Benefits of Binaural Amplification in Participants with Asymmetric Hearing Impairment

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Abstract

Binaural hearing involves the integration of signals from each of the two ears into a single hearing sensation. The advantages of loudness summation, localization and discrimination enhancement especially in noise are a result of this binaural hearing process. However, when the signals to each ear are disproportionate with each other in an individual with hearing impairment, binaural integration process is less effective and binaural advantages are correspondingly diminished or even lost (Davis & Haggard, 1982). The present study was undertaken to assess the benefits of binaural amplification over monaural amplification in individuals with sensorineural hearing loss with various degrees of asymmetry. Twenty-two individuals with post-lingually acquired bilateral sensorineural hearing loss served as participants in this study. The participants were assigned to one of the three groups based on the degree of hearing loss in the ears. The most comfortable levels (MCL), speech recognition scores (SRS) and speech recognition threshold in noise (SRT) were established for each participant in the three-aided conditions- amplification to the better ear, to the poorer ear and to both ears. It was observed that lowest MCL was obtained in the binaural amplification condition compared to the monaural amplification condition in all three groups of participants. For speech recognition in quiet, it was found that providing binaural amplification did not result in significant improvement over monaural amplification for participants with bilateral symmetric hearing loss. In participants with asymmetric hearing loss (Groups II & III), providing binaural amplification resulted in improved speech recognition performance compared to monaural amplification either to better or poorer ear. It was observed that the participants obtained higher speech recognition threshold in noise (SNR) with binaural amplification than with monaural amplification condition.

Key words: Most comfortable levels (MCL), speech recognition scores (SRS), speech recognition threshold in noise (SNR)

Introduction

The loss of hearing ability characterized by decreased sensitivity to sound in comparison to normal hearing is termed as hearing loss (Silman and Silverman, 1991). Hearing loss is measured by the amount of loss in terms of decibels (dB) hearing level (HL). The magnitude of hearing loss can be equal (symmetric) in both the ears or unequal (asymmetric). Symmetric hearing loss refers to a difference of less than 15 dB in the pure tone average and less than 8% difference in the speech recognition scores between ears (Markides, 1977). Asymmetric hearing loss implies a difference of greater than 15 dB between the two ears regardless of the magnitude of hearing loss (Valente, 1994).

Asymmetric hearing impairment can be defined as interaural differences in threshold sensitivity. A working definition of asymmetric hearing loss, relative to the application of hearing aids, would be that an asymmetrical hearing loss implies a

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significant difference between ears. Regardless of the magnitude of asymmetry, use of amplification must improve hearing performance so that it can be verified by objective and subjective evaluations. Such differences can be expressed in terms of pure tone threshold, most comfortable listening levels, word recognition scores, loudness growth compensation, and positive response to amplified sound in everyday listening environments (Valente, 1994).

Individuals with asymmetric losses have been the participants of many studies in which the researchers have concluded that, because binaural redundancy advantage tends to decrease as the average threshold differences of the two ears increase, these individuals may not benefit as much from a binaural fitting. However, there are certainly other physical acoustic factors (e.g. head shadow effect) and auditory processing factors (e.g., squelch) that can contribute to audition and speech understanding in noise.

Studies have also shown that the loudness levels depend on the degree of hearing loss. Speech recognition abilities are adversely affected in individuals having sensorineural hearing impairment. The amount of degradation in the speech recognition abilities in quiet and in noise condition depends upon the degree of hearing impairment in these individuals (Sandlin, 2000). Many studies have reported a lack of amplification in adults with asymmetric sensorineural hearing impairment that leads to auditory deprivation (Arlinger, Gatehouse & Bentler, 1996).

Thus, it is evident that speech recognition abilities in an individual with hearing impairment might depend upon the amplification condition. However, there is a dearth in literature regarding the comparison of aided MCL, speech recognition scores and speech recognition threshold in noise in different amplification conditions in individuals with symmetrical and asymmetrical hearing impairment.

