PROJECT REPORT

Relationship between hearing aid benefit and auditory processing abilities in elderly individuals with hearing impairment

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List of Abbreviations

SNR-50 U = unaided SNR-50

SNR-50 A = aided SNR-50

RDCV = Right dichotic consonant-vowel

LDCV = Left dichotic consonant-vowel

DCS = Double correct score

GDT = Gap detection threshold (ms);

DPT = Duration pattern test

MLD = Masking level difference

RSPIN = Right speech perception in noise);

LSPIN = Left speech perception in noise

FW = Forward span

BW = Backward span

IOI-HA = International Outcome Inventory – Hearing Aids.

Abstract

The current study aimed to evaluate the relationship between auditory processing abilities, working memory, and hearing aid benefit in naïve and experienced hearing aid users in older adults. There were two groups of individuals in the age range of 51 to 70 years participated in the study. There were 30 participants with mild to moderate hearing loss without any hearing aid experience and 20 participants with mild to moderate hearing loss with hearing aid experience of 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 SNR-50 measures. International Outcome Inventory – Hearing Aids (IOI-HA) hearing aid benefit questionnaire was used to assess the hearing aid benefit in experienced hearing aid users. The results showed that there was a correlation between auditory closure ability and binaural integration abilities with hearing aid benefit in experienced users.

Chapter 1

Introduction

Age-related hearing loss (Presbycusis) is one of the most common conditions affecting older adults (National Institute on Deafness and other Communication Disorders, 2016). 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 (Cruickshanks et al., 1998; Lichtenstein, Bess, & Logan, 1988; Mościcki, Elkins, Baum, & McNamara, 1985).

The complex nature of hearing problems, especially difficulty in perception of speech in noise, in older adults has been attributed to changes in the auditory periphery as well as in the central mechanisms (Jerger, Alford, Lew, Rivera, & Chmiel, 1995). Therefore, hearing impairment in older individuals has been reported to be associated with adverse effects on the quality of life. These effects could be perceived as severe handicap by older individuals even when the extent of hearing loss is mild to moderate degree (Mulrow et al., 1990). Hence, research on factors affecting the intervention of hearing impairment in older adults has increased drastically in the past few years (Jerger & Hayes, 1976; Kapteyn, 1977; Surr, Schuchman, & Montgomery, 1978).

A hearing aid is the primary intervention option in most of the older individuals. However, there are many elderly users of hearing aids who are dissatisfied with the outcome of hearing aids. One of the reasons for dissatisfaction by hearing aid users is the speech perception difficulty in the presence of background noise (Surr et al., 1978). These speech perception issues could be because of the changes in central auditory processing with aging. Older individuals with hearing loss show decreased performance in auditory processing skills, such as temporal processing (John, Hall, & Kreisman, 2012), dichotic listening (Martin & Jerger, 2005), and speech recognition (Humes, Busey, Craig, & Kewley-Port, 2013). The current study probes into the relationship between auditory processing and hearing aid usage in elderly listeners. Below is the literature related to the same:

1.1 Effect of Age and Hearing loss on Auditory Processing Abilities

Auditory processing abilities tend to decline with age (Willott, 1991), and the performance of younger adults is better compared to older individuals on most of the suprathreshold auditory skills (Marshall, 1981). These differences in older adults are due to the changes in the auditory periphery as well as in the central mechanisms responsible for processing the auditory signals. 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, Johns, and Price (1976) compared dichotic listening performance among 36 individuals with normal hearing sensitivity and 36 individuals with bilateral symmetrical sensorineural hearing loss (SNHL). Digits and consonant-vowel (CV) nonsense syllables were presented dichotically to assess dichotic listening performance. Results showed that individuals with normal hearing sensitivity performed significantly better than the individuals with hearing impairment, and right ear advantage was noticed in the recall of digits and CV nonsense syllables. Further, the dichotic scores reduced in individuals with hearing loss, and as the severity of hearing loss increased, the dichotic scores decreased. Similarly, Cañete, Almasio, Mariela Torrente, and Purdy (2019) evaluated the effect of age and hearing loss on binaural integration ability using staggered spondaic word Spanish Version (SSW-SV). They reported a correlation between raw and corrected SSW 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 (1982) compared gap detection thresholds (GDT) in individuals with normal hearing sensitivity and individuals with hearing loss. GDT was measured with broadband notch noise with octave band noises as stimuli (with a bandwidth of 400–800 Hz, 800–1600 Hz, and 2000–4000 Hz). Results showed that the temporal resolution was significantly poorer in individuals with hearing loss compared to individuals with normal hearing. In another study, John, Hall and Kreisman (2012) studied the effect of age and sensorineural hearing loss on temporal resolution using GDT in older adults with SNHL, older adults with normal hearing, and young adults with normal hearing sensitivity. The results showed that GDT was poorer in older listeners with hearing loss compared to both younger and older listeners with normal hearing sensitivity. This was attributed to the changes taking place in the central nervous system and central auditory processing with aging. Palmer and Musiek (2014) and Roberts and Lister (2004) also reported similar results.

Kelly-Ballweber and Dobie (1984) compared binaural interaction abilities in younger and older adults with mild sloping SNHL. Binaural interaction abilities were measured using electrophysiological and behavioral measures. Behavioral tests included binaural fusion test (BFT), masking level difference (MLD, at 500 Hz), and rapid alternating speech perception test. The electrophysiological test included the Binaural interaction component (BIC) for mid latency response (MLR) and auditory brainstem response (ABR) for both the groups. The results showed that younger adults performed better than older adults on all the tests though the difference was not statistically significant.

