SPEECH IDENTIFICATION IN THE NON-AIDED EAR IN MONAURAL HEARING AID USERS

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Contents

LIST OF APPENDIX

Abstract

Aim: *The study aimed to compare the speech identification scores of hearing aid users before and after the use of monaural amplification. The study also aimed to compare the two ears before and after monaural amplification and investigate the differences in performance in those who consistently use the device in one ear with those who alternate the device between their ears. The influence of the number of years of auditory deprivation as well as the influence of degree of hearing impairment on speech identification scores in the aided and the non-aided ears were also determined.*

Methods: *Seventy-four adults, aged 18 to 50 years, with stable bilateral acquired symmetrical sensorineural hearing loss were evaluated. Among them, 39 participants consistently used the device in one ear and 35 participants alternated the device between their two ears at regular intervals. All the participants had used their monaural hearing for at least one year. Information regarding pre-amplification speech identification scores, measured at the time of prescribing their hearing aid, was obtained from the case records of the participants. Information about their use of hearing aid was obtained through a face-to-face interview. Their current speech identification was evaluated using the same tests with which they had been evaluated earlier.*

Results: *Prior to the use of amplification, no significant difference was seen between the left and right ear scores in alternate-ear hearing aid users as well as the constant-ear hearing aid users. However, following the use of amplification, a significant decrease in score was found in the non-aided ear compared to the aided ear in the constant-ear users. Such a difference between ears was not seen in the alternate-ear users. Further, a significant improvement in score was found in the aided ear of the constant-ear users, but a significant decrease was observed in their non-aided ear. In the alternate-ear users, the scores improved significantly in both ears after the use of amplification. Additionally, no significant correlation was obtained between the duration of use of monaural amplification and reduction in speech identification in the constant-ear users. Also, there was no significant correlation between the decrease in speech identification scores in the non-aided ear and their pure-tone average.*

Conclusions: *The findings of the study indicate that the use of monaural amplification in individuals with symmetrical hearing loss results in a significant reduction* *in speech identification scores in their non-aided ear. However, the deterioration in scores can be averted by the participants alternating their monaural hearing aid between their ears at least once in two weeks. The quantum of deterioration in the constant-ear users was not affected by the number of years they had used monaural amplification as well as by their degree of hearing loss.*

Key Words: Symmetrical hearing loss, constant-ear hearing aid users, alternate-ear hearing aid users, auditory deprivation

Introduction

The advantages of binaural hearing over monaural hearing have been noted several decades ago (Koenig, 1950). It has been demonstrated that binaural amplification is more beneficial than monaural amplification. These benefits of binaural amplification have been documented over 50 years ago (Markle & Aber, 1958). The advantages reported in literature include improved speech understanding (Day, Browning, & Gatehouse, 1988; Köbler, Rosenhall, & Hansson, 2001; Kwak, Kang, Kim, An, & Shim, 2018; Noble & Gatehouse, 2006), binaural loudness summation (Cox, Schwartz, Noe, & Alexander, 2011), and improved localization (Cox et al., 2011; McKenzie & Rice, 1990). Apart from the advantages in challenging situations, Kim, Lee, and Lee (2014) observed that their binaural amplification users had significantly greater acceptance of noise compared to the monaural amplification users. This was observed on a task that assessed acceptable noise levels. Owing to these benefits, the patients with bilateral hearing loss are usually recommended binaural amplification.

The benefit of binaural amplification over monaural amplification was studied by Erdman and Sedge (1981) in 30 subjects with bilateral sensorineural hearing loss (mean age = 40 years; age range = 23 to 58 years). Initially, the participants were instructed to wear either monaural or binaural hearing aids for specific durations of time, and then switch such that they all had experience using both fitting procedures. Their preference for monaural and binaural was then checked. It was observed that 90% of the subjects preferred binaural amplification because of the overall clarity in noisy situations and functionally enhanced speech perception.

Likewise, Day et al. (1988) assessed the benefits of binaural hearing aids over monaural hearing aids in individuals with bilateral severe sensorineural hearing loss. Fiftyone subjects aged 31 to 82 years, who were previously fitted with monaural hearing aids, were given two devices. Their sentence perception in the presence of noise was evaluated after 3 months and again after 9 to 12 months of binaural fitting. A mean benefit of 8.7% was found in binaural over monaural aids. However, 22% of the participants chose to return the second hearing aid and rejected binaural amplification. It was observed that those who rejected binaural hearing aids did not differ from those who accepted binaural devices in terms of age, hearing level, asymmetry, and airborne gap.

Participants have been noted to change their selection of monaural or binaural amplification after repeated visits to a centre providing hearing aids. Vaughan-Jones and Christmas (1993) observed that their participants (n = 56), aged 40 to 83 years (average age = 68 years), demonstrated varying amplification preferences. Their participants were randomly provided monaural or binaural amplification, and later switch over to binaural or monaural amplification, respectively. While, none preferred binaural amplification in their initial visit, the number who chose it increased to only 22% by the end of the third visit, but further increased to 53% at the end of their fourth visit. The 53% represented only 19 out of 36 of the participants who were offered binaural amplification.

To find out the factors influencing binaural amplification, Chung and Stephens (1986) conducted survey on 200 patients who were fitted with binaural hearing aids about patient satisfaction, mode of amplification, localization and state of problems. Binaural amplification was found to be of major benefit in noisy situations, especially by full-time users. Also, patients with asymmetrical hearing loss used binaural aids as much as the symmetrical hearing loss patients. With reference to gender, most females were found to be reluctant to use two hearing aids when compared to males. Additionally, significantly greater use of binaural hearing aids was seen among patients with moderately-severe to profound hearing loss than those with mild hearing loss in their better ear.

The patterns of hearing aid use and consumer satisfaction levels in monaural and binaural amplification was studied on 144 subjects with bilateral fitting and 40 subjects with unilateral fitting by Köbler et al. (2001). The participants, who were above the age of 15 years, answered a questionnaire about their lifestyle and benefit from amplification. It was observed that two-thirds of the bilaterally fitted subjects used both hearing aids. Bilateral amplification was chosen over monaural fitting for aspects such as speech recognition, sound localization, and superior sound quality.

Similarly, Noble and Gatehouse (2006) investigated the benefits of bilateral fitting over unilateral fitting using the Speech, Spatial and Qualities of Hearing Scale. Three independent groups, unaided participants, unilaterally fitted and bilaterally fitted participants were studied. The overall benefit with one hearing aid was seen in normal contexts like one-to-one conversations, groups, in quiet and in noise. The challenging situations showed benefit with one aid and further benefit with two. In the spatial domain, with one hearing aid some directional hearing was possible. However, further benefit in distance and movement discrimination was obtained with two devices.

The review of literature indicates that several researchers have confirmed that binaural amplification is preferred over monaural amplification. Preference for binaural amplification was found to be influenced by the degree of hearing impairment, gender of the individual and the listening situation. There are reports in literature that not everyone with bilateral hearing loss chooses to wear two hearing aids.

Preference for monaural amplification over binaural amplification has been reported in certain situations, although it is generally accepted that binaural amplification is preferred over monaural amplification. Köbler et al. (2001) reported of participants with bilateral symmetrical mild to moderately-severe sensorineural hearing loss having a high preference for binaural amplification over monaural fitting. However, one-third of the subjects preferred only one hearing aid, which was attributed to ear asymmetry.

Further, Stephens et al. (1991) noted that 45% of their participants with bilateral sensorineural hearing loss, aged 50 to 65 years, chose monaural fitting due to convenience and cosmetic concerns. The participants, who were provided either monaural or binaural amplification randomly, were evaluated for the acceptability level of binaural hearing aids. After 4 to 6 weeks of usage of their devices, the subjects were re-administered a 'Localization questionnaire', a 'Satisfaction/Benefit Questionnaire' and the 'Four Alternative Auditory Feature test'. Following this, their participants switched to using monaural or binaural amplification for the next 4 to 6 weeks, after which they were re-evaluated. Among the participants, 55.2% preferred binaural fitting over monaural fitting owing to the acoustic benefits like clarity, localization, loudness. The remaining chose monaural fitting.

Unlike the above studies, Schreurs and Olsen (1985) reported that among their 30 participants who had experience using monaural or binaural hearing aids, most preferred the latter in quiet and the former in noisy situations. The patients with mild to moderate bilateral symmetrical sensorineural hearing loss responded to a questionnaire. At the end of the trial period, most of the patients decide to purchase a single hearing aid. Factors like listening needs, financial status, cost, affluence, recommendations of relative and friends as well as inputs from professional co-workers were found to influence the decision making of the participants.

The preference for monaural or binaural amplification has been noted to depend on the listening situation. Noble and Gatehouse (2006) noted a significant difference between the responses of unilateral and bilateral hearing aid users on the Speech, Spatial, and Qualities of Hearing scale. The subjects reported more benefit with two devices for directional hearing and movement discrimination than with a single device. However, unilateral amplification was noted to assist in one-to-one conversation.

Also, unlike the typically findings of mentioned in literature, no significant difference between the outcome of monaural and binaural fitting strategies was observed by Azevedo, Santos, and Costa (2015). This was noted for sentence recognition in quiet and in noise among older adults aged 60 to 80 years (n = 27) having symmetrical moderately-severe sensorineural hearing loss, while using monaural as well as binaural hearing aids.

Thus, studies reported in literature have noted that individuals with hearing loss in both ears may choose to wear a single hearing aid as they may have asymmetrical hearing loss, or due to specific listening needs. Additionally, those with bilateral hearing loss may opt to wear a single device due to financial constraints, cosmetic concerns, and / or due to peer suggestions.