Need for the Study

It is evident that there are equivocal reports on the efficacy of binaural amplification in individuals with asymmetric hearing loss. Also, there is a dearth of studies in literature regarding the effect of degree of asymmetry on monaural and/or binaural amplification. Hence, the present study was undertaken to assess the benefits of binaural amplification over monaural amplification in individuals with sensorineural hearing loss with various degrees of asymmetry.

Objectives of the Study

The following objectives were evaluated in participants with bilateral sensorineural hearing loss of different degrees of asymmetry:

1. To compare the Most Comfortable loudness Level (MCL) with monaural and binaural amplification conditions.

2. To compare the Speech Recognition Scores (SRS) with monaural and binaural amplification conditions.
3. To compare the Speech Recognition in Threshold in Noise, in terms of signal to noise ratio (SNR), with monaural and binaural amplification conditions.
4. To assess the effect of asymmetry in aided monaural Most Comfortable Levels (MCL) between the two ears on Speech Recognition Scores in binaural amplification condition.
5. To assess the effect of asymmetry in aided monaural Most Comfortable Levels (MCL) between the two ears on Speech Recognition in Threshold in Noise in terms of signal to noise ratio (SNR) in binaural amplification condition.

Method

To evaluate the effect of different amplification conditions on MCL, SRS and SNR, the following procedures were administered.

Participants

Twenty-two individuals with post-lingually acquired bilateral sensorineural hearing loss served as participants in this study. The age range of the participants varied from 18 to 60 years (mean age = 48.6 years). All participants were naïve hearing aid users. All participants had Kannada as their native language. The participants had mild to severe degree of hearing loss with flat audiometric configuration, a slope of ≤ 5 dB rise or fall per octave (Lloyd & Kaplan, 1978). The speech recognition score was ≥ 60% in the both ears with the difference between the ears ranging from 5% to 40%.

The participants were assigned to one of the following three groups based on the degree of hearing loss in the ears.

1. Group I with participants having symmetrical sensorineural hearing loss (S-SN): Eight participants were included in this group. The inclusion criterion for participants in this group was that the difference between the pure tone average (PTA for 500 Hz, 1000 Hz, and 2000 Hz) of the right and left ears was within 15 dB.

2. Group II with participants having a lesser extent of asymmetrical sensorineural hearing loss (A-SN I): Seven participants were included in this group. The inclusion criterion for participants in this group was that the difference in the PTA of the right and left ears was between 16 dB and 25 dB.

3. Group III with participants having a greater extent asymmetrical sensorineural hearing loss (A-SN II): Seven participants were included in this group. The inclusion criterion for participants in this group was that the difference in the PTA of the right and left ears was between 26 dB and 35 dB.

Instrumentation

A calibrated two channel diagnostic audiometer with sound field-testing facility was used. A computer connected to the auxiliary input of the audiometer to administer the speech recognition tasks. A HiPro interface unit, personal computer (PC) with NOAH-3 and hearing aid programming softwares were also used. In addition, digital behind-the-ear (BTE) hearing aids with a fitting range from mild to severe degree of hearing loss was used. The hearing aids had single channel, single band and were programmable.

Speech Material

A bi-syllabic phonemically balanced word lists in Kannada (Yathiraj & Vijayalakshmi, 2006) was used. The test material was recorded in a female voice on a CD. It consisted of eight lists with 25 words each. In addition, a word list in Kannada for measurement of SNR (Sahgal, 2005). The list was recorded in male voice on a CD. The word list consisted 40 sets of words. Each set had three words with a combination of low-mid, low-high and high-mid frequency speech sounds. A passage in Kannada (Sairam, 2002) was used. The passage was recorded in a male voice with normal effort on a CD.

Procedure

The testing was carried out in a sound treated double-room set-up with the ambient noise levels within permissible limits. The MCL, SRS and speech recognition threshold in noise, in terms of SNR, were established for each participant in the three aided conditions. The three aided conditions were amplification to the better ear, amplification to the poorer ear and binaural amplification. In case of symmetric hearing loss, since both ears had similar audiometric thresholds, monaural amplification to the individual ears (right and left) and binaural amplification formed the three aided conditions.