There have been numerous studies comparing speech perception abilities of listeners with normal hearing with that of listeners with hearing loss, or younger with that of older listeners, in the presence of babble (Arbogast, Mason, & Kidd Jr, 2005; Best, Gallun, Mason, Kidd Jr, & Shinn-Cunningham, 2010; Humes & Coughlin, 2009; Marrone, Mason, & Kidd

Jr, 2008; Neher et al., 2009; Neher, Laugesen, Søgaard Jensen, & Kragelund, 2011). Humes, Burk, Coughlin, Busey, and Strauser (2007) 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 poorer than the other two groups. Hence, they concluded that age and hearing loss affect auditory closure abilities. In another study, Best et al. (2010) measured the effect of hearing loss on an individual's ability to understand messages presented separately to the two ears, and the messages were systematically degraded by adding speech-shaped noise. Results showed that as the level of the noise increased, performance declined. Listeners with hearing loss showed a larger deficit in the recall of the second message than the first one compared to listeners with normal hearing sensitivity, and this difference was not seen at a poorer signal to noise ratio. Sanchez, Nunes, Barros, Ganança, and Caovilla (2008) also reported that sentence identification in the presence of ipsilateral competing signals was poorer in older individuals with normal hearing compared to adults with normal hearing sensitivity.

Sandeep and Yathiraj (2012-13) studied the effect of age on speech in noise test, GDT, Duration pattern test (DPT), and dichotic CV in younger and older adults with normal hearing sensitivity. The results showed that older individuals performed poorer in all four auditory processing tests compared to the younger group. It was also noted that 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.

1.2 Effect of Age and Hearing loss on Cognitive Abilities

Age-related cognitive decline is a known factor that influences the auditory processing performance, predominantly because of the deterioration in cognitive-sensory interaction with aging (Cohen, 1987; Füllgrabe, Moore, & Stone, 2015; Hällgren, Larsby, Lyxell, & Arlinger, 2001; Humes et al., 2013; Moore et al., 2014; Spilich, 1983; Wright, 1981). Hällgren et al. (2001) studied the effect of age on central auditory functions and cognition. Thirty individuals with bilateral moderate hearing loss were considered between the age range of 42 to 84 yrs of age, and they were divided into younger and older groups. Dichotic listening was assessed using digits, low redundancy sentences, and consonant-vowel syllables. The participants reported whether they heard in both ears or one ear. Short term memory, verbal information processing speed, and phonologic processing were used to assess cognitive abilities. Results revealed that there was an overall reduced performance in all dichotic tests and the reading span test in the older group.

Morris, Gick, and Craik (1988) assessed the effect of age on working memory using operation span tasks and results indicated that geriatric participants responded more slowly and that an increase in the memory load and sentence complexity was associated with longer verification latencies. Hester, Kinsella, and Ong (2004) studied auditory working memory using forward and backward digit tasks in adults and geriatrics. Results showed an age-related decline in both digit forward and digit backward tasks, and both the abilities deteriorated to the same extent. Thus, it is apparent that the age-related decline is seen in working memory.

Humes et al. (1994) measured the speech recognition ability of 50 elderly participants with hearing impairment. They studied the relationship with measures of auditory processing (TBAC) and cognitive function (Wechsler Adult Intelligence Scale-Revised [WAIS-R], and the Wechsler Memory Scale-Revised [WMS-R], Wechsler, 1981, 1987). Results revealed that hearing loss affected speech recognition performance among the elderly participants and the auditory processing abilities, and however, cognitive function showed no significant effect on speech recognition. Murphy et al. (2018) assessed the influence of hearing loss and working memory on the auditory processing skills of middle-aged and elderly individuals. They reported that there was a partial contribution of peripheral auditory sensitivity to the reduction in speech in noise performance.

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 (Cohen, 1987; Füllgrabe, Moore, & Stone, 2015; Humes et al., 2013; Moore et al., 2014), peripheral hearing loss could, to some extent, affect specific central auditory function (Murphy et al., 2018). 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.

1.3 Relationship among Age, Auditory Processing Abilities, Cognitive Abilities, and Hearing Aid Benefit

Hearing aid benefit is influenced by many factors, including age (Wu, 2010), speech perception abilities (Helfer & Wilber, 1990), working memory (Lunner, 2003), personality (Ciorba, Bianchini, Pelucchi, & Pastore, 2012), etc. The influence of auditory processing and cognitive abilities on hearing aid benefit have been studied in the past. Humes (2002) measured aided and unaided speech recognition scores on 171 elderly participants using a hearing aid. Auditory discrimination ability of participants was assessed using measures of auditory processing (TBAC) at 30 dB SL. Cognitive assessment was done through WAIS-R (Wechsler, 1981). There was an age-related difference in scores, which could be attributed to cognitive factors. Humes (2002) determined the predictors of hearing aid success in older adults using results of three studies on hearing aid outcome. The degree of hearing loss, cognitive performance, and age of the listener could predict the speech recognition performance in older adults.

Lunner (2003) studied the relation between cognitive abilities and usage of hearing aid in 72 hearing aid users (used for one year). Hearing aid benefit was assessed using speech recognition in noise tests with and without hearing aids. Reading span test and verbal information processing speed were done to evaluate cognitive abilities. Results showed that there was a significant correlation between cognitive skills and speech recognition in noise, both with and without hearing aids. Individuals having high cognitive abilities had high performance in speech recognition.

