 45o angle, was used. These speakers were calibrated using Larson Davis Sound level meter at 70 dB SPL before the experiment. Speech intelligibility in noise was assessed using the sentence test in Kannada developed by Geetha et al., [31]. This test has twenty-five equivalent lists with ten sentences each. These sentences were presented in the presence of four talker speech babble at different SNRs from +20 dB SNR to -7 dB SNR varied in 3 dB step size at 0o angle. The test was conducted in two conditions viz unaided and aided. The SNR at which 50% of the sentences were correctly identified was calculated (SNR-50) using the Spearman-Kärber equation [32], which is as follows:

where, I is the initial presentation level (dB SNR), d is the decrement step size (attenuation), and w is the number of words per decrement.

Test conditions were randomized and counterbalanced to reduce order effects. Each sentence list was used only once to avoid the practice effect. Both the groups performed the above task.

Hearing aid benefit using a questionnaire

IOI-HA hearing aid benefit questionnaire in Kannada [33] was used to assess the hearing aid benefit from the participants in different situations. The questionnaire consists of eight questions with a five-point response scale ranging from very dissatisfied to very satisfied. Hence, the maximum total score possible is 40. Higher the score in IOI-HA indicates greater satisfaction with the hearing aid, and a lower score indicates less satisfaction with the hearing aid. The participants were asked to read the questionnaire before filling it. If assistance required, the questionnaire was administered using the interview method, and the total score was calculated for each participant. IOI-HA questionnaire was administered only on group II who had experience with the hearing aid.

Statistical analyses

Data obtained from the naïve hearing aid users and with the experienced hearing aid users were tabulated and analyzed using IBM Statistical Package for the Social Sciences (SPSS) statistics version 20. Shapiro-Wilks test of normality was done to check for the normality of the data. The results revealed that the data showed a skewed distribution for most of the parameters. Therefore, Spearman's correlation, a non-parametric test, was administered to find a relationship between auditory processing abilities and hearing aid benefit in naïve and experienced hearing aid users.

Results

The present study aimed to find the relationship between auditory processing abilities and hearing aid benefit in naïve and experienced hearing aid users and determine the effect of hearing aid experience on auditory processing abilities. Group I had 30 participants with mild to moderate SNHL without any hearing aid experience, and Group II had 20 participants with mild to moderate SNHL with hearing aid experience. Auditory processing abilities were assessed using different behavioral auditory processing tests; hearing aid benefit was

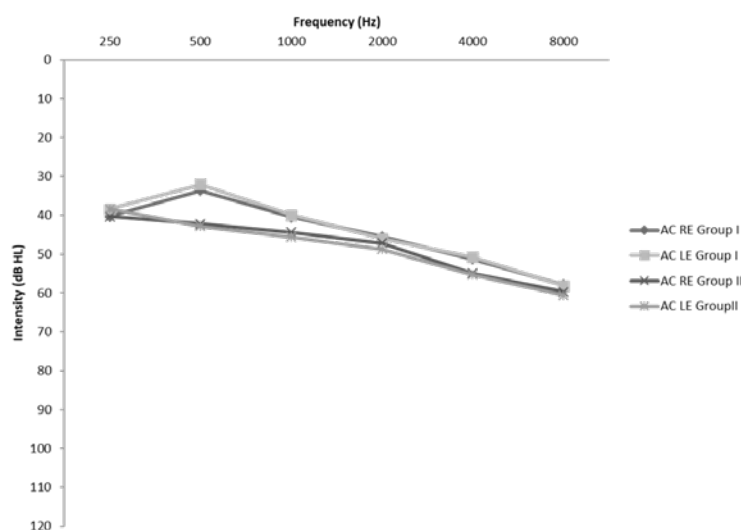


Figure 1. Mean hearing threshold of both groups across different frequencies. AC; air conduction, RE; right ear, LE; left ear, Group I; naïve hearing aid users, Group II; experienced hearing aid users

assessed using SNR-50 in the aided condition in both the groups; and IOI-HA hearing aid benefit questionnaire in the group (Group II) with hearing aid experience.