The speech material was played through a computer connected to auxiliary input of the audiometer. Before the presentation of the stimuli, the level of presentation was monitored with a calibration tone. During the presentation of the stimuli also, it was ensured that the mean deflection of VU-meter of the audiometer was about 0 dB. For the speech recognition tasks participants were instructed to repeat the speech stimuli heard. For speech recognition tasks and establishment of most comfortable levels, the speech stimuli were presented through a loudspeaker located at 0° Azimuth at a distance of one meter in front of the participant. The speaker Azimuth and distance remained the same for all the three tasks. The speech and noise were routed through the same speaker. To evaluate the objectives of the study, the data were collected in the following two phases.

Phase I

In the first phase of the study, hearing aid fitting and establishment of most comfortable levels were carried out.

1. Hearing Aid Fitting

Each participant was fitted with a single channel programmable digital behind-the-ear (BTE) hearing aid in each ear. The hearing aids were programmed using a PC and a HiPro interface unit using the NAOH and the hearing aid software. For each participant the hearing aid was programmed according to the 'first fit' using the generic NAL-NL1 formula. The right and the left hearing aids were programmed separately and binaural balancing was done. The establishment of Most Comfortable Level (MCL) and speech recognition tasks was carried out with the programmed hearing aid, which the participant wore with an appropriately sized standard ear tip during the test.

2 Aided Most Comfortable Level (MCL)

For each participant the MCLs were established for each ear separately in the aided condition only. The MCLs were established in three aided conditions, two monaural (right ear aided and left ear aided) and one binaural condition. In each aided condition, the participant was instructed to rate the loudness of a recorded Kannada passage being presented based on the seven-point rating scale (Cox, 1995) – very soft, soft, comfortable but slightly soft, **comfortable**, comfortable but slightly loud, loud but okay and uncomfortably loud. The recorded passage was presented in sound filed condition. The initial presentation level (PL) of the passage was 10 dB SL (re: aided speech reception threshold). The level of the recorded passage was increased in 2 dB steps if the participant judged the loudness to be below comfortable level and decreased in 4 dB steps if loudness was judged to be above comfortable level. The monaural MCL was noted down for each ear separately. In participants with asymmetrical hearing loss, the non-test better ear was masked to avoid its participation in the monaural testing of the poorer ear by providing broadband noise at 70 dB SPL through the insert earphone. The binaural MCLs were also established with hearing aids to both ears using a similar procedure with the initial presentation level being 10 dB SL (re: aided speech reception threshold of the better ear).

Phase II

In the second phase of the study, two speech recognition tasks were administered, one in quiet and the other in the presence of noise:

1. Aided speech recognition scores (SRS)
2. Aided speech recognition threshold in noise in terms of Signal to noise ratio (SNR).

1. Aided Speech Recognition Scores

The speech recognition score (SRS) gives an indication of the ability of the individual to discriminate different speech sounds (Moore, 1998). In the present study, aided SRS were measured using recorded (phonemically balanced) speech material in Kannada (Yathiraj and Vijayalakshmi, 2005) in the sound field condition. The presentation level (PL) of speech stimuli was fixed at 35 dB HL if the hearing loss in either one or both ears was of mild degree and the level was set to 40 dB HL otherwise. The right and left ear of each participant was aided with appropriately programmed digital BTE hearing aids. The SRSs were measured in each of the above mentioned amplification conditions.

The aided SRS in each of the above mentioned aided conditions were measured by presenting one complete word-list of 25 words for each condition. The participants were instructed to repeat the words being presented. If the participant correctly repeated the word, then a score of '1' was given, and if not, a score of '0' was given. The total number of words correctly repeated in the list was noted for each condition. This was considered as the speech recognition score of the participant for the respective aided condition. Therefore, each participant had three SR scores, one for each aided condition.

2. Aided Speech Recognition Threshold in Noise (SNR)

One of the advantages of binaural hearing aids is that it improves speech perception in the presence of noise. For the aided Speech Recognition Threshold (SRT) in Noise, the signal to noise ratio (SNR) associated with 50% recognition performance was measured.