Shruti and Geetha (2010-11) evaluated the effect of working memory on the amount of gain required for obtaining the best speech recognition scores and on the selection of the time constants of wide dynamic range compression (WDRC) hearing aids. The study included twenty-two elderly individuals in the age range of 60 to 70 years. Results revealed that the gain required to obtain the best speech recognition scores was lesser in individuals with good working memory abilities in the presence of noise. They also found that syllabic compression resulted in poorer speech recognition scores in the group with poor working memory. Syllabic compression involves short time constants in a compressor resulting in substantial temporal envelope distortion. Individuals with good working memory compensate for these distortions with representations in the long term memory, while individuals with poor working memory may not be able to do the same resulting in poorer speech recognition scores with shorter time constants.

Baviskar and Kumar (2013-14) evaluated the relationship between working memory and hearing aid benefit in 20 elderly individuals in the age range of 50 to 80 years. The auditory digit span, visual span, spatial span, and visuospatial span test scores were correlated with aided speech perception scores in noise. Results showed no relationship between hearing aid benefit and working memory. They hypothesized that no relation between working memory and hearing aid benefit could be because the tasks used to assess working memory included simple tasks.

Lessa and Costa (2016) studied the correlation between temporal processing and cognitive performance in the elderly population, and assessed their influence on hearing aid fittings. In elderly individuals, a positive correlation was observed between temporal skills and cognitive test results. However, individuals with poor cognition showed more improvement in temporal processing before and after the hearing aid fittings. This indicates that even when there is poor cognition, neural plasticity does exist with hearing aid usage. Similar results have been reported by van Hooren et al. (2005).

1.4 Need for the Study

Many communicative situations occur in environments where the presence of competitive noise impairs listening. It has been reported that understanding speech against a noisy background is a challenging task for older adults. To reduce the handicap felt in the real-life situation, many researchers have probed into the factors affecting the speech perception and processing of sounds in older adults (Füllgrabe et al., 2015; Humes et al., 2013; Schoof & Rosen, 2014). Factors such as age, hearing loss, higher auditory processing, and cognitive abilities have been found to affect the perception under challenging environments (Larsby, Hällgren, Lyxell, & Arlinger, 2005; Willott, 1991).

It has also been reported that individuals with hearing impairment show differential benefits with the hearing aid device depending on their cognitive abilities (Pichora-Fuller & Souza, 2003; Souza, 2000). The studies have individually evaluated the effect of hearing loss

(Lunner, 2003), cognition (Shruti & Geetha, 2010-11), and a few of auditory processes (Humes, 2002; Lessa & Costa, 2016) on hearing aid benefit.

There is a shortage of research on the cognitive and auditory processing abilities in older adults with hearing impairment. The limited studies on individuals with hearing impairment have mostly assessed only the cognitive function and correlated with the benefit of hearing devices. Since the auditory processing ability can also affect speech perception abilities, it is essential to assess the extent to which the sensory stimulation with hearing aid improves auditory processing abilities. Thus, there is a need to determine all the auditory processes and working memory and its effect on hearing aid benefit in older adults with hearing impairment. There are no studies, to our knowledge, which compared auditory processing abilities between 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 between naïve and hearing aid users. Such a study will help in modifying the protocol of hearing aid fitting, counseling, and in planning an effective rehabilitation program based on the needs of the client.

1.5 Aim of the Study

The present study aimed to evaluate the relationship between auditory processing abilities, working memory, and hearing aid benefit of elder naïve and experienced hearing aid users.

1.6 Objectives of the Study

1. To study the relationship between temporal processing and hearing aid benefit in naïve and experienced hearing aid users.
2. To study the relationship between auditory closure and hearing aid benefit in naïve and experienced hearing aid users.

3. To study the relationship between binaural integration and hearing aid benefit in naïve and experienced hearing aid users.
4. To study the relationship between binaural interaction and hearing aid benefit in naïve and experienced hearing aid users.
5. To study the relationship between working memory and hearing aid benefit in naïve and experienced hearing aid users.

Chapter 2

Methods

2.1 Participants

The present study included two groups of participants: 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 sensorineural hearing loss (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. Table 2.1 includes the demographic and audiological details of the participants in two groups. Figure 2.1 consists of the mean pure-tone air conduction and bone conduction thresholds of both the groups.

The routine audiological evaluation was carried out in the acoustically treated air-conditioned room (noise level as per ANSI S3.1 (1999)). Informed consent was taken from the participants who fulfilled the above criteria.

Participant Selection criteria

- All the participants had Speech Identification Scores (SIS) of more than or equal to 60%.
- All the participants had 'A' type of tympanograms with acoustic reflex thresholds appropriate to the degree of hearing loss.
- To rule out cognitive related issues, Minnesota mental status examination (Folstein, Folstein, & McHugh, 1975) was carried out, and individuals having a score of more than 20 were considered for the study.
- All the participants were native speakers of Kannada- a south Indian language.

- 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.

Table 2.1.