Table 1 gives the mean, standard deviation (SD), median, range and quartile ranking of various auditory processing tests and working memory scores for the two groups of participants. Table 1 also includes aided SNR-50, unaided SNR-50 and hearing aid benefit. Hearing aid benefit (HAB) was derived by subtracting aided SNR-50 from the unaided SNR-50. Besides, experienced hearing aid users rated their self-perceived benefit using IOI-HA questionnaire.

Relationship between temporal processing and hearing aid benefit in naïve and experienced hearing aid users

Spearman correlation was done to find the relationship between temporal processing and hearing aid benefit in naïve and experienced hearing aid users. Temporal processing abilities were assessed using DPT and GDT, and hearing aid benefit was assessed using SNR-50 in both the groups and using IOI-HA questionnaire in Group II only. Results showed no correlation between DPT and HAB ($r=-0.221$, $p=0.241$); GDT and HAB ($r=0.198$, $p=0.293$) in naïve hearing aid users. Also, there was no correlation between DPT and HAB ($r=-0.196$, $p=0.516$); GDT and HAB for experienced hearing aid user ($r=0.041$, $p=0.806$).

Correlation analysis between IOI-HA questionnaire and temporal processing abilities in experienced hearing aid users was done, and the results showed no correlation between IOI-HA questionnaire and temporal processing

abilities (for GDT, $r=0.20$, $p=0.244$; for DPT, $r=-0.085$, $p=0.241$).

Relationship between auditory closure abilities and hearing aid benefit in naïve and experienced hearing aid users

Spearman correlation was done to find a relationship between auditory closure and hearing aid benefit in naïve and experienced hearing aid users. Auditory closure abilities were done using SPIN for the right and left ear. Results revealed that there was no correlation between RSPIN and HAB ($r=-0.155$, $p=0.415$), and between LSPIN and HAB ($r=-0.195$, $p=0.302$) in naïve hearing aid users. In experienced hearing aid users (Group II) also, there was no correlation between RSPIN and HAB ($r=-0.194$, $p=0.112$), LSPIN and HAB ($r=-0.166$, $p=0.317$).

However, when the correlation analysis was done on SPIN scores and aided SNR-50 in experienced hearing aid users (Group II), there was a moderate negative correlation between RSPIN and HAB ($r=-0.573$, $p=0.023$), LSPIN and HAB ($r=-0.584$, $p=0.010$), i.e. as the SPIN scores increased, the aided speech perception improved. Figures 2 (a and b) show the scatter plots of auditory closure abilities (RSPIN and LSPIN) as a function of aided SNR-50.

Additionally, the correlation analysis was done between the IOI-HA questionnaire and auditory closure abilities in experienced hearing aid users. Results showed that there was no correlation between IOI-HA questionnaire and auditory closure abilities (for RSPIN, $r=0.17$, $p=0.369$; for LSPIN, $r=0.16$, $p=0.487$).

Table 1. Mean, standard deviation median, minimum, maximum, quartile range scores of different auditory processing test scores and speech in noise-50 in two groups