For the purpose of the study, signal to noise ratio (SNR) is defined as the difference between the intensity of recorded speech material and the intensity of the competing speech-shaped noise in dB when the individual correctly repeats two or more than two words in a set of three words being presented in the presence of competing speech babble.

The SNR was measured in a sound-field condition using the recorded Kannada word list developed by Sahgal (2005). The speech material and speech shaped noise were routed through the same speaker. The presentation level of the word list was fixed at 44 dB HL and the initial level of the speech noise was set at 16 dB below the speech signal and varied systematically to measure the SNR. The participant was instructed to repeat the words heard in presence of competing speech shaped noise. The participant was presented a set of 3 words at each level of noise. If the participant correctly repeated at least 2 words out of 3, then the level of noise was increased by 4 dB and if the participant failed to repeat at least 2 words, the level of noise was decreased in 2 dB steps till the participant repeated at least 2 out of 3 words. Further, the level of noise was increased in 1 dB steps till the participant repeated at least 2 out of 3 words. At this point, the difference between the intensity of speech and competing speech-shaped noise in dB was considered as the SNR.

The SNR was measured in all the three aided conditions using the above-described procedure. Therefore, each participant had three SNR values, one in each aided condition. The MCL, SRS and speech recognition threshold in noise (SNR) in the three aided conditions were obtained for each participant and tabulated for statistical analysis.

Results and Discussion

The results of the study are discussed in terms of MCL, SRS and SNR for three groups of participants (Group I, Group II and Group III) in three different amplification conditions (amplification to the better ear, amplification to the poorer ear, binaural amplification). The data obtained were subjected to statistical analysis using Statistical Package for Social Sciences (SPSS, version 14) software.

To know if there was a significant main effect of amplification on MCL, SRS and SNR in each of the three groups of participants repeated measures analysis of variance (ANOVA) was carried out. If a main effect was present, Bonferroni post-hoc analysis was carried out to know if a significant difference between the scores of the three groups in three amplification conditions was present.

I. Aided most comfortable loudness level (MCL)

Individuals with hearing impairment have altered most comfortable loudness levels compared to normal hearing individuals (Dillon, 2001).

A. Comparison of MCL in three groups of participants in three amplification conditions

The mean values revealed that MCL in binaural amplification condition (MCLbin) was lowest compared to MCL with amplification to the better ear alone (MCLb) which in turn was better than amplification to the poorer ear alone condition (MCLp) (Figure 1) in all three groups of participants.

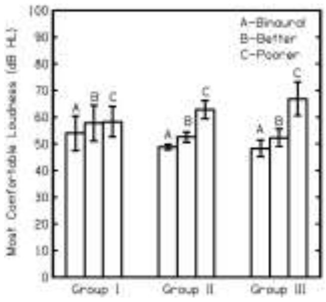

Figure 1: Mean and standard deviation (SD) of the MCL with A. binaural amplification (MCLbin), B. amplification to better ear (MCLb) and C. amplification to poorer ear (MCLp) in three groups of participants.

The lowest MCL in binaural amplification condition could be attributed to binaural summation of loudness. The results of the present study are in consensus with the earlier studies (Verhey, Anweiler and Hohmann, 2006).

Group I (Symmetrical Hearing loss)

Repeated measures ANOVA revealed a significant main effect of the amplification conditions on MCL [F (2, 14) = 26.27; p< 0.001], indicating that the mean MCLs in the three amplification conditions were significantly different from each other. Bonferroni post-hoc pair-wise analysis revealed a significant difference between MCLb and MCLbin (p<0.01) and between MCLp and MCLbin (p<0.01). In these pair-wise comparisons, the MCLbin was the lowest. However, there was no significant difference in the MCL between MCLb and MCLp (p>0.05). This can be attributed to almost similar thresholds in both ears, as the participants in this group had symmetrical hearing loss.

Group II (Asymmetrical Hearing loss I)

Repeated measures ANOVA which revealed a significant main effect of the amplification conditions on MCL [F (2, 12) = 128.86; p< 0.001]. The mean MCLs in the three amplification conditions were significantly different from each other. Bonferroni post-hoc pair-wise analysis revealed a significant difference between MCLb and MCLbin (p<0.05), between MCLp and MCLbin (p<0.001) and also between MCLb and MCLp (p<0.001).