Demographic and audiological details of the participants in Group I and II

Group I				Group II			
Sl.No	Age/G	Right PTA	Left PTA	Sl.No	Age/G	Right PTA	Left PTA
1	54/M	57.3	51.25	1	60/F	45	43.75
2	54/M	51.25	52.5	2	57/M	41.25	41.25
3	54/M	47.5	50	3	60/F	47.8	48.75
4	51/M	50	47.5	4	69/M	52.5	51.25
5	57/F	46.25	56.25	5	54/M	56.3	51.25
6	55/M	41.25	53.6	6	70/M	45.5	48.75
7	59/M	55	57.5	7	70/M	52	51.75
8	59/F	52.5	52.5	8	62/M	55	54.25
9	65/M	52.5	57.5	9	59/M	51.25	52.5
10	65/F	52	44.3	10	55/M	40	45
11	62/M	52.5	57.25	11	70/F	46.75	48.54
12	69/M	48.75	52.5	12	69/M	48.75	52.5
13	60/M	55	46.25	13	66/M	53.25	54.25
14	68/F	56.25	52.5	14	64/F	43.75	42.5
15	54/M	47	55	15	64/M	50	43.75
16	60/M	50	46.25	16	64/M	55	53.25
17	65/M	45	46.25	17	70/F	43.75	50.25
18	65/F	52.5	46.25	18	70/M	48.75	50.75
19	60/M	47.5	46.25	19	70/M	57.5	57.5
20	65/M	38.75	39.75	20	57/M	35	30
21	58/M	38	36.25				
22	58/M	35.25	36.5				
23	57/M	35	30				
24	54/F	33.75	40				
25	55/M	35	39.75				
26	70/M	27.5	25				
27	70/M	28.25	42.5				
28	65/M	40	36.25				
29	63/M	32.5	40				
30	65/M	30	26.2				

*PTA: Pure tone Average

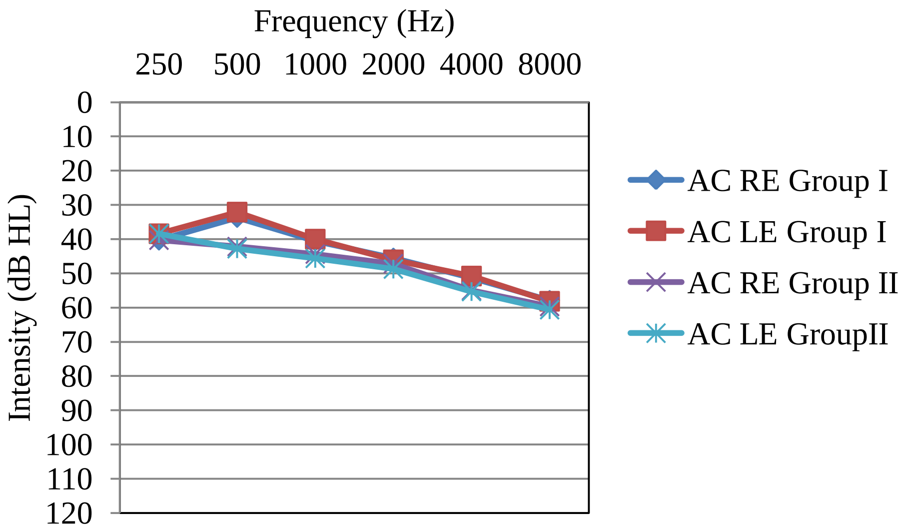

Figure 2.1: Mean hearing threshold of both groups across different frequencies. AC = Air conduction thresholds; RE = Right ear; LE = Left ear; Group I = Naïve hearing aid users; Group II = Experienced hearing aid users.

The PTA 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 (2007) 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 WDRC 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. It was ensured that the processing schemes and the number of channels of hearing aids worn by participants in Group II were similar.

2.2 Test environment

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 (ANSI S3.1, 1999).

2.3 Instrumentation

- A calibrated dual-channel audiometer Inventis Piano with TDH-39 headphones and the B-71 bone vibrator was used to determine air and bone conduction thresholds, respectively. Masking level difference (MLD) to assess binaural interaction was also administered through the audiometer.
- A calibrated immittance meter Grason-Stadler Inc. Tympstar (GSI – Tympstar version 2 middle ear analyzer) was used to assess middle ear status.
- A laptop (HP) installed with MATLAB version 7.10 (Mathworks Inc., 2014) was used to measure gap detection thresholds, and all the other tests of CAPD were routed via Inventis Piano audiometer. The same laptop was loaded with Smriti Shravan software developed by Kumar and Sandeep (2013) to assess working memory abilities (forward digit span and backward digit span tests) in the participants.
- Cubase 6 software connected with eight speakers (Genelec 8020B) was used to assess speech intelligibility.

2.5 Test materials

- Paired words in Kannada developed at the Department of Audiology, All India Institute of Speech and Hearing, Mysuru, was used for establishing speech recognition thresholds (SRT).

- SIS was obtained using phonetically balanced word lists in Kannada developed by Yathiraj and Vijayalakshmi (2005).
- The aided and unaided speech recognition measurements in the actual experiment were obtained using the sentences in Kannada developed by Geetha, Kumar, Manjula, and Pavan (2014).
- Auditory closure was assessed using speech perception in noise (SPIN) test using the Kannada word list developed by Manjula, Antony, Kumar, and Geetha (2015).
- Binaural integration was assessed using the Dichotic CV test developed by Gowri and Yathiraj (2001).
- Temporal processing was assessed using a gap detection test (GDT) and duration pattern test (DPT). The maximum likelihood procedure (mlp) toolbox implemented in MATLAB version 7.10 (Mathworks Inc., 2014) was used to measure GDT. DPT was assessed using material developed by Jain & Kumar (2016).
- Cognitive training module - Part 1 (Kumar & Sandeep, 2013) presented through the auditory digit span module of the software 'Smriti Shravan' was used to assess the working memory.
- International Outcome Inventory – Hearing Aids (IOI-HA) hearing aid benefit questionnaire was used to assess the subjective hearing aid benefit in Group II.