Test administered	Group I						Group II					
	Mean	SD	Median	Range		QR	Mean	SD	Median	Range		QR
				Min	Max					Min	Max	
SNR-50 U	4.07	1.94	4.25	1.25	9.50	2.25	5.00	1.21	5.00	1.25	6.50	0.75
SNR-50 A	3.27	2.75	1.87	-0.25	8.75	2.25	2.90	0.09	2.75	1.25	5.00	1.50
Hearing aid Benefit	0.80	0.70	0.75	0.00	2.25	1.50	2.10	1.07	2.25	0.00	3.75	1.50
RDCV	13.77	5.46	13.00	4.00	26.00	3.50	9.25	4.71	9.00	3.00	21.00	3.50
LDCV	10.97	4.65	11.00	2.00	21.00	3.00	9.65	5.01	8.00	3.00	23.00	3.00
DCS	1.57	3.38	0.00	0.00	12.00	0.50	0.65	2.25	0.00	0.00	10.00	0.00
GDT	15.84	17.25	8.21	3.23	64.50	6.96	12.34	7.56	11.49	3.90	26.17	5.77
DPT	18.83	6.01	18.50	10.00	29.00	5.00	21.30	6.99	22.50	9.00	30.00	6.00
MLD	12.83	3.86	15.00	5.00	20.00	2.50	8.50	3.28	10.00	5.00	15.00	2.50
RSPIN	3.67	4.29	2.00	0.00	14.00	3.50	1.35	2.96	0.00	0.00	11.00	1.00
LSPIN	4.03	3.89	3.00	0.00	12.00	3.50	1.45	2.83	0.00	0.00	9.00	1.00
FW	4.23	0.67	4.00	3.00	5.00	0.50	4.65	0.81	5.00	3.00	6.00	0.50
BW	3.20	0.76	3.00	2.00	4.00	0.50	3.75	0.91	4.00	2.00	6.00	0.50
IOI-HA	-	-	-	-	-	-	29.79	3.56	29.00	25.00	36.00	3.00

SNR-50 U; unaided signal to noise ratio (at which 50% scores are achieved), SNR-50 A; aided signal to noise ratio (at which 50% scores are achieved), Hearing aid benefit; difference between SNR-50 A and SNR-50 U, RDCV; right dichotic consonant-vowel (No. of syllables repeated), LDCV; left dichotic consonant-vowel (No. of syllables repeated), DCS; double correct score (No. of syllables repeated), GDT; gap detection threshold, DPT; duration pattern test (No. of patterns repeated), MLD; masking level difference (dB), RSPIN; right speech perception in noise (No. of words repeated), LSPIN; left speech perception in noise (No. of words repeated), FW; forward span (No. of digits repeated), BW; backward span (No. of digits repeated), IOI-HA; international outcome inventory-hearing aids. The maximum score for IOI-HA is 40, which indicate more usefulness of hearing aids, and the minimum score for IOI-HA is 8, which indicate limited usefulness of hearing aids

Relationship between binaural integration and hearing aid benefit in naïve and experienced hearing aid users

Spearman correlation was done to find the relationship between binaural integration using DCV and hearing aid benefit in naïve and experienced hearing aid users. The results showed no correlation between single ($r=0.296$, $p=0.112$ for right single correct score and $r=-0.151$, $p=0.426$ for left single correct score) and double correct scores with HAB ($r=-0.315$, $p=0.096$) in naïve hearing aid user. There was no correlation between single correct score and HAB ($r=-0.164$, $p=0.601$ for right single correct score and $r=-0.109$, $p=0.347$ for left single correct score) and double correct scores and HAB ($r=-0.391$, $p=0.083$) in experienced hearing aid users.

However, when the correlation analysis was done between DCV and SNR-50 in experienced hearing aid users, there was a moderate negative correlation between Right single correct score and aided SNR-50 ($r=-0.540$, $p=0.014$, given in [Figure 2c](#)), and double correct scores and aided SNR-50 ($r=-0.466$, $p=0.038$, given in [Figure 2d](#)). However, no correlation was found between left single correct score and aided SNR-50 ($r=-0.226$, $p=0.103$).

Spearman correlation was also done between IOI-HA questionnaire and binaural integration abilities in experienced hearing aid users. Results showed no correlation between the IOI-HA questionnaire and binaural integration abilities (for right single correct score, $r=-0.16$,