The effect of auditory deprivation on speech perception has been studied in those using a monaural hearing aid. These studies have proven that providing only monaural stimulation to those with symmetrical hearing problem affects their performance in noise and localization abilities (Gelfand, 1995; Köbler & Rosenhall, 2002; Köbler et al., 2001; McArdle, Killion, Mennite, & Chilsolm, 2012; Silman, Gelfand, & Silverman, 1984; Stephens et al., 1991). The studies support the viewpoint that auditory deprivation can occur in adults long after the critical period of auditory stimulation (Stein & Schuckman, 1973). This was noted to manifest as a regression in the speech identification or recognition scores in the ear which is left unstimulated by any acoustic input for a certain period of time. The deterioration was attributed to prolonged deprivation of amplification in the non-aided ear in symmetrical sensorineural hearing loss.

One of the earliest studies on the presence of auditory deprivation in the non-aided ear of those who used monaural amplification was conducted by Silman et al. (1984). Participants with bilateral symmetrical hearing loss were divided into two groups, one fitted monaurally (n = 44; average age = 59 years) and the other fitted binaurally (n = 23; average age = 58 years). On re-assessment of the participants 4 to 5 years after the initial fitting, a significant decrease between the initial and retested speech recognition scores was observed only in the non-aided ears of the monaurally fitted group, but not in their aided ear. While the decrease was 18.5% in the non-aided ear, it was just 2.6% in the aided ear. However, they found no such significant difference in scores of those fitted binaurally, where the decrease was only 1.9% for the right ear and 1.6% for the left ear.

To substantiate the contributions of monaural and binaural fitting in auditory deprivation and binaural hearing advantage, Silverman and Silman (1990) reported the responses of two adults having symmetrical hearing loss. The speech recognition scores were reviewed for 11.5 years for one subject and 6 years for the other, subsequent to their monaural hearing aid fitting. Their suprathreshold word recognition score was found drop in the non-aided ear to the 95% critical-difference lower limit at the 6^{th} year in the first subject and at the 22^{nd} month in the second subject. Such a drop in scores was not seen in the aided ears in both subjects. Shifting the participants to a binaural fitting strategy resulted in the previously non-aided ear showing a marked improvement in word recognition, approximately 2 years after the binaural fitting, which was ascribed to the effect of binaural hearing.

Silman, Silverman, Emmer, and Gelfand (1992), in a subsequent study again demonstrated the possibility of recovery from auditory deprivation following binaural amplification in a 64 year old adult who had been earlier fitted with a single device. The significant decrement in word identification scores (below the 95% critical-differences lower limit) was seen at an evaluation done 3 years after the use of monaural amplification. However, a shift to a binaural amplification strategy resulted in the scores improving significantly at the end of 2 years of consistent use of hearing aids in both ears.

Silverman and Emmer (1993) also observed that word scores dropped in the non-aided ear of the six monaural hearing aid users they studied who had asymmetrical hearing loss. Additionally, they reported of a recovery in two of the six subjects after the use of binaural amplification. However, they made no mention of the duration of the deprivation or the quantum of recovery.

Similar results were noted by Boothroyd (1993) in a 26 year old woman having severe hearing loss who majorly used monaural amplification from age 4 to 24 years. Although hear hearing thresholds remained constant, her phoneme recognition scores in the non-aided was much poorer (40%) than the aided ear (80%). With the use of binaural amplification for 2 years, the scores in the previously non-aided ear increased (75%).

Hurley (1993) also noted that their nine subjects fitted with monaural amplification had a steady decline in speech recognition scores in the non-aided ear. This reduction in scores was observed as early as one year after post fitting or as late as 5 years after the initial monaural fitting.

The impact of auditory deprivation subsequent to the use of monaural amplification was also observed by Gelfand (1995) in six males aged 31 to 64 years having bilateral symmetrical sensorineural hearing loss. The poorer performance in the non-aided ear was observed within 2 years of use of monaural amplification, with it occurring as early as 6 months in one participant. The decrease in speech recognition scores of the non-aided ear ranged from 14% to 48%. Two of the subjects exhibited a delayed onset of auditory deprivation that commenced after 6 years in one and 11 years in the other. While complete recovery was seen after just 10 months of consecutive binaural amplification in two subjects, two had incomplete recovery even after several years of binaural amplification. The other two participants who had delayed onset of deprivation, failed to recover from even after years of binaural fitting.

To rule out the influence of ageing influencing auditory deprivation in individuals with symmetrical hearing loss using monaural hearing aids, Hurley (1998) compared 20 young (age range = 39 to 45 years) and 20 older adults (age range = 60 to 65 years). Half the participants in each group used monaural hearing aids and the other half used binaural hearing aids. Word recognition scores declined significantly in both groups over a 3 to 5-year span in the non-aided ear of the monaural hearing aids users. Further, there was no significant difference between the groups in terms of the rate of decline. In contrast, there was no decline in the aided ears of both age groups, irrespective of whether they used monaural or binaural hearing aids. Thus, it was concluded that the decline in the non-aided ear was not related to age-related auditory changes.

To confirm their earlier stand on auditory deprivation occurring following the use of monaural amplification in symmetrical hearing aid users, Hurley (1999) studied 142 subjects, 77 of whom were fitted monaurally and 65 were fitted binaurally. The participants, aged 26 to 76 years (mean = 58 years), were revaluated at 1, 3, and 5 years after the initial hearing aid fitting. Those monaural hearing aid users, whose word recognition scores dropped to the 95th percentile critical value, were fitted with binaural hearings. Similarly, those binaural hearing aid users whose scores reduced to the 95th percentile critical value were fitted with monaural hearing aids. This was done to see if the change in fitting would result in an improvement in scores. The results showed an overall 1% prevalence of poor word scores after 1 year of initial hearing aid fitting, 8% prevalence after 3 years and 26% prevalence after 5 years post fitting. Further, Hurley noted that those with a significant decline in recognition score had higher PTA_1 and PTA_2 values (46 & 58 respectively) compared to those did not have a significant decline in recognition scores (35 & 46 respectively). Hence, the decline in word recognition scores over the years was also linked to the pure-tone average of the participants.

Evidence of auditory deprivation occurring in monaural hearing aid users has also been demonstrated in a study using electrophysiological measures. Wieselberg and Iório (2012) evaluated 35 participants with bilateral symmetrical sensorineural hearing loss, 15 fitted monaurally and 10 fitted binaurally and 10 not provided amplification. In addition to behavioural tests (pure-tone audiometry, speech recognition threshold in silence, & speech recognition in noise), electrophysiological tests were conducted (P_{300} & long latency auditory evoked potential). The bilateral fitted group and the unilateral fitted group did not show any statistical difference in the performance when the right and left ears were compared in all the tests. However, the unilateral fitted group showed significantly higher P_{300} latency in the ear with reference to auditory deprivation when compared to the aided ear. The influence of age was not ruled out as they used a very large age arrange (48 years to 90 years) and made no mention regarding the three groups being age matched. Additionally, they did not provide information regarding the number of years the participants had been deprived of amplification.

Apart from changes in speech identification, other parameters like difference limens and acceptable noise levels have also been reported to alter after monaural amplification in the non-aided ear. Robinson and Gatehouse (1994) studied the effect of long-term use of monaural hearing aids on intensity discrimination in four adults aged 54 to 82 years. They were compared with five normal hearing adults aged 18 to 35 years. Difference limens were measured using a gated pedestal method with an adaptive, three-interval-forced-choice procedure, and Weber function was derived for statistical analysis. The normal hearing group were found to show a 'near-miss' to Weber's law and performance improved with increase in level. No differences were found to exist between the Weber functions for the aided and non-aided ears of those with hearing impairment. The gradient of the Weber function at 3 kHz for the aided ear was steeper than that found for the non-aided ear, steeper than that found for the aided and non-aided ears at 0.25 kHz.

From the review of literature, it can be observed that several studies indicate that the non-aided ear of monaural hearing aid users exhibit a reduction in speech identification scores due to auditory deprivation. It is speculated that the non-aided ear of a monaurally fitted individual may lose its functional capability in comparison with the aided ear. This deterioration was found to commence as early as 6 months and was present in those using the device up to 15 years. However, the studies have not determined whether the quantum of deprivation in the non-aided ear varies as a function of the duration of use of monaural amplification usage. Also, studies do not mention whether the participants constantly in one ear or whether they alternated their device between their ears. Hence, it is not known whether these two ways of using monaural amplification have an impact on the performance of the participants following amplification.

Further, several of the earlier studies on the deterioration in speech identification in the non-aided ear of monaural hearing aid users have been conducted on adults aged 50 and above (Byrne, Noble, & LePage, 1992; Gelfand, 1995; Gelfand, Silman, & Ross, 1987; Schreurs & Olsen, 1985; Silman et al., 1984). It is known that with advance in age, the probability of having auditory processing problems increases (Kumar & Sangamantha, 2011;

Sanchez, Nunes, Barros, Gananca, & Caovilla, 2008; Vaidyanath & Yathiraj, 2015). Thus, the findings of studies reporting deterioration in the non-aided ear may be confounded with age related decline. This may contaminate the actual effect of auditory deprivation. Hence, to understand the true effect of auditory deprivation in the non-aided ear, younger adults with bilateral symmetrical hearing loss need to be studied. Additionally, several of the studies have small sample sizes, thereby making it difficult to generalize their conclusions to the general population. Thus, studying a larger group of individuals using monaural amplification requires to be done. Further, most studies mentioned in literature do not mention if the impact of degree of hearing impairment on the reduction of speech identification scores. To address these issues, the study aimed to compare the two ears before and after monaural amplification and investigate the differences in performance in those who consistently use the device in one ear with those who alternate the device between their ears. The study also aimed to compare the speech identification scores of hearing aid users before and after the use of monaural amplification in their aided as well as non-aided ear. The influence of the number of years of auditory deprivation as well as the influence of degree of hearing impairment on speech identification scores in the aided and the non-aided ears were also determined.