Group III (Asymmetrical Hearing loss II)

A significant main effect of the amplification conditions on MCL was revealed by repeated measures ANOVA [F (2, 12) = 64.81; p< 0.001] indicating that mean MCLs in the three amplification conditions were significantly different from each other. Bonferroni post-hoc pair-wise analysis revealed a significant difference between MCLb and MCLbin (p<0.001), between MCLp and MCLbin (p<0.001) and also between MCLb and MCLp (p<0.01). Thus, the results for Group II and Group III were similar but were different from Group I. This indicates that in participants in Group II and Group III, binaural amplification yielded an MCL that is much lower than MCLb, thus increasing the range of comfortable loudness. The performance in the binaural condition was significantly better than either amplification to the better ear or amplification to the poorer ear; in terms of lowered MCL.

B. Comparison of MCL across the three groups of participants in binaural amplification condition.

In the literature, it has been documented that most comfortable loudness levels are affected by the amplification condition and the degree of asymmetry of hearing loss in participants with sensorineural hearing impairment (Ricketts, 2000). Table 1 summarizes the mean and SD of the MCL in binaural amplification condition (MCLbin) in the three groups of participants.

Table 1: Mean and SD of the MCL in binaural amplification condition (MCLbin) in the three groups of participants

Groups	*MCLbin*	
	Mean (dB HL)	*SD*
I	54.0	6.5
II	48.85	1.06
III	48.28	3.14

One-way ANOVA revealed no significant main effect of degree of asymmetry of hearing loss on the MCLbin [F (2, 19) =3.96; p>0.05]. The results indicate that the MCL in binaural amplification condition did not vary as a function of degree of asymmetry of hearing loss between the two ears. Also, the results of the present study are in consensus with the earlier reports that the type of amplification affects the most comfortable loudness levels in individuals with hearing impairment (Sandlin, 2000; Dillon, 2001).

C. Correlation of degree of asymmetry of hearing loss and MCL

Studies have reported that the most comfortable loudness level depends upon the degree of hearing loss in individuals with sensorineural hearing impairment (Summers & Cord, 2007). Spearman's correlation analysis revealed no significant correlation between the degree of asymmetry of hearing loss and MCLbin in Group I, II and III ($\rho = 0.35$; $p>0.05$ for Group I, $\rho = 0.00$; $p>0.05$ for Group II and $\rho = 0.69$; $p>0.05$ for Group III). Therefore, binaural amplification gives equal benefit irrespective of the degree of hearing loss in both ears.

II. Speech recognition scores (SRS)

The present study analyzed the speech recognition abilities in individual with hearing impairment in three different amplification conditions.

A. Comparison of speech recognition scores in three groups of participants in three amplification conditions

The mean values of SRS indicate that performance in binaural amplification condition was better when compared to amplification to better ear condition, which in turn was better than amplification to poorer ear condition, in all the three groups of participants (Figure 2). The mean difference between SRSbin and SRSb or SRSp is highest in Group III followed by Group II and then by Group I.

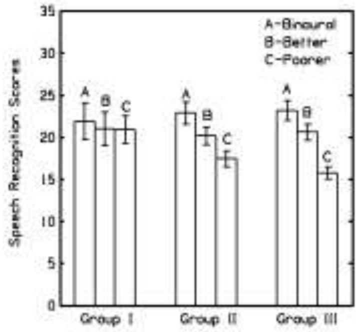

Figure 2: Mean and SD of SRS A. amplification to better ear condition (SRSb), B. amplification to poorer ear condition (SRSp) and C. binaural amplification condition (SRSbin) in three groups of participants.