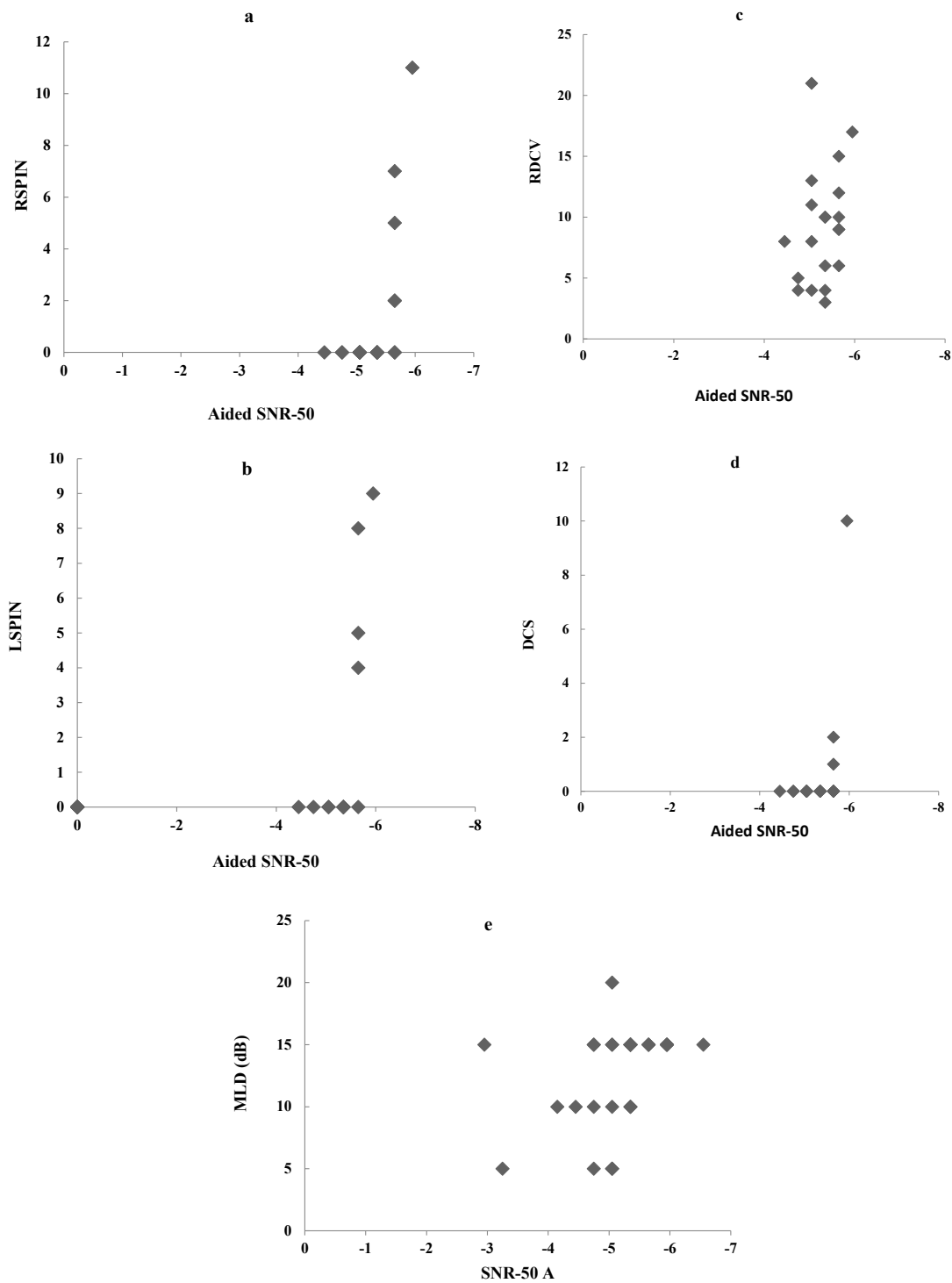


Figure 2. Scatter plot representing the correlation between (a) speech perception in noise in right ear and aided signal to noise ratio-50 in experienced hearing aid users, (b) speech perception in noise in left ear and aided signal to noise ratio-50 in experienced hearing aid users, (c) right dichotic consonant-vowel and aided signal to noise ratio-50 in experienced hearing aid users, (d) double correct scores and aided signal to noise ratio-50 in experienced hearing aid users, (e) masking level difference and aided signal to noise ratio-50 in naïve hearing aid users. RSPIN; right speech perception in noise, LSPIN; left speech perception in noise, SNR-50; signal to noise ratio-50, RDCV; right dichotic consonant-vowel, DCS; double correct score, MLD; masking level difference, SNR-50 A; aided signal to noise ratio-50

$p=0.488$; for left single correct score, $r=-0.10$, $p=0.241$; for double correct scores, $r=0.09$, $p=0.336$).