Methods

The study was carried out using a pre-post design. Initially, audiology related data from the case files of adults who wore monaural hearing aids were captured. Following this, those who wore their hearing aid for at least one year were evaluated to measure their unaided speech identification scores, following the use of the device.

2.1 Participants

The participants were selected using a purposive sampling technique. Seventy-four individuals with bilateral acquired symmetrical sensorineural hearing loss were selected randomly among the clients who underwent audiological evaluation in the department of Audiology of the All India Institute of Speech and Hearing, and who met the inclusion criteria. The majority of the participants had been tested in the past five years. The selected participants were aged between 18 to 50 years (mean age = 35.4 years). To be included in the study the participants were required to have sensorineural hearing loss and stable pure-tone thresholds over the past five years. From their case files maintained at the records section of the All Indian Institute of Speech and Hearing, Mysuru, it was confirmed that their pure-tone air-condition average ranged from 30 dBHL to 70 dBHL and they had A-type tympanograms. None of the participants had a history of middle ear disorders, neurological impairments or speech and language impairment.

They were selected only if they were fitted with monaural digital hearing aids, which they had used for at least one-year. They were divided into two groups based on their report of using their hearing aid consistently in one ear or alternating between their two ears. Among the 74 participants who were selected, 39 consistently wore their hearing aid in one ear (constant-ear users) and the remaining 35 alternated their device between their two ears at least once in 15 days (alternate-ear users). Demographic details of the participants are given in Appendix 1. The duration of use of hearing aids among the constant hearing aid users ranged from 1 to 9 years (mean = 2.69; median = 2.00), while it ranged from 01 to 08 years (mean = 2.37; median = 2.00) among the alternate-ear users.

The participants were studied further only if they passed the 'Screening Checklist for Auditory Processing in Adults' developed by Vaidyanath and Yathiraj (2014), indicating that they were not at-risk for an auditory processing problem. They were also required to have similar audiological findings as that seen in the evaluation done at the time on hearing aid prescription, which included pure-tone and immittance findings. All the participants had at least secondary school education with the language of instruction being either Indian-English or Kannada.

2.2 Equipment

The basic pure-tone and speech audiometry evaluations were conducted using a calibrated dual-channel audiometer (Inventis Piano) with TDH-39 headphones, B-71 bone vibrator and facility to route recorded audio signals through an auxiliary input. Immittance evaluation was done with a calibrated immittance meter (GSI tympstar) to rule out conductive component.

2.3 Material

The Screening Checklist for Auditory Processing in Adults developed by Vaidyanath and Yathiraj (2014) was used to rule out those at-risk for auditory processing disorders. Speech recognition threshold was measured using CID-22 spondaic words (Hirsh et al., 1952) or the paired Kannada word test developed in the Department of Audiology, All India Institute of Speech and Hearing. Evaluation of speech identification was done using phonemically balanced word test developed by Yathiraj and Vijayalakshmi (2005), while testing those who spoke Kannada, or by Yathiraj and Muthuselvi (2009), while evaluating those who spoke Indian-English. For each of the languages, two equivalent lists were used (List 1 & List 2).

2.4 Test Environment

All the audiological tests were carried out in an acoustically treated suite that met the specification of ANSI S3.1-1999 (R2013). The testing suites had optimum temperature and lighting and were free of any type of distractions.

2.5 Procedure

Prior to evaluating each of the clients, their audiological test findings, measured when their hearing aid was prescribed, were noted from their case files. This included their speech identification scores. Those who met the participant-section criteria were subjected to a face-to-face interview. Information regarding the following were noted: variations in hearing abilities after the onset of hearing loss; the model of hearing aid/s used; duration of hearing aid use; number of times they replace the devices utilised by them; and whether they used their hearing aid constantly in one ear or alternated between their two ears. Further, those who alternated their hearing aid between the two ears where required to provide information about how frequently they alternated the device between their two ears.

Before further evaluation, the participants were *screened for the presence of auditory processing problems* with the 'Screening checklist for Auditory Processing' was administered individually on all the participants. The individuals who passed this checklist, indicating the absence of the condition, were included for the study.

All the participants underwent *basic audiological testing* to confirm that their hearing thresholds had not altered from their testing done at the time of hearing aid prescription. The pure-tone air conduction and bone conduction thresholds were measured using the modified Hughson and Westlake procedure (Carhart & Jerger, 1959). The air conduction and bone conduction were evaluated at octave frequencies between 250 Hz to 8 kHz and 250 Hz to 4 kHz, respectively. From their pure-tone air conduction thresholds PTA_1 (average of 500 Hz, 1 kHz and 2 kHz) and PTA_2 (average of 1 kHz, 2 kHz and 4 kHz) were calculated. The average PTA_1 was 54 dBHL (range = 33 to 70 dBHL) and 55 dBHL (range = 40 to 70 dBHL) in right and left ears, respectively. Likewise, the average PTA_2 was 58 dBHL (range = 37 to 75 dBHL) and 59 dBHL (range = 40 to 75 dBHL) in right and left ears, respectively. Additionally, their middle ear function was tested using a calibrated immittance meter. Tympanograms was measured using a standard 256 Hz probe-tone. The ipsilateral and contralateral acoustic reflexes were obtained at 500 Hz, 1 kHz, 2 kHz, and 4 kHz in both the ears. The participants were subjected to further evaluation only if their pure-tone and immittance findings did not alter from the baseline evaluation carried out at the time of hearing aid prescription. Speech recognition threshold and speech identification were measured for each ear independently. The participants were tested in Kannada or Indian-English depending on the language that they had been tested earlier. It was ensured that they had been evaluated on the same test earlier, based on the information available in their case files.

All *speech audiometry* evaluations were done under headphones, after the participants removed their prescribed hearing aids. However, all instructions to respond were given with them wearing their hearing aids. The speech recognition thresholds and speech identification were measured in the language each participant had been evaluated earlier, using live voice. The speech recognition threshold was measured using a bracketing technique. The participants were instructed to repeat the words heard by them and were told that they could guess the words in case they were unsure of what was presented. The lowest level at which 50% of the words were repeated correctly was noted as the speech recognition threshold.

As done while measuring the speech recognition thresholds, the speech identification of the participants was obtained in the language they were tested earlier. Half the participants were first evaluated in their right ear and the other half were tested first in their left ear. Among those who wore their hearing aids constantly in one ear, half were tested first in the ear in which they used the hearing aid and the other half were evaluated first in the non-aided ear. This was done to prevent an ear-order effect. It was ensured that the participants heard two different equivalent lists in each ear, to prevent familiarity of the test stimuli influencing the test results. Further, half the participants were tested with List 1 in their right ear and half with List 2 in their right ear, to avoid a list-order effect.

The stimuli used to measure speech identification were presented at 40 dBSL (Ref. SRT) or at a lower level for four Constant-ear users and five alternate ear users, as they were restricted by their hearing level. The lowest level at which they were evaluated was 25 dBSL. The participants were instructed to listen to the stimuli carefully and to repeat the words heard by them. Their open-set responses were noted and scored. Each correct response was awarded a score of one and each incorrect response a score of zero. The scores of each ear of the participants were tabulated. As the environment, material, and method used to evaluate the participants were standard ones, only minor procedural variations would have occurred between the two evaluations that were conducted on each individual.

2.6 Analyses

The data obtained from the case files and from the evaluations carried out on the participants were statistically analysed using SPSS (Version 20) software. Shapiro Wilks test of normality indicated that the data were not normally distributed. Hence, non-parametric statistical tests were conducted.

Results

The within group as well as between group comparisons of the speech identification scores of the constant-ear and alternate-ear hearing aids user are provided below. The results are of the speech identification scores measured without the participants using their devices. The within group comparison of the speech identification scores was carried out to check the difference in scores prior to and after the use of amplification. Within group comparison was also measured to check for differences in scores in the aided and the non-aided ears. This was done for each participant group (constant-ear users & alternate-ear users) using Wilcoxon signed rank test. The between group comparison was carried out to check the difference in speech identification scores between the constant-ear and alternate-ear hearing aid user groups using the Mann-Whitney U test. This comparison between the two groups was done before as well as after their use of amplification.

In addition, the correlation between the number of years of use of the device with the reduction in speech identification scores in the non-aided ear; and the correlation between the pure-tone averages (PTA_1 & PTA_2) of the participants with the decline in speech identification scores in the non-aided ear was checked. This was done using Spearman's rank correlation.

The results are provided under the following headings:

3.1 Comparison of the left and right ear scores prior to and after the use of amplification in each participant group, 3.2 Comparison of the scores prior to and after the use of monaural amplification in the two ears of each participant group,

3.3 Comparison of the scores of the constant-ear and alternate-ear hearing aid users, before and after the use of amplification,

3.4 Relation between the number of years of use of monaural amplification with the decline in speech identification scores in the non-aided ear,

3.5 Correlation between the pure-tone averages (PTA_1 & PTA_2) of the participants with the decline in speech identification scores in the non-aided.