Group I (Symmetrical Hearing loss)

Repeated measures ANOVA revealed no significant main effect of the amplification conditions on SRS [F (2, 14) = 2.38; p> 0.05], that is, SRS in the three amplification conditions were not significantly different from each other. Results of the present study indicate that providing binaural amplification for participants with bilateral symmetric hearing loss does not result in significantly improved speech recognition performance since the amplification depends on the auditory thresholds of either poorer ear or better ear. There are several studies that have investigated the benefits of amplification in individuals with various degrees of hearing loss (Ching, Dillon and Byrne, 1998).

Group II (Asymmetrical Hearing loss I)

Repeated measures ANOVA revealed a significant main effect of the amplification conditions on SRS [F (2, 12) = 90.25; p< 0.001], indicating a significant difference between the SRS in the three amplification conditions. The Bonferroni post-hoc analysis revealed a significant difference between SRSb and SRSbin (p<0.001), between SRSp and SRSbin (p<0.001), between SRSb and SRSp (p<0.05). Further, from figure 2 it can be noted that the SRS is best in the binaural amplification condition followed by SRSb and then followed by SRSp. Hence, it can be inferred that binaural amplification is significantly beneficial compared to monaural amplification, either to better ear or poorer. The results of the present study are in consensus with the earlier reports (Gelfand, Silman and Ross, 1987).

Group III (Asymmetrical Hearing loss II)

Repeated measures ANOVA revealed a significant main

effect of the amplification conditions on the SRS [F (2, 12) = 126.78; p< 0.001]. This indicated a significant difference between the SRS in the three amplification conditions. The Bonferroni post-hoc analysis revealed a significant difference in the SRS between amplification to better ear and binaural amplification condition (p<0.001), between amplification to poorer ear and binaural amplification condition ($p<0.001$), between the amplification to better ear and amplification poorer ear amplification condition ($p<0.001$).

Hence, binaural amplification results in better speech recognition abilities compared to monaural amplification, either to better ear or poorer ear only condition which is in agreement with that reported by Persson, Harder, Arlinger and Magnuson (2001) which had concluded that individuals achieved significantly better speech recognition scores in the binaural amplification condition compared to monaural conditions.

The results of the present study contradict that reported by Rothpletz, Tharpe and Grantham (2004). In their study, the effect of different degrees of degradation of speech signal on speech recognition task was investigated. There was a significant binaural advantage (average of 7 dB) when listening to symmetrically degraded signals as compared to when listening monaurally. Further, little or no binaural benefit was reported, on an average, when listening to asymmetrically degraded signals. Also, the overall performance of the adults was significantly worse when listening to binaural asymmetrically degraded signals than when listening to monaural signals, thus demonstrating evidence of binaural interference. However, the study considered asymmetrical degradation of signals and did not consider participants having asymmetrical hearing loss. The effect of asymmetrical degradation may be different from that of asymmetrical hearing loss. This might have contributed to the differences in the results observed in their study and the present study.

The present study indicated that providing binaural amplification resulted in improved speech recognition performance compared to amplification to better ear only and amplification to poorer ear only in participants with asymmetry in pure tone thresholds across the two ears ranging from 16 to 35 dB.

B. Comparison of speech recognition scores across the three groups of participants in binaural amplification condition.

The present study analyzed the SRS in binaural amplification condition across all three groups of participants. Results indicated that mean SRSbin was better in Group III when compared to Group II, which in turn was better than Group I participants (Table 2).

Table 2: Mean and SD of SRSbin in the three groups of participants

Group	*SRSbin*	
	Mean (dB HL)	*SD*
I	21.87	2.16
II	22.85	1.34
III	23.14	1.21

. One-way ANOVA revealed no significant effect of the degree of asymmetry on the speech recognition scores [$F(2, 19) = 1.21$; $p>0.05$], suggesting that participants in each group performed similarly in quiet with binaural amplification.

In the present study, participants having symmetrical and asymmetrical hearing impairment were included. The maximum degree of asymmetry between the ears of these participants included in the study was 35 dB. It may be possible that the degree of asymmetry did not have an effect on the speech recognition abilities in binaural amplification condition since the audibility provided from the hearing aids was sufficient enough to understand speech stimuli. Previous investigators have also reported that audibility may be a major factor in speech recognition abilities in individuals with sensorineural hearing impairment (