2.6 Procedure

All the participants were informed about the objectives and the procedure of the study, and informed consent was taken from them. An informal interview was carried out initially to gather information regarding the history of middle ear, neurological and psychological problems and hearing aid usage. The participants were assessed individually for all the central auditory processing skills and working memory. The central auditory processes assessed were auditory closure, binaural interaction and binaural integration, temporal processing, and working memory.

Assessment of central auditory processing skills

Auditory closure. The phonemically balanced Kannada word lists developed by Manjula et al. (2015) was used as the stimuli to assess auditory closure. The sentences were presented along with the speech noise ipsilaterally at 0 dB SNR to both the ears separately. The participants were asked to repeat the words. Twenty-five words were presented to each ear at 40 dB SL (ref: SRT), and percent correct scores were calculated for both the ears.

$$\text{SPIN} = \frac{\text{Number of words correctly repeated}}{\text{Total number of words}} \times 100$$

Binaural interaction. Binaural interaction was assessed using MLD**.** 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 dB SL (Ref PTA). The masking level difference was calculated as the difference in threshold between homophasic (SoNo) and antiphasic (SπNo) conditions.

$$\textbf{MLD} = \textbf{SoNo} - \textbf{S}\boldsymbol{\pi}\textbf{No}$$

Binaural integration. The dichotic CV test (developed by Gowri & Yathiraj, 2001) 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 a total of 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 SRT), and participants were asked 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 (Harris, Eckert, Ahlstrom, & Dubno, 2010). 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. 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 (Jain & Kumar, 2016). Tones in each pattern are either of 250 ms or 500 ms duration and are 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 auditory working memory of the individuals 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 (2013). 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 (3AFC). 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. For example, if the stimuli was ‘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. Thus, for the same stimuli, the expected response was ‘eight, six, nine, and four.’

Assessment of hearing aid benefit

Hearing aid benefit was measured using speech intelligibility in noise test and IOI-HA) hearing aid benefit questionnaire

Speech intelligibility in noise. A computer with Cubase 6 software connected with eight speakers (Genelec 8020B) covering 0^o to 360^0, kept at a distance of 45^o 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. (2014). 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 0^o 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 (Finney, 1978), which is as follows:

$$\mathrm{SNR\ 50} \;= \mathrm{I} + (0.5 \times \mathrm{d}) - \mathrm{d}\ (\#\ \mathrm{correct})/\mathrm{w}$$

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 lists were used only once to avoid the practice effect. This was assessed for both the groups.

Hearing aid benefit using questionnaire. IOI-HA hearing aid benefit questionnaire in Kannada 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 an experience with the hearing aid.

2.7 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, which is 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.

Chapter 3

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 to 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 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 3.1 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. In addition, IOI-HA questionnaire scores for experienced hearing users are included in Table 3.1.

Table 3.1. *Mean, SD, Median, minimum (Min), maximum (Max), Quartile range (QR) scores of different auditory processing test scores and SNR-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	9.5	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	.096	2.75	1.25	5.00	1.5
RDCV	13.77	5.46	13.00	4.00	26.00	3.5	9.25	4.71	9.00	3.00	21.00	3.5
LDCV	10.97	4.65	11.00	2.00	21.00	3	9.65	5.01	8.00	3.00	23.00	3.0
DCS	1.57	3.38	0.00	0.00	12.00	0.5	0.65	2.25	0.00	0.00	10.00	0.0
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	21.30	6.99	22.50	9.00	30.00	6.0
MLD	12.83	3.86	15.00	5.00	20.00	2.5	8.50	3.28	10.00	5.00	15.00	2.5
RSPIN	3.67	4.29	2.00	0.00	14.00	3.5	1.35	2.96	0.00	0.00	11.00	1.00
LSPIN	4.03	3.89	3.00	0.00	12.00	3.5	1.45	2.83	0.00	0.00	9.00	1.00
FW	4.23	0.67	4.00	3.00	5.00	05	4.65	0.81	5.00	3.00	6.00	0.5
BW	3.20	0.76	3.00	2.00	4.00	0.5	3.75	0.91	4.00	2.00	6.00	0.5
IOI-HA	-	-	-	-	-	-	29.79	3.56	29.00	25.00	36.00	3.00

Note. 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); 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 (ms); 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.

3.1 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 that there was no correlation between DPT and aided SNR-50 (r = -0.256, $p > 0.05$); GDT and aided SNR-50 (r = 0.003, $p > 0.05$) in naïve hearing aid users. Also, there was no correlation between DPT and aided SNR-50 (r = -0.294, $p > 0.05$); GDT and aided SNR-50 for experienced hearing aid user (r = 0.424, $p > 0.05$).

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, $p > 0.05$; for DPT, r = -0.085, $p > 0.05$).

3.2 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 aided SNR-50 (r = -0.318, $p > 0.05$), and between LSPIN and aided SNR-50 (r = -0.343, $p > 0.05$) in naïve hearing aid users.

In experienced hearing aid users (Group II), there was a moderate negative correlation between RSPIN and aided SNR-50 (r = -0.573, $p < 0.05$), LSPIN and aided SNR-50 (r = -

0.584, $p < 0.05$), i.e., as the SPIN scores increased, the aided speech perception improved. Figure 3.1 and 3.2 shows the scatter plots of auditory closure abilities (RSPIN and LSPIN) as a function of aided SNR-50.