Table 3.1 *Mean, Median, Standard deviation (SD) and 95% confidence interval (CI)) of the unaided speech identification scores prior to and after monaural amplification in the aided and non-aided ears of the two participant groups.*

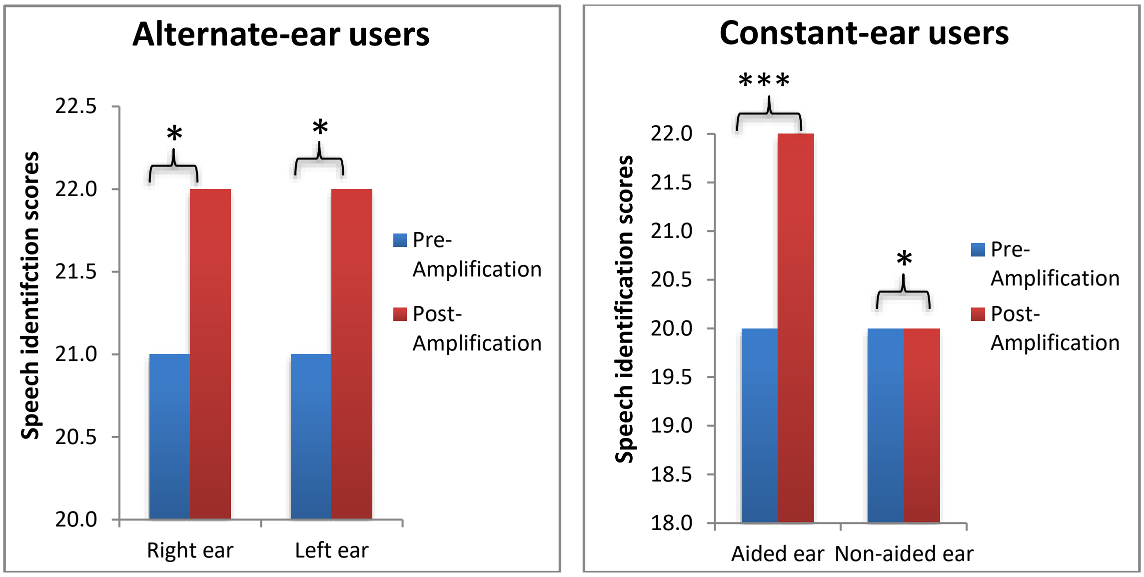
	Alternate-ear users (n = 35)				**Constant-ear users (n = 39)**			
	Right ear		**Left ear**		**Aided ear**		**Non-aided ear**	
	Pre-Amp	*Post-Amp*	*Pre-Amp*	*Post-Amp*	*Pre-Amp*	*Post-Amp*	*Pre-Amp*	*Post-Amp*
Mean	20.91	21.94	20.77	21.82	20.02	21.71	20.25	19.68
Median	21.00	22.00	21.00	22.00	20.00	22.00	20.00	20.00
SD	2.54	1.94	2.55	2.02	2.20	1.58	1.96	2.01
95% CI	20.0 – 21.78	21.28 – 22.60	19.89 – 21.64	21.13 – 22.52	19.27 – 20.78	21.17 – 22.25	19.58 – 20.93	18.99 – 20.37
Interquartile range	3	2	4	2	4	2	3	3

Note. Maximum possible total word score = 25; Amp = Amplification

3.1 Comparison of the left and right ear scores prior to and after the use of monaural amplification

Comparison of the left and right ear scores, prior to and after the use of monaural amplification was done separately for the constant-ear and separately for the alternate ear hearing aid users. The mean, median and 95% confidence interval of the speech identification scores (Table 3.1) of the left and right ears, prior to the use of amplification were similar in both the participant groups. After the use of the hearing aids, the unaided scores continued to be similar in the two ears of those who alternated the hearing aids between their two ears. However, in the constant-ear hearing aid users the scores were poorer in the non-aided ear compared to the aided ear.

To confirm whether the scores between the two ears were significantly different, Wilcoxon signed-rank test was carried out. Prior to the use of amplification, no significant difference was seen between the two ears in the alternate ear users [$Z = 0.369$, $p > 0.05$, $r = 0.062$] as well as in the constant ear users [$Z = 1.32$, $p > 0.05$, $r = 0.21$]. In contrast, following the use of amplification, the speech identification scores between the previously aided and non-aided ear was significantly different in the constant-ear users [$Z = 4.63$, $p < 0.001$, $r = 0.74$], with it being poorer in the non-aided ear. However, the two ears were not significantly different in the alternate-ear users [$Z = 0.60$, $p > 0.05$, $r = 0.10$].



Note. * = $p < 0.05$; *** = $p < 0.001$; Maximum speech identification score = 25

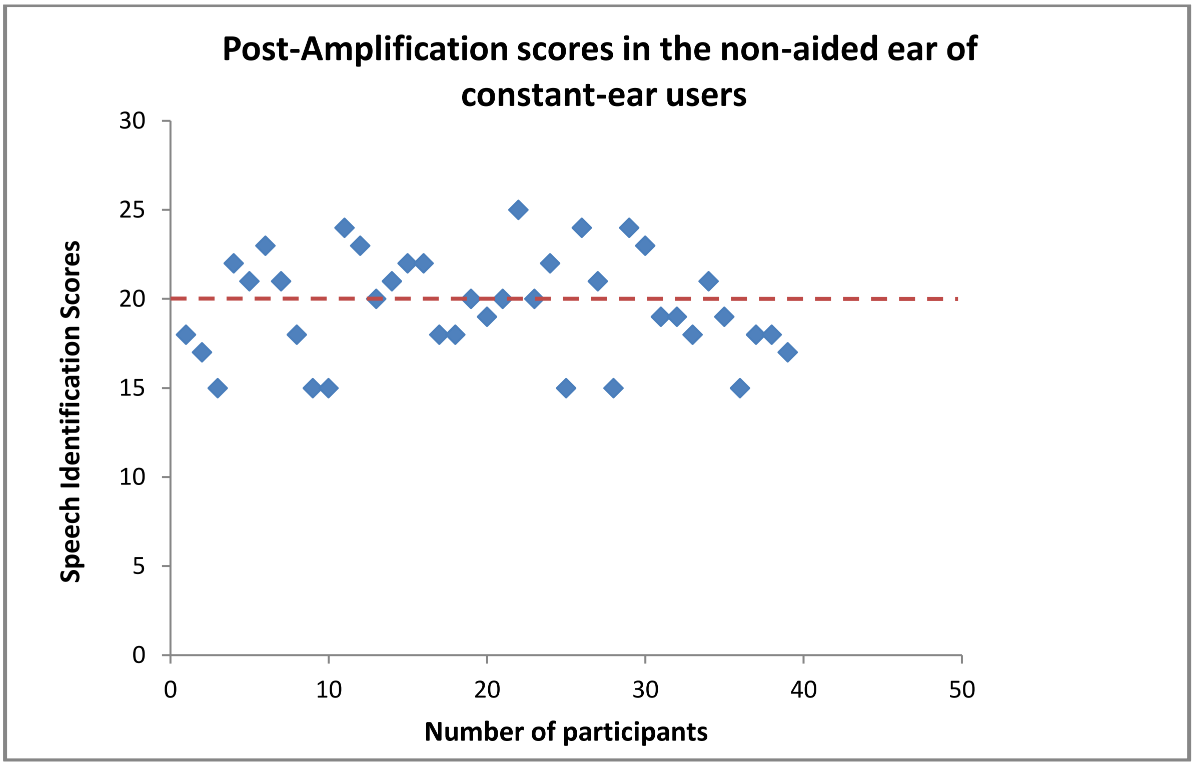
Figure 3.1. Median pre-amplification and post-amplification unaided speech identifications scores of the alternate-ear and constant-ear hearing aid users.

3.2 Comparison of the scores prior to and after the use of amplification

A comparison of the mean and median scores, prior to and after the use of amplification in each ear (Table 3.1), indicated that in the alternate-ear hearing aid users it did not differ much. This could be seen in their non-aided ear as well as their previously aided ear. In contrast, in the constant-ear users the scores in the ear where the hearing aid had been used did not alter, but dropped in the non-aided ear.

Statistical comparison of the scores was done using a Wilcoxon signed-rank test. As shown in Figure 3.1, in the alternate-ear users a significant improvement in scores was seen between the speech identification scores measured after the use of amplification in their right ear [Z = 3.10, $p < 0.01$, r = 0.52] and left ear [Z = 3.18, $p < 0.05$, r = 0.53]. Likewise, a significant improvement in scores was seen in the previously aided ear of the constant-ear users [Z = 4.75, $p < 0.001$, r = 0.76]. However, a significant decrease was observed in their non-aided ear [Z = 2.49, $p < 0.05$, r = 0.39].

Further, it was checked if the group differences present in the constant-ear users was also evident in the individual scores of the participants. This was not done for the alternate-ear users as they did not demonstrate any reduction in scores. After amplification, the number of constant-ear users whose speech identification scores in the non-aided ear fell below the lower bound of the confidence interval (calculated based on the pre-amplification scores) is depicted in Figure 3.2. It can be seen that the scores fell below this lower bound in 19 of the 39 individuals (49%). The 95% critical difference value was not utilized as it is derived from the mean value and not the median.



Note. The dashed line represents the lower bound of the pre-amplification scores of the constant-ear users (n = 39)

Figure 3.2. Individual post-amplification scores of non-aided ears of the constant-ear hearing aid users

3.3 Comparison of the constant-ear and alternate-ear users, before and following the use of amplification

Prior to the use of amplification, the scores of both ears of the alternate-ear and constant-ear hearing aid users were similar, as can be seen in Table 3.1. A Mann Whitney U confirmed that no significant difference existed between the scores of the constant-ear users and the alternate-ear users in their right ear (Z = 0.26, U = 366.0, $p > 0.05$, r = 0. 03) as well as left ear (Z = 0.09, U = 314.5, $p > 0.05$, r = 0.01).

Post-amplification, the scores continued to be similar between the two groups of participants when the ear in which the constant-ear users had used their device was compared with either ear of the alternate-ear users. However, the scores were poorer when non-aided ear of the constant ear user was compared with either ear of the alternate-ear hearing aid user. Mann Whitney U test revealed a significant difference (Figure 3.1) when the scores of the non-aided ear of the constant-ear users was compared with the right ear of the alternate-ear user (Z = 3.07, U = 419.0, $p < 0.01$, r = 0.35) as well as the left ear of the alternate-ear users (Z = 2.68, U = 173.0, $p < 0.01$, r = 0.31). The alternate-ear hearing aid users obtained significantly better speech identification scores when compared to the constant-ear hearing aid users.