Relationship between binaural interaction and hearing aid benefit in naïve and experienced hearing aid users

Spearman correlation was done to find a relationship between binaural interactions assessed using MLD and hearing aid benefit in naïve and experienced hearing aid users. Results showed that there was no correlation between MLD and HAB ($r=-0.170$, $p=0.369$) in naïve hearing aid users and in the experienced hearing aid users ($r=-0.045$, $p=0.852$).

However, there was a moderate negative correlation between MLD and aided SNR-50 ($r=-0.464$, $p=0.01$) in naïve hearing aid users. Figure 2e shows the scatter plot of a significant correlation.

Correlation analysis was also done between the IOI-HA questionnaire and binaural interaction abilities in the experienced hearing aid users. Results showed no correlation between IOI-HA questionnaire and binaural interaction abilities ($r=0.076$, $p=0.640$).

Relationship between working memory and hearing aid benefit in naïve and experienced hearing aid users

Spearman correlation was done to find the relationship between working memory and hearing aid benefit in naïve and experienced hearing aid users. Results showed that there was no correlation between forward span test and HAB ($r=0.310$, $p=0.096$); backward span test and HAB ($r=-0.056$, $p=0.770$) in naïve hearing aid users. Similar results were obtained for the experienced hearing aid users (for FW, $r=-0.024$, $p=0.791$; for BW, $r=-0.132$, $p=0.498$).

Correlation analysis was done between IOI-HA questionnaire and working memory in the experienced hearing aid users, and the results revealed that there was no correlation between IOI-HA questionnaire and working memory as well (for FW, $r=0.05$, $p=0.880$; for BW, $r=-0.10$, $p=0.377$).

Discussion

The study aimed to assess the relationship between the hearing aid benefit and the auditory processing abilities in naïve and experienced hearing aid users. The results of the present study are discussed below.

Relationship between temporal processing abilities and hearing aid benefit in naïve and experienced hearing aid users

The results showed no relationship between temporal processing skills and hearing aid usage. Similar results were found in a study done by Lessa and Costa [34], where the correlation between temporal processing tests and cognitive function before and after hearing aid use was done. They reported that even without hearing aids, individuals performed better in temporal processing tests when the cognitive function was better. The reason for no change in the temporal processing with the usage of hearing aid could be that temporal processing is significantly poorer in individuals with hearing loss [14], which cannot be reversed with the usage of hearing aids. Also, the signal processing algorithms in digital hearing aids tend to alter the signal's temporal envelope leading to distorted temporal cues in the input signal [35]. Hence, the higher cortical areas responsible for temporal processing might not have appropriate input, leading to no significant temporal processing changes.

Relationship between auditory closure abilities and hearing aid benefit in naïve and experienced hearing aid users

Results of the present study revealed that there was no correlation between SPIN and HAB in both the groups. Nevertheless, in the experienced hearing aid users, there was a moderate negative correlation between RSPIN and aided SNR-50, LSPIN, and aided SNR-50, i.e., as the SPIN scores increased, the aided speech perception improved. Humes et al. [5] reported that auditory closure abilities are affected in individuals with hearing impairment compared to the normal hearing group and concluded that hearing loss affects speech recognition abilities. Murphy et al. [7] found that poor performance in a SNR test in individuals with mild to moderate hearing loss compared to the normal hearing individuals. The above studies have been conducted in the unaided condition, and in the present study, the results suggest that with the usage of hearing aid, the auditory closure abilities improve.

Relationship between binaural integration and hearing aid benefit in naïve and experienced hearing aid users

The results showed no correlation between any of the binaural integration scores and HAB in both the groups. However, there was a moderate negative correlation between right single correct score and aided SNR-50 and between double correct score and aided SNR-50 for experienced hearing aid users. There was no correlation

between left single correct score and aided SNR-50 in the experienced hearing aid users. These results indicate a relationship between binaural integration abilities and usage of binaural hearing aids, i.e. as the aided speech perception abilities improved, the integration abilities also improved. These results agree with the findings in the literature. Lavie et al. [36] found that unaided dichotic listening and unaided speech identification in noise scores improve significantly in the nondominant ear by eight weeks of hearing aid usage. It can be inferred from the present study that the use of binaural hearing aids not only improves speech perception performance with the hearing aids but may contribute to the ability of the auditory system to utilize binaural input when tested in unaided condition. These improvements in the binaural integration may be related to perceptual changes [37] and neural plasticity [38] that takes place after weeks of hearing aid use.

Relationship between binaural interaction and hearing aid benefit in naïve and experienced hearing aid users

Binaural interaction is an important auditory processing ability wherein the auditory messages sent by the two cochleae resolve into auditory objects, the segregation, and localization of which plays a vital role in SPIN. Binaural interaction encompasses binaural redundancy, head shadow effect, and binaural release from masking. In the present study, experienced hearing aid users did not show a correlation with MLD. The reason for this could be that the hearing aid users in the current study used two binaural hearing aids that were not connected to each other through wireless connection. Hence, there will be mismatched directional microphone configurations between left and right hearing aids that impacts the inter-aural time differences. Further, independently acting multi-channel wide dynamic range compression and digital noise reduction features between left and right hearing aids also tend to affect the inter-aural level differences, leading to poor interaction between the two ears [39].

Relationship between working memory and hearing aid benefit in naïve and experienced hearing aid users

Results showed no correlation between forward digit span test and HAB; backward digit span test and HAB in both naïve and experienced hearing aid users. These results agree with the findings in the literature. van Hooren et al. [40] found that cognitive abilities did not improve with hearing aid usage. The hearing aid can only restore impairments at the sensory organ level but does not affect the central nervous system. The present study also

indicates that cognitive abilities did not improve with hearing aid usage. However, numerous findings in the literature have shown a link between SPIN and working memory [3, 23, 41]. The difference in the results could be attributed to the material used to assess the working memory. In the present study, simple tasks using digit span were utilized to evaluate the working memory. In the earlier studies, N-Back tasks, operation span tasks, reaction time, etc. were used to assess the working memory, which might have been more sensitive to detect smaller changes in the working memory due to hearing aid usage. In the future, complex tasks can be used to assess the relationship between aided speech perception scores and working memory.

Another reason for no correlation between hearing aid benefit the auditory processes and working memory could be that many clients in the experienced group had used hearing aids for only approximately 2-3 months. Though reports show that, on average, about 30 days are sufficient for hearing aid users get accustomed to hearing aids [27], it may require a longer duration for the functional changes to occur in the higher auditory system in response to amplification.

Conclusion

To conclude, there was no correlation between hearing aid usage and most auditory processing abilities in the present study. In the future, studies can be done using speech perception and working memory tests with a higher level of difficulty in studying the relationship between hearing aid benefit and processing abilities. Besides, individuals with a longer duration of hearing aid usage may be included as participants. Further, a longitudinal study involving only one group of individuals would give better control of extraneous variables.

Ethical Considerations

Compliance with ethical guidelines

The study was approved by the AIISH ethical committee (Ref: SH/CDN/ARF-AUD-7/2017-2018).

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Authors' contributions

GC: Study design and supervision, interpretation of the results, and drafting the manuscript; KSP: Acquisition of data, statistical analysis; CJ: Study design and supervision, interpretation of the results, and critical revision of the manuscript.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest.

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