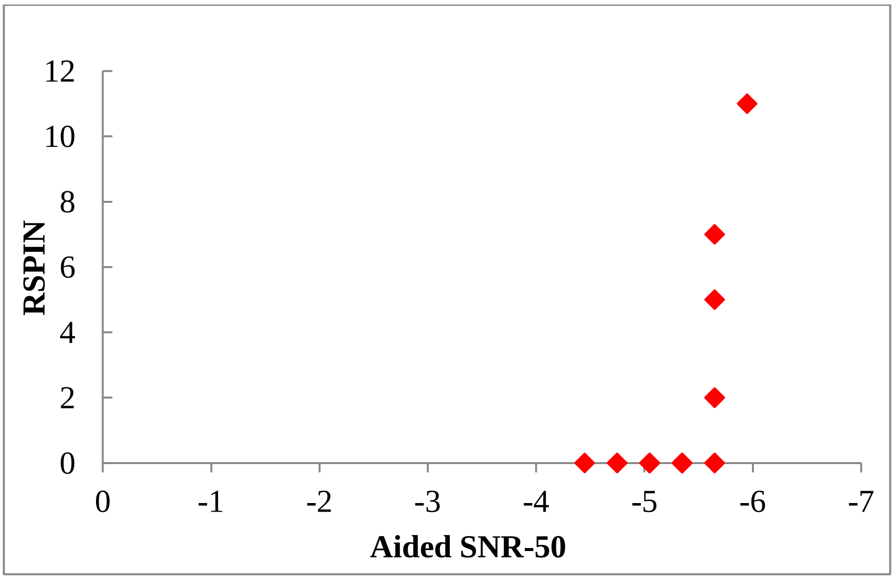

Figure 3.1. Scatter plot representing the correlation between RSPIN (speech perception in noise in right ear) and aided SNR-50 in experienced hearing aid users.

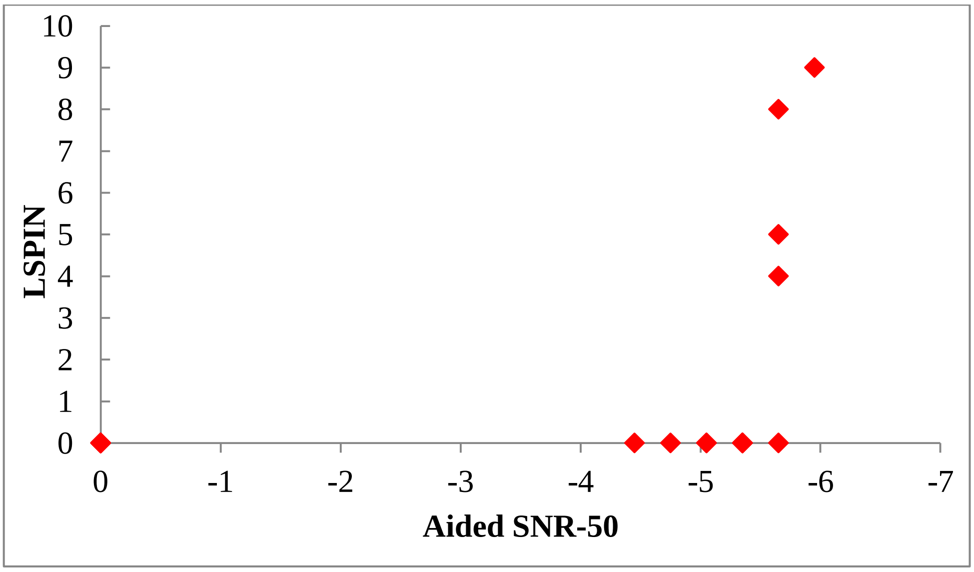

Figure 3.2. Scatter plot representing the correlation between LSPIN (speech perception in noise in left ear) and aided SNR-50 in experienced hearing aid users.

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, $r = 0.17$, $p > 0.05$; for LSPIN, $r = 0.16$, $p > 0.05$).

3.3 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 that there was no correlation between single ($r = -0.234$, $p > 0.05$ for RCV and $r = -0.335$, $p > 0.05$ for LCV) and double correct scores with aided SNR-50 (($r = -0.262$, $p > 0.05$) in naïve hearing aid user.

There was a moderate negative correlation between Right DCV and aided SNR-50 ($r = -0.540$, $p < 0.05$) and double correct scores and aided SNR-50 ($r = -0.466$, $p < 0.05$) in experienced hearing aid users which are represented in Figure 3.3 and 3.4. However, no correlation was found between Left DCV and aided SNR-50 in experienced hearing aid user ($r = -0.226$, $p > 0.05$).

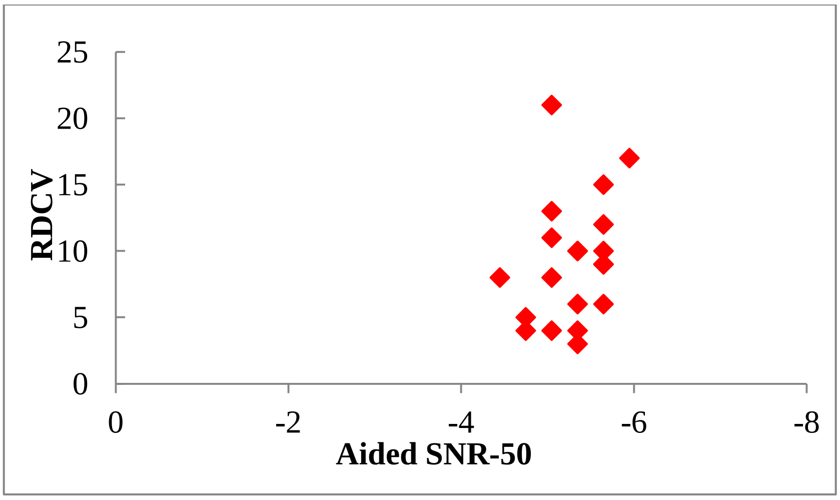

Figure 3.3. Scatter plot representing the correlation between RDCV (Right dichotic consonant-vowel) scores and aided SNR-50 in experienced hearing aid users.