3.4 Relation between the number of years of use of monaural amplification and decline in speech identification

The effect of the number of years of hearing aid use and speech identification scores of the non-aided ear was determined by checking their correlation as well as their significance of difference. While the correlation was measured using a Spearman's rank correlation test, the significance of difference was measured using a Wilcoxon signed-rank test. These were checked only in the constant-ear users as they demonstrated a decline in speech identification scores after the use of hearing aids and not the alternate-ear users.

The Spearman's rank correlation test indicated that there was no significant correlation (r = 0.24, $p > 0.05$) was obtained between the number of years the participants used their monaural hearing aids and the reduction in speech identification scores in their non-aided ear. Likewise, the Wilcoxon signed-rank test revealed no significant difference between the non-aided ear scores of those who used the device for 1 year and those who used it for more than 1 year [Z = 0.21, $p > 0.05$, r = 0.03]. Likewise, there was no significant difference between the non-aided ear scores of those who used the device for 2 year and those who used it for more than 2 year [Z = 0.98, $p > 0.05$, r = 0.15]. The difference was not checked between those who had used their device for a longer duration as the number of such participants was small.

3.5 Correlation between the pure-tone averages (PTA_1 & PTA_2) of the participants with the decline in speech identification scores in the non-aided.

The effect of a decline in speech identification scores in the non-aided ear on the pure-tone averages (PTA_1 & PTA_2) was checked by administering a Spearman's rank correlation. As a decline in score with the use of monaural hearing aids was observed only in the constant-ear users, their scores were analyzed and not that of the alternate-ear users. The results revealed no significant correlation between the decrease in scores and PTA_1 (r = 0.15, $p > 0.05$) as well as the decline in scores and PTA_2 (r = 0.18, $p > 0.05$) in the constant-ear group.

From the findings of the study it was observed that after amplification the speech identification scores declined in the non-aided ear of the constant-ear users. On the other hand, the scores in the alternate-ear users did not reduce significantly with the use of monaural amplification. Further, no significant correlation or difference was seen between the decline in scores in the non-aided ear of the constant-ear users and the number of years of use of monaural hearing aid. Likewise, no significant correlation was observed between the pure-tone averages (PTA_1 & PTA_2) and the decline in scores in the non-aided ear of the constant-ear users.

Discussion

The results of the study are discussed in the following subsections:

4.1 Comparison of speech identification scores within and between constant-ear and alternate-ear monaural hearing aid users,

4.2 Relation between decrease in speech identification scores post-amplification in monaural hearing aids users and covariables (duration of hearing aid use & PTA)

4.1 Comparison of speech identification scores within and between constant-ear and alternate-ear monaural hearing aid users

The findings of the study indicated that there was no significant difference between the speech identification scores of the left and right ears in the alternate-ear users before and after the use of amplification. Similarly, in the constant-ear users no significant difference between their ears was found before the use of amplification. On the contrary, they had a significant decline in scores in their non-aided ears compared to their aided ear following the use of amplification. Further, a significant improvement in the post-amplification scores compared to the pre-amplification scores occurred in those who alternated their monaural hearing aid between their ears. Likewise, after the use of amplification there was a significant improvement in scores in the aided ear of the constant-ear users, but a significant reduction in scores in their non-aided ear. Further, before the use of hearing aids, there was no significant difference between the two groups of participants. There continued to be no significant difference between the groups after amplification, when the scores of either ear of the alternate-ear users were compared with the ear in which the constant-ear users had used their hearing aid. Unlike these scores, the post-amplification scores of the two groups were significantly different when the scores of either ear of the alternate-ear users were compared with the non-aided ear of the constant-ear users.

During the face-to-face interview of the participants they reported that they opted to use monaural amplification due to cosmetic reasons or financial constraints. While they were aware of the advantages of using binaural amplification, they did not know that lack of amplification in one ear could result in deterioration in speech identification in the non-aided ear.

The significant deterioration seen in the speech identification scores of the non-aided ear of the constant-ear users can be attributed to auditory deprivation subsequent to inadequate acoustic stimulation. However, alternating a monaural hearing aid between the two ears at least once in two weeks prevented such deterioration.

The finding of the current study regarding the deterioration in scores in the non-aided ear of constant-ear users is in consensus with previous research that have reported a similar decline in the speech recognition scores of the non-aided ear in individuals who used one hearing aid in one particular ear only. Silverman and Silman (1990) reported a drop in the speech identification scores in the non-aided ear of subjects with symmetrical hearing loss who used monaural amplification. This decline was not seen in the aided ears of the participants. Similarly, Silman et al. (1992), Silverman and Emmer (1993), Hurley (1993), and Gelfand (1995) also reported significant reduction in the non-aided ears of participants consequent to the use of monaural amplification.

In the current study, the significant reduction in speech identification scores was observed only in those who constantly wore their hearing aid in one ear and not seen in those who alternated their device between their ears. This reduction was seen even in those constant-ear participants who had used their hearing aid just one year. Thus, it can be inferred that a deprivation in speech identification scores, following the use of monaural amplification, can be averted by shifting the monaural hearing aid between ears at least once in two weeks. This could result in providing adequate stimulation to both the ears, thereby avoiding either ear being deprived of acoustic stimulation, resulting in symptoms of auditory deprivation. Studies on the impact of monaural hearing aid users alternating their device between their two ears are sparse. The studies reported in literature do not provide information regarding their participants wearing their device constantly or alternating between the two ears. However, as most of the studies did find a reduction in scores in the non-aided ear, it can be inferred that the participants probably wore their device constantly in one side.

From the findings of the present study, it is recommended that individuals with symmetrical hearing loss be advised to alternate their device between their ears regularly. This should be recommended, in those who chose to use monaural hearing aids. However, they should be informed about the added advantage of using binaural hearing aids.

Further, despite the group data in the present study indicating a significant decrease in speech identification scores in the non-aided ear of constant-ear hearing aid users, their individual data indicated that the quantum of deterioration varied across participants. It was found that among the 39 constant-ear users, only 19 (49%) had scores in the non-aided ear that fell below the lower bound of the confidence interval, calculated from the pre-amplification scores. The remaining 20 participants (51%) did not demonstrate deterioration below the cut-off value. Among them, five participants (12%) showed no change in scores. This finding is in line with that of Gelfand (1995) who also reported that the use of monaural amplification can result in no deterioration to marked deterioration in the non-aided ear, after one year of use.

Thus, while counseling monaural hearing aid users, they could be informed that there is approximately 50% chance that their speech identification may reduce if they did not alternate their hearing aid between their two ears. Despite everyone not having deterioration in speech identification scores in the non-aided ear, it is still advisable that they alternate their hearing aid between their two ears. This is recommended as currently there is no biomarker to indicate who would or would not have deterioration in speech identification.

Additionally, compared to studies reported in literature regarding a reduction in speech identification scores in the non-aided ear (Gelfand, 1995; Gelfand et al., 1987; Hurley, 1999; Silman et al., 1984), the amount of decrease in scores in the present study was relatively less. The larger reduction in scores reported in studies mentioned in literature could have been due to a combination of an age-related change along with a decrease in score due to auditory deprivation. Most of the studies reported in literature have evaluated those who are above the age of 50 years (Gelfand, 1995; Gelfand et al., 1987; Schreurs & Olsen, 1985; Silman et al., 1984). It has been demonstrated that with advance in age, the likelihood of having auditory processing problems is high (Kumar & Sangamantha, 2011; Sanchez et al., 2008; Vaidyanath & Yathiraj, 2015). However, as relatively younger participants were evaluated in the current study (range = 18 to 50 years; mean = 35.4 years), the findings are probably independent of an age-related deterioration.

4.2 Relation between decrease in speech identification scores post-amplification in monaural hearing aid users and covariables (duration of hearing aid use & PTA)

The relation between the decrease in speech identification scores post-amplification in the non-aided ear of monaural hearing aid users and two different variables (number of years of device use & PTA) was conducted only in constant-ear users. The relation was checked only in them as they had a decline in speech identifications scores with the use of amplification, which was absent in the alternate-ear users.

The duration of hearing aid use was found to not have a significant correlation or a significant difference with the decline in speech identification scores. An examination of the individual data also demonstrated that a few participants who had used their monaural amplification for just one year had as much deterioration as those who had used their device for four or more years. However, those who obtained scores below the lower limit of the 95% confidence interval of the baseline evaluation, increased with an increase in the number of years of use of the device. While four individuals fell below this cut-off value after the use of the device for 1 year, the number increased to five and six after the use of the device for 2 and 3 years respectively. The number of individuals who fell below the cut-off value did not increase with a further increase in the number of years as only a limited number of participants who had used their device for four or more years were included in the study.

Similar findings was reported by Hurley (1993), who also found that the reduction in scores could commence as early as one year after the use of monaural amplification. In a subsequent article, Hurley (1999) also reported that the number of individuals who obtained scores below the 95th percentile critical difference value increased with an increase in the duration in monaural amplification. Thus, it can be construed from the studies in literature and the findings of the present study, that the number of individuals who are likely to have a decrease in scores in the non-aided will increase with an increase in number of years of use of monaural amplification.

PTA_1 *and* PTA_2, measured in the current study, were found to have no significant correlation with the reduction in speech identification scores in the non-aided ear following monaural hearing aid use. This lack of correlation indicates that the decline in scores in the non-aided ear subsequent to the use of monaural amplification was not influenced by the variations in average thresholds across the participants. Thus, it can be inferred that the decline seen in the speech identification scores of the participants of the present study were purely due to auditory deprivation following the use of monaural amplification and not on account of variations in the degree of hearing loss.

Conclusions

From the results of the present study, it can be inferred that the use of monaural amplification in individuals with symmetrical hearing loss results in a significant reduction in speech identification scores in the non-aided ear. However, the deterioration in scores can be averted by the participants alternating their monaural hearing aid between their ears at least once in two weeks.

Among those who wore their hearing aid consistently in one ear, the quantum of reduction varied from individual-to-individual. The quantum of deterioration was not affected by the number of years the monaural amplification had been used as well as the degree of hearing loss of the individuals. Thus, some of those who used their monaural hearing aid constantly in one ear for just one year had similar deterioration as those who had used it for longer periods. The reduction in scores was seen only in approximately 50% of the participants and started as early as one year after the use of monaural amplification consistently in one ear.

Implications of the study

- The study throws light on the impact of monaural amplification on speech identification scores in participants with symmetrical sensorineural hearing loss.
- The study provides information regarding the differences in performance in those who constantly use their hearing aid in one ear and those who alternate their device between their ears.
- The findings reflect the need for consistent stimulation of both the ears, even in younger adults with symmetrical hearing loss, irrespective of the degree of hearing loss.

- The information about the deterioration in speech identification scores and ways to prevent it can be used while counseling patients who prefer monaural amplification over binaural amplification.

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Appendix

Appendix 1

Demographic details of the constant-ear and alternate-ear hearing aid users

Sl.No.	Age (in years)	Gender	Type of usage	Past PTA (in dBHL)		Present PTA (in dBHL)		Duration of use (in years)
				Right ear	Left ear	Right ear	Left ear	
1	35	M	Constant; Lt	45	43.7	50	45	2
2	37	M	Constant; Rt	70	70	70	70	4
3	43	M	Constant; Lt	66.25	62.5	70	63.5	1
4	43	M	Constant; Rt	60	53.75	65	62.75	1
5	31	F	Constant; Lt	52.5	53.75	53.7	56.2	2
6	33	F	Constant; Rt	67.5	55	70	70	6
7	39	M	Constant; Rt	50	45	55	50	2
8	25	F	Constant; Rt	58.3	56.6	57.5	60	7
9	39	M	Constant; Rt	46.25	42.5	50	45	3
10	36	F	Constant; Lt	48.75	52.5	55	50	3
11	21	M	Constant; Rt	61.25	57.5	60	65	2
12	23	F	Constant; Rt	62.5	66.25	58.75	63.75	5
13	45	M	Constant; Rt	48.75	53.75	55	55	1
14	32	M	Constant; Rt	63.3	61.6	63.75	62.5	9
15	24	M	Constant; Lt	65	66.25	60	63.75	1
16	27	F	Constant; Rt	40	40	35	40	2
17	37	F	Constant; Lt	61.25	60	60	65	1
18	38	M	Constant; Lt	66.25	68.25	65	70	2
19	48	M	Constant; Rt	52.5	42.5	45	55	3
20	42	M	Constant; Lt	57.5	68.25	55	65	4
21	40	F	Constant; Rt	50	55	46.25	50	1
22	36	M	Constant; Lt	66.25	63.75	68.25	68.75	2
23	39	M	Constant; Lt	46.25	48.75	45	50	3
24	49	M	Constant; Rt	45	42.5	45	45	2
25	20	M	Constant; Lt	63.75	70	65	65	2
26	22	F	Constant; Rt	45	41.25	45	45	2
27	39	F	Constant; Rt	45	52.5	45	55	4
28	27	M	Constant; Lt	48.3	41.6	50	45	1
29	50	M	Constant; Rt	66.25	67.5	70	75	2
30	30	M	Constant; Lt	61.25	60	65	60	2
31	39	M	Constant; Lt	46.25	42.5	45	50	5
32	42	M	Constant; Rt	56.6	58.75	60	65	3
33	34	M	Constant; Lt	50	52.5	55	50	3
34	34	F	Constant; Rt	51.25	50	50	50	1
35	50	F	Constant; Lt	56.25	56.25	60	60	3

36	34	F	Constant; Rt	66.25	63.75	65	65	1
37	33	M	Constant; Rt	50	50	55	60	2
38	33	M	Constant; Lt	46.2	55	50	50	2
39	44	M	Constant; Lt	46.25	48.75	45	50	3
40	28	M	Alternate	65	62.5	66.25	58.7	1
41	37	M	Alternate	53.3	65	60	61.25	2
42	25	M	Alternate	56.6	55	63.3	55	7
43	28	M	Alternate	65	65	67.5	70	2
44	38	M	Alternate	66.6	58.3	58.3	56.6	4
45	42	M	Alternate	68.7	62.5	70	70	1
46	32	M	Alternate	68.75	60	63.75	65	1
47	42	M	Alternate	57.5	60	60	53.75	3
48	25	F	Alternate	65	68.3	70	65	8
49	18	M	Alternate	70	70	70	71.25	2
50	20	M	Alternate	55	52.5	50	48.75	2
51	47	F	Alternate	55	52.5	58.25	51.25	2
52	24	M	Alternate	65	57.5	65	61.25	2
53	41	M	Alternate	46.25	52.5	46.25	52.25	2
54	23	M	Alternate	46.25	50	45	50	2
55	45	M	Alternate	60	58.75	60	63.75	2
56	47	F	Alternate	68.75	67.5	66.25	63.75	1
57	39	F	Alternate	47.5	53.75	50	55	1
58	26	F	Alternate	68.75	66.25	66.25	63.75	1
59	26	F	Alternate	55	51.25	55	55	2
60	23	F	Alternate	66.5	65	65	65	2
61	49	F	Alternate	61.25	58.75	65	60	2
62	46	M	Alternate	47.5	46.25	45	50	2
63	48	M	Alternate	51.25	55	55	60	3
64	25	F	Alternate	66.25	66.25	70	65	2
65	33	M	Alternate	58.75	60	60	65	1
66	24	M	Alternate	62.5	65	65	70	2
67	41	M	Alternate	47.5	45	45	50	2
68	32	F	Alternate	58.3	58.75	60	58.3	3
69	40	M	Alternate	47.5	45	50	50	5
70	50	F	Alternate	55	55	60	60	1
71	49	F	Alternate	51.25	52.5	53.75	53.75	2
72	36	M	Alternate	55	50	55	55	5
73	31	M	Alternate	57.5	60	55	65	2
74	50	F	Alternate	45	46.25	45	50	1

Appendix 2

Speech Identification in the Non-Aided Ear in Monaural Hearing Aid Users

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ABSTRACT

Introduction: Binaural amplification has been reported to be more beneficial than monaural amplification. The advantages include better word recognition scores for binaural hearing aid users (Feuerstein, 1992; McKenzie & Rice, 1990), better subjective rating of sound clarity (Balfour & Hawkins, 1992; McKenzie & Rice, 1990) and significant improvement in patients with tinnitus (Brooks & Bulmer, 1981). It has also been reported that auditory deprivation occurs in individuals who use monaural amplification for an extended period of time. It was demonstrated by Silverman and Silman (1990) that the unaided ear of two monaurally fitted individuals had marked decrement in word identification scores after an extended period of time. This decrement was not observed in the aided ear. However, Azevedo, Santos, and Costa (2015) reported no major differences in performance between monaural and binaural hearing aid users.

Need for the study: Although binaural amplification offers various benefits, individuals with symmetrical hearing loss may not be able to make use of it due to certain financial or cosmetic constraints. Therefore, they choose to use monaural amplification, which may lead to auditory deprivation in the non-aided ear over time. In literature there is no consensus regarding the adverse effect of using monaural amplification for an extended period of time. Hence, there is a need to confirm whether the use of a monaural amplification affects speech identification in the ear with no amplification.

Aims: The study aimed to compare the speech identification scores of hearing aid users before and after the use of monaural amplification for at least one year, in the aided as well as unaided ear. The study also aimed to compare the two ears before and after monaural amplification and investigate the differences in performance in those who consistently use the device in one ear with those who alternate the device between their ears.

Methods: Sixty adults, aged 18 to 50 years, with bilateral acquired symmetrical sensorineural hearing loss (pure-tone averages ranging from 30 dB HL to 70 dB HL) were evaluated. Among them, 30 individuals consistently used the hearing aid in one ear and 30 alternated the hearing aid between the two ears at regular intervals. They should have used their device for at least one year regularly and not have any history of middle ear problems.

Information regarding their hearing thresholds and pre-amplification speech identification scores, measured at the time of prescribing the hearing aid, were obtained from the case records of the participants. They were tested to determine their current speech identification scores using phonemically balanced words developed by Yathiraj and Vijayalakshmi (2005) and Yathiraj and Muthuselvi (2009) respectively. The testing was carried out in a sound-treated suite that met ANSI standards S3.1-1999 (R2013). Informed consent was obtained from all participants, adhering to the guidelines of the institute.

Results and Discussion: Non-parametric statistics was used as the data were not normally distributed, as indicated by Shapiro Wilks test of normality. Prior to the use of amplification the mean and median speech identification scores were similar between the left and right ears in both participant groups. However, after the use of the hearing aid, the scores were better in those who alternated the hearing aids between the two ears compared to those who consistently used their hearing aid in one ear.

Comparison of the scores prior to and after the use of monaural amplification was done in the consistent-ear users as well as the alternate-ear users using a Wilcoxon signed-rank test. Significant improvement in scores was seen in the speech identification scores before and after the use of amplification in the alternate-ear users in their right ear [Z = 2.53, $p < 0.05$] and left ear [Z = 2.98, $p < 0.05$]. Likewise, a significant improvement in scores was seen in the aided ear of the consistent-ear users [Z = 3.97, $p < 0.001$]. However, a significant decrease was observed in their non-aided ear [Z = 2.38, $p < 0.05$].