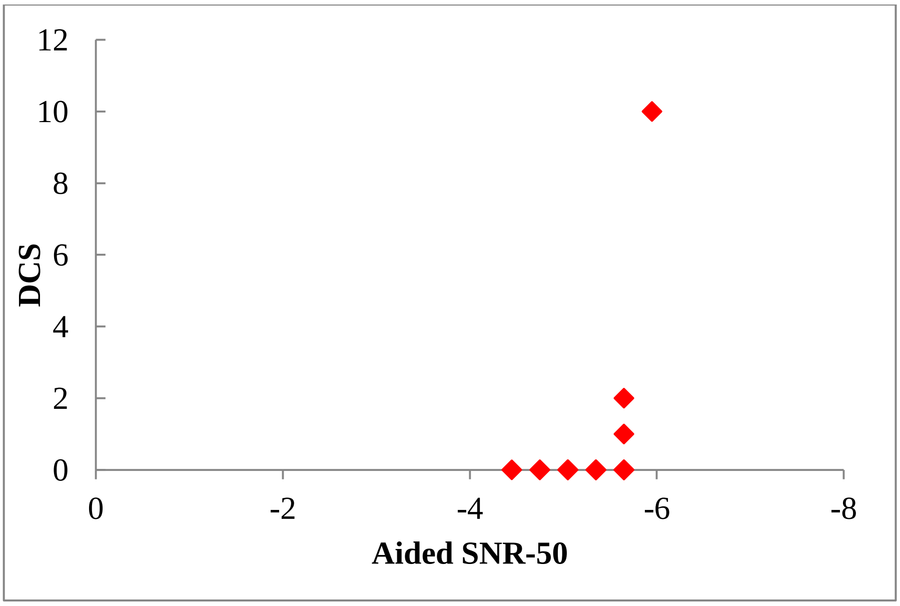

Figure 3.4. Scatter plot representing the correlation between DCS (Double correct score) and aided SNR-50 in experienced hearing aid users.

Spearman correlation was also done between IOI-HA questionnaire and binaural integration abilities in experienced hearing aid users. Results showed that there was no correlation between the IOI-HA questionnaire and binaural integration abilities (for RDCV, r = -0.16, $p > 0.05$; for LDCV, r = -0.10, $p > 0.05$; for DCS, r = 0.09, $p > 0.05$).

3.4 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 interaction assessed using MLD and hearing aid benefit in naïve and experienced hearing aid users. Results showed that there was a moderate negative correlation between MLD and aided SNR-50 ($r = -0.464$, $p < 0.05$) in naïve hearing aid users. Figure 3.5 shows the scatter plot of a significant correlation. However, there was no correlation between MLD and aided SNR-50 in experienced hearing aid users ($r = -0.263$, $p > 0.05$).

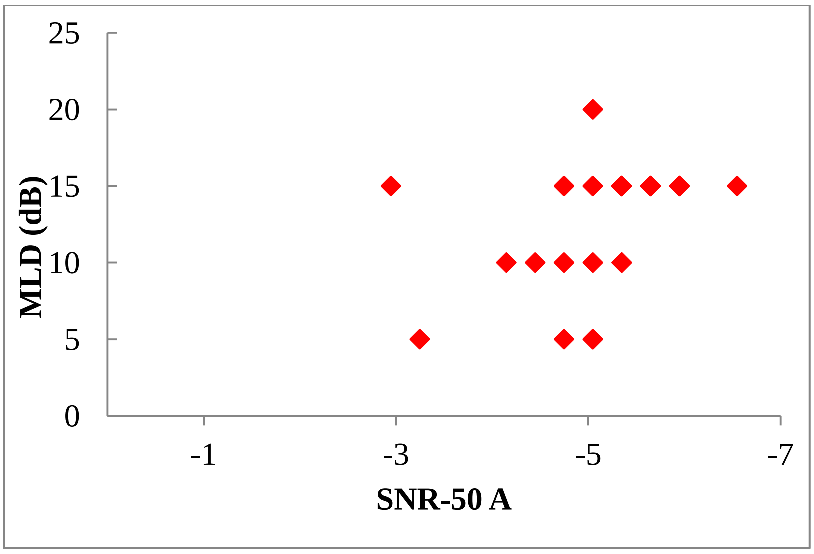

Figure 3.5. Scatter plot representing the correlation between MLD (Masking Level Difference) and aided SNR-50 in naïve hearing aid users.

Correlation analysis was also done between the IOI-HA questionnaire and binaural interaction abilities in experienced hearing aid users. Results showed that there was no correlation between IOI-HA questionnaire and binaural interaction abilities ($r = 0.076$, $p > 0.05$).

3.5 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 aided SNR-50 (r = -0.003, $p > 0.05$); backward span test and aided SNR-50 (r = -0.071, $p > 0.05$) in naïve hearing aid users. Similar results were obtained for the experienced hearing aid users (for FW, r = 0.208, $p > 0.05$; for BW, r = 0.013, $p > 0.05$).

Correlation analysis was done between IOI-HA questionnaire and working memory in 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, $p > 0.05$; for BW, r = -0.10, $p > 0.05$).