Comparison of the scores in the aided and the non-aided ear was evaluated using Wilcoxon signed-rank test. This was done before the use of amplification and after the use of amplification. Prior to the use of amplification, no significant difference was seen between their two ears [Z = 5.93, $p > 0.05$]. In contrast, following the use of amplification, the speech identification scores between the aided and non-aided ear was significantly different in the consistent-ear users [Z = 4.25, $p < 0.001$], with it being poorer in the non-aided ear. However, it was not significantly different in the alternate-ear users [Z = 6.32, $p > 0.05$]. The reduction in performance in the non-aided ear can be attributed to auditory deprivation in those who consistently used the device only in one ear.

Comparison of the consistent-ear and alternate-ear users, following the use of amplification, calculated using Mann Whitney U test, revealed a significant difference between the two groups in the right ear [Z = -2.02, U = 315.0, $p < 0.05$] and left ear [Z = -2.62, U = 274.0, $p < 0.01$]. The alternate-ear hearing aid users obtained significantly better speech identification scores when compared to consistent-ear hearing aid users. Thus, it can be construed that auditory deprivation can be prevented by the user alternating their hearing aid between the two ears.

Summary and Conclusion:

The findings of the study indicate that consistently not using hearing aids in an ear can result in degradation in speech identification scores in that ear. This reduction in speech identification can be ascribed to auditory deprivation. Alternating the hearing aid between the two ears can mitigate this deterioration. Thus, it is recommended that those who cannot afford to purchase binaural hearing aids should alternate their monaural hearing aid between the two ears. This can be done provided they have symmetrical hearing loss.

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Appendix 3

Effect of Duration of Monaural Amplification on the Speech Identification Scores of the Non-Aided Ear

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Introduction

Binaural amplification in individuals with symmetrical sensorineural hearing loss has been reported to bring about significant benefit in speech identification. [1] In line with the earlier studies, Köbler, Rosenhall [2] reported of participants with bilateral symmetrical mild to moderately-severe sensorineural hearing loss having a high preference for binaural amplification over monaural fitting. However, one-third of the subjects preferred only one hearing aid, which was attributed to ear asymmetry.

Likewise, Noble and Gatehouse [3] noted a significant difference between the responses of unilateral and bilateral hearing aid users on the Speech, Spatial, and Qualities of Hearing scale. The subjects reported more benefit with two devices for directional hearing and movement discrimination than with a single device. However, unilateral amplification was noted to assist in one-to-one conversation. Apart from the advantages in challenging situations, Kim, Lee [4] observed that their binaural amplification users had significantly greater acceptance of noise compared to the monaural amplification users. This was observed on a task that assessed acceptable noise levels.

Although binaural amplification has several advantages, not everyone who requires them chooses to wear two hearing aids, as noted in the above literature. In monaural hearing aid users, studies have demonstrated the existence of auditory deprivation in their non-aided ear. Silverman and Emmer [5] observed that word scores dropped in the non-aided ear of the six monaural hearing aid users they studied. Additionally, they reported of a recovery in two out of the six subjects after the use of binaural amplification, but made no mention of the duration of the deprivation or the quantum of recovery.

The effect of the duration of use of monaural amplification on the reduction of speech identification scores in the non-aided ear has also been studied. Gelfand, Silman [6] reported that auditory deprivation occurred in the non-aided ear of monaural hearing aid users. This reduction of word scores was seen in the non-aided ear after four years or more use of monaural amplification. Hurley [7] also noted that their nine subjects fitted with monaural amplification had a steady decline in speech recognition scores in the non-aided ear. This reduction in scores was observed as early as one year after post fitting or as late as 5 years after the initial monaural fitting. Likewise, Silverman and Silman [8] reported of a decline in word identification scores in the non-aided ear after 22 months of use of monaural amplification in two individuals. With the use of binaural amplification for approximately 2 years, this deprivation recovered partly in one and completely in the other.

Similarly, it was noted by Gelfand [9] that their six subjects with bilateral symmetrical sensorineural hearing loss had significant auditory deprivation. However, the poorer performance in the non-aided ear was observed within 2 years of use of monaural amplification, with it occurring as early as 6 months in one participant. The decrease in speech recognition scores of the non-aided ear ranged from 14% to 48%. Two of the subjects exhibited a delayed onset of auditory deprivation that commenced after 6 years in one and 11 years in the other. While complete recovery was seen after just 10 months of consecutive binaural amplification in two subjects, two had incomplete recovery even after several years of binaural amplification. The other two participants who had delayed onset of deprivation, failed to recover from even after years of binaural fitting.

In an attempt to describe the long term effect of auditory deprivation, Boothroyd [10] described a single case with congenital bilateral sensorineural hearing loss who used a monaural hearing aid for 14 years. Slow recovery was seen in the thresholds of the non-aided ear after 2 years of binaural amplification.

More recently, it was observed by Cohen and Svirsky [11] that auditory deprivation in single sided deafness may have a deleterious effect on central auditory processing. Their observation was based on a systematic review on the relationship between the duration of single sided deafness and speech outcomes after cochlear implantation. The duration of unilateral deafness had a significant negative effect on the outcome with cochlear implant.

From the review of literature, it can be observed that the non-aided ear of monaural hearing aid users tends to exhibit auditory deprivation. The deterioration was found to commence as early as 6 months and was seen to be present in those using the device up to 15 years. However, the studies report of considerable variation as to how early the deterioration could start. Also, it has not been studied whether the quantum of deprivation in the non-aided ear varies as a function of the duration of use of monaural amplification.

Further, several of the earlier studies on the deterioration in speech identification in the non-aided ear of monaural hearing aid users have been conducted on adults aged 50 and above. [6, 9, 12-14] It is known that with advance in age, the probability of having auditory processing problems increases. [15-17]

Thus, the findings of studies reporting deterioration in the non-aided ear may be confounded with age related problems. This may mitigate the actual effect of auditory deprivation. Hence, to understand the true effect of auditory deprivation in the non-aided ear, younger adults with bilateral symmetrical hearing loss need to be studied. Additionally, most of the studies have small sample sizes, thereby making it difficult to generalize their conclusions to the general population. Hence, studying a larger group of individuals using monaural amplification requires to be done. Thus, the present study aimed to examine the effect of the number of years of monaural hearing aid use on the speech identification scores of the non-aided ear. The study also aimed to compare the speech identification scores before and after the use of monaural amplification, separately in the aided and the unaided ear as well as between the two ears before and after monaural amplification.

Methods

The study was carried out using a pre-post design. Using a purposive sampling technique, speech identification of adults using monaural amplification was evaluated before and after the use of monaural amplification, in the aided ear as well as the non-aided ear. Information regarding the number of years of monaural hearing aid use was also obtained.

Participants

Thirty-nine adults, aged 18 to 50 years (mean age = 35.4 years) and diagnosed to have bilateral mild to severe acquired symmetrical sensorineural hearing loss (pure-tone averages = 30 dB HL to 70 dB HL) were studied. Among them 26 were males and 13 were females. It was ensured that they had bilateral stable hearing loss that had not changed over a period of four to five years. This was ascertained from the audiological findings maintained in their case files. The participants were required to have used digital behind-the-ear hearing aids prescribed by qualified audiologists for durations greater than one year. The participants selected used their device ranging from 1 to 9 years. Only those who did not alternate the device between the two ears were selected. None of them had any history of middle ear problems or any speech and language problems. All the participants had at least secondary school education with the language of instruction being either Indian-English or Kannada.

Equipment

Pure-tone and speech audiometry testing were conducted using a calibrated dual-channel audiometer (Inventis Piano), with TDH-39 headphones, B-71 bone vibrator and facility to route recorded audio signals through an auxiliary input. Immittance evaluation was done with a GSI tympstar immittance meter to rule out conductive component.

Test Environment

All the audiological tests were carried out in an acoustically treated suite that met the specification of ANSI S3.1-1999 (R2013). The testing suites had optimum temperature and lighting and were free of any type of distractions.

Material

Speech recognition thresholds were measured using CID-22 spondaic words [18] or paired Kannada words developed in the Department of Audiology, All India Institute of Speech and Hearing. Speech identification was evaluated using phonemically balanced words developed by Yathiraj and Vijayalakshmi [19], when testing Kannada speakers or by Yathiraj and Muthuselvi [20], when testing Indian-English speakers.

Procedure

Informed consent was obtained from the participants, adhering to the guidelines of the institute. Participants who met the inclusion criteria were subjected to a face-to-face interview to obtain their case history, especially regarding their hearing aid usage. This included information regarding any variations in hearing abilities after the onset of hearing loss; the type of hearing aid used; duration of hearing aid use; number of times they changed the devices utilised by them; and whether they used their hearing aid constantly in one ear or alternated between their two ears. From the case files of the participants, maintained in the institute's official records, the following were noted regarding the evaluations don at the time of hearing aid prescription: Information pertaining to their hearing thresholds; immittance findings; and the unaided speech identification scores for each ear, measured under headphones.

The participants who met the inclusion criteria were subjected to basic audiological testing. The pure-tone air conduction and bone conduction thresholds were measured using the procedure given by Hughson and Westlake [21]. The air conduction and bone conduction thresholds were evaluated at octave frequencies between 250 Hz to 8 kHz and 250 Hz to 4 kHz, respectively. Additionally, their middle ear function was tested using a calibrated immittance meter. Tympanogram was measured using a standard 256 Hz probe-tone. The ipsilateral and contralateral acoustic reflexes were obtained at 500 Hz, 1 kHz, 2 kHz, and 4 kHz in both the ears. The participants were subjected to further evaluation only if their pure-tone and immittance findings did not alter from the baseline evaluation carried out at the time of hearing aid prescription. Speech recognition threshold and speech identification were measured for each ear independently. The participants were tested in Kannada or Indian-English depending on the language that they had been tested earlier. It was ensured that they had been evaluated on the same test earlier, based on the information available in the case files.

The stimuli were presented at 40 dB SL (Ref. SRT) or at a lower level, if restricted by their hearing level. The participants were instructed to listen to the stimuli carefully and to repeat the words heard by them. The scores from the previous evaluations were tabulated along with the speech identification scores from the present evaluation. The duration that they had used their hearing aid constantly in one ear was also noted.

Analyses

The data obtained from the case files and from the evaluations carried out on the participants were statistically analysed using SPSS (Version 20) software. Shapiro Wilks test of normality indicated that the data were not normally distributed. Hence, non-parametric statistical tests were conducted.

Results

The comparison of the scores prior to and after the use of monaural amplification is provided along with the comparison of the scores in the aided and the non-aided ear. Additionally, the correlation between the number of years of hearing aid use and the speech identification scores of the non-aided ear are also provided.

The mean and median speech identification scores were similar in the left and right ears, prior to the use of amplification. However, after the use of the hearing aid, the scores were better in the aided ear compared to the non-aided ears of all the participants (Table 1 & Figure 1).

Prior to analysing the impact of duration of monaural amplification on speech identification scores of the non-aided ear, the scores before and after the use of monaural amplification were analyzed separately in each ear. Additionally, the score of the two ears were compared before and after monaural amplification.

Comparison of the scores prior to and after the use of monaural amplification was done using a Wilcoxon signed-rank test (Figure 1). Significant improvement in speech identification scores was seen after the use of amplification in the ear in which the hearing aid was used [Z = 4.75, $p < 0.01$]. However, a significant decrease in scores was observed in their non-aided ear [Z = 2.49, $p < 0.05$].

Comparison of the scores in the aided and the non-aided ear was also evaluated using Wilcoxon signed-rank test. This was done before the use of amplification and after the use of amplification. Before the use of amplification, no significant difference was seen between their two ears [Z = 1.32, $p > 0.05$]. In contrast, following the use of amplification, the speech identification scores were significantly poorer in the non-aided ear compared to the aided ear [Z = 4.63, $p < 0.001$].

Effect of the number of years of hearing aid use and speech identification scores of the non-aided ear was determined by check the correlation as well as the significance of difference. A Spearman's correlation, done between the number of years of hearing aid use and the speech identification scores of the non-aided ear, was not significant (r = 0.24, p > 0.05). Further, a Wilcoxon signed-rank test also indicated no significant difference in the unaided ear scores between those who used the device for 1 year compared to those who used it for more than 1 year [Z = 0.21, $p > 0.05$].

Discussion

The results indicated that monaural amplification resulted in a marked decline in speech identification scores in the non-aided ear. These findings are in consonance with the findings of Boothroyd [10] and Hurley [7], who also observed a significant decrement in speech identification scores in the non-aided ear. Thus, the use of monaural amplification, constantly in one ear, can result in auditory deprivation, resulting in poorer speech identification in the non-aided ear. This may be attributed to the modifications in experience-related reorganization within the central nervous system due to auditory deprivation. Studies have also provided electrophysiological evidence regarding the cortical reorganization due to changes in acoustic environments. [22, 23]

Further, in the current study, the duration of use of a monaural hearing aid did not have a significant correlation with the speech identification scores obtained in the non-aided ear. However, on examination of the individual scores obtained by the participants in their non-aided ear, it was observed that a few participants who had used their monaural amplification for just two years had as much deterioration as those who had used the device for longer durations. Thus, just one year of not using amplification in an ear resulted in almost similar deterioration in speech identification as seen in those who had deprivation for longer durations. This finding are in consonance with the findings of Hurley [7] who also found that the reduction in scores could commence as early as one year post fitting of monaural amplification.

Although the speech identification scores of the non-aided ear decreased significantly, not all individual showed a marked reduction in scores. Five of the 39 participants showed no change in speech identification scores in their non-aided ear. This indicates that the quantum of deterioration varies across participants. However, this variation in scores in the non-aided ear did not depend on the number of years of use, as mentioned earlier. This finding was in line with that of Gelfand [9] who reported that the commencement of deterioration varied across the participants. Thus, it can be construed the use of monaural amplification can result in no deterioration in the non-aided ear to marked deterioration, after one year of use.

The findings also indicate that although the participants studied were relatively young adults aged 18 to 50 years, auditory deprivation did occur. However, compared to studies mentioned in literature [9, 12, 24], the quantum of reduction in speech identification scores in the non-aided ear of monaural hearing aid users of the present study was relatively less. It is highly likely that the findings of the studies reported in literature were influenced with age-related deterioration, which was not present in the current study as most of the participants (n = 30) were below the age of 40 years. Thus, the findings of the current study can be attributed purely to auditory deprivation and not due the compounding effect of age-related changes.

To prevent deterioration in speech perception due to the use of monaural amplification constantly in one ear, it is ideal that individuals with bilateral hearing loss use binaural amplification. However, for those who do not wish to use binaural amplification, either due to personal preferences or due to financial constraints, alternating the device between the two ears is recommended. Such alternating has been found to retard such deprivation [25].

Conclusions

The current study demonstrated that consequent to auditory deprivation, the non-aided ear of individuals using monaural hearing aids had a reduction of speech identification scores. The study also highlights that such deterioration can occur even in young adults after just one year of deprivation. This reduction in scores was seen in most of the participants, with the quantum of reduction varying across them. While it is ideal that those with bilateral hearing loss to used binaural hearing aids, for those who prefer to use monaural amplification or cannot afford to purchase two devices it is recommended that they alternate the device between their two ears. This is recommended, provided the hearing aid settings are similar in the two ears. Further, the influence of degree of hearing loss on auditory deprivation in monaural hearing aid users needs to be studied.

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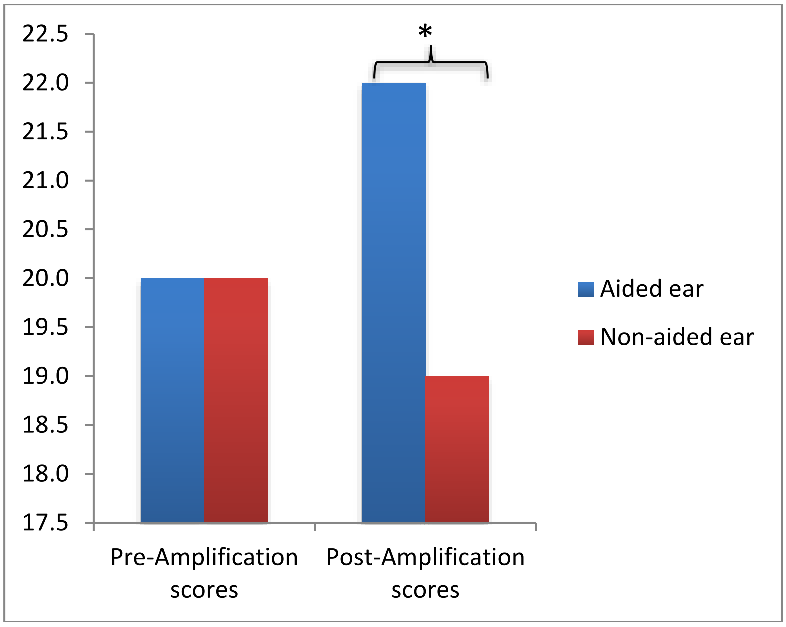
Tables and Figures

Table 1: *Mean, Median, Standard deviation (SD) and 95% confidence interval (CI)) of the speech identification scores prior to and after monaural amplification in the aided and non-aided ears.*

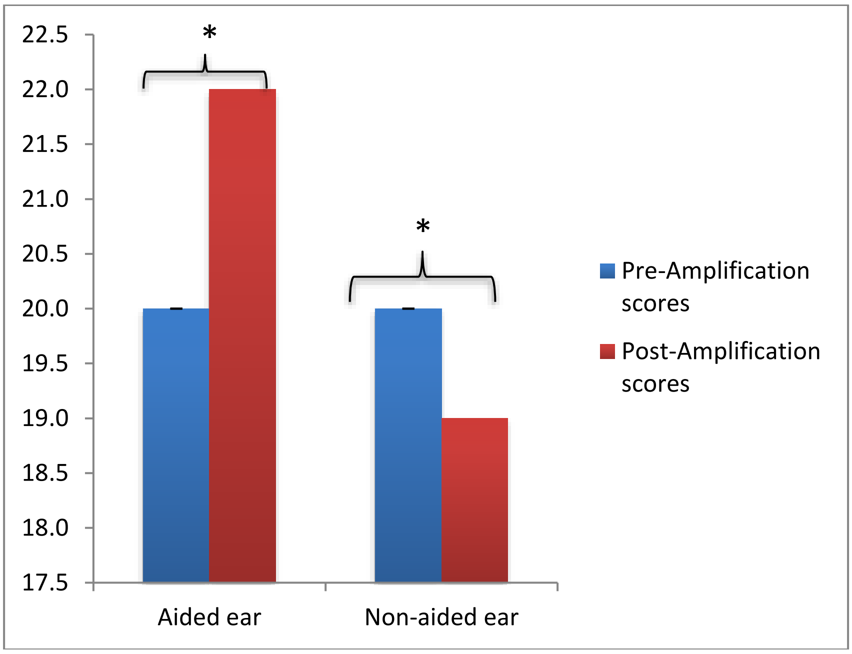
Parameter	Aided ear scores		Non-aided ear scores	
	Pre amplification	Post amplification	Pre amplification	Post amplification
Mean	19.84	21.61	20.1	19.58
Median	20.00	22.00	20.00	20.00
SD	2.2	1.59	1.96	1.94
95% CI	19.12 - 20.56	21.09 - 22.13	19.49 - 20.76	18.95 - 20.21

Note. Maximum possible total word score = 25



Note. * = $p < 0.05$

Figure 1. Median speech identification scores of the aided and non-aided ear prior to and after the use of monaural amplification



Note. * = $p < 0.05$

Figure 2. Median speech identification scores prior to and after the use of monaural amplification in the aided and non-aided ears