Chapter 4

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.

4.1 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 (2016) where correlation between temporal processing tests and cognitive function before and after hearing aid use was done. They reported that even without the use of 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 (Fitzgibbons & Wightman, 1982) which cannot be reversed with the usage of hearing aids. In addition, the signal processing algorithms in digital hearing aids have been found to alter the temporal envelope of the signal leading to distorted temporal cues in the input signal (Souza, Hoovern & Gallun, 2012; Venn, Souza, Brennan, & Stecker, 2009). Hence, the higher cortical areas responsible for temporal processing might not have got appropriate input leading to no significant changes in the temporal processing.

4.2 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 RSPIN and aided SNR-50, and between LSPIN and aided SNR-50 in naïve hearing aid users. In 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. (2007) reported that auditory closure abilities are affected in individuals with hearing impairment compared to normal hearing group and concluded that hearing loss affects speech recognition abilities. Murphy et al. (2018) found that poor performance in a speech in noise test in individuals with mild to moderate hearing loss compared to 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.

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

The results showed that there was no correlation between any of the binaural integration scores and aided SNR-50 in naïve hearing aid users. There was a moderate negative correlation between RDCV and aided SNR-50 and between DCS and aided SNR-50 for experienced hearing aid users. There was no correlation between LDCV and aided SNR-50 in experienced hearing aid users. These results indicate that there was 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 are in consensus with the findings in the literature. Lavie, Banai, Karni, and Attias (2015) found that unaided dichotic listening and unaided speech identification in noise scores improve significantly in the nondominant ear by 8 weeks of hearing aid usage. It can be inferred from the present study that the use of binaural hearing aids may improve not only the speech perception performance with the hearing aids, but it may also 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 (Scheffler, Bilecen, Schmid, Tschopp, & Seelig, 1998) and neural plasticity (Munro, Pisareva, Parker, & Purdy, 2007; Neuman, 2005) that takes place after weeks of hearing aid use.

4.4 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 resolves into auditory objects, the segregation, and localization of which plays an important role in speech perception in noise. 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 (ITD). Further, independently acting multi-channel WDRC and DNR features between left and right hearing aids also tend to affect the inter-aural level differences (ILD) leading to poor interaction between the two ears (Keidser et al., 2006).

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

Results showed that there was no correlation between forward digit span test and aided SNR-50; backward digit span test and aided SNR-50 in both naïve and experienced hearing aid users. These results are in consensus with the findings in the literature. van Hooren et al. (2005) found that cognitive abilities didn't improve with hearing aid usage and hearing aid can only restore impairments at the level of the sensory organ but does not affect the central nervous system. The present study also indicates that cognitive abilities didn’t improve with hearing aid usage. However, numerous findings in the literature have shown that there is a link between speech perception in noise and working memory (Lunner, 2003; Mackersie, Prida, & Stiles, 2001; Ng, Rudner, Lunner, Pedersen, & Rönnberg, 2013). 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 assess 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 as a result of hearing aid usage. In future, complex tasks can be used to assess the relationship between aided speech perception scores and working memory.

Chapter 5

Summary and Conclusions

The aim of the current study was to evaluate the relationship between auditory processing abilities, working memory, and hearing aid benefit in naïve and experienced hearing aid users in older adults. A total of 50 individuals in the age range of 51 to 70 years participated in the study. They were divided into two groups; 30 participants with mild to moderate hearing loss without any hearing aid experience and 20 participants with mild to moderate hearing loss with hearing aid experience of at least six weeks. Their auditory processing abilities and hearing aid benefit 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 and SNR-50 aided and unaided measures. International Outcome Inventory – Hearing Aids (IOI-HA) hearing aid benefit questionnaire was used to assess the hearing aid benefit in experienced hearing aid users.

The association between the auditory processing abilities and hearing aid benefit were analyzed, and the results showed that there was a correlation between RSPIN and aided SNR-50; LSPIN and aided SNR-50; unaided SNR-50 and aided SNR-50; RDCV and aided SNR-50; DCV and aided SNR-50 in experienced users. There was no correlation between IOI-HA questionnaire and auditory processing abilities. A correlation was observed between unaided SNR-50 and aided SNR-50; MLD and aided SNR-50 in naïve hearing aide user. Thus, it can be understood that binaural stimulation with hearing aids improve a few auditory processing abilities in mild to moderate hearing loss elderly individuals.

In future, studies can be done using speech perception and working memory tests with higher level of difficulty to study the relationship between hearing aid benefit and processing abilities. Further, a longitudinal study involving only one goup of individuals would give a better control of extraneous variables.

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List of research papers presented

Sl. No.	Conference Name	Authors	Title	Oral/Poster
1.	1th Kerala ISHA, 15-16thSep, 2018	Geetha Chinnaraj, Chandni Jain, Keerthi Sringari Parmeshwara	Effect of age on binaural integration using dichotic digit test	KSB, Oral
2.	Kerala ISHA, 15-16th Sep, 2018	Geetha C, Chandni Jain, Keerthi S P	Auditory processing abilities in naïve and experienced hearing aid users	KSB, Poster
3.	WSPD, 8-9 Sep, 2018	Geetha C, Chandni Jain, Keerthi S P	Effect of age and hearing loss on Auditory processing abilities	WSPD, Oral

List of publication

Chandni Jain, Keerthi Sringari Parmeshwara & Geetha Chinnaraj. (2019). Effect of age on binaural integration using dichotic digit test in Kannada, Hearing, Balance and Communication, DOI: 10.1080/21695717.2019.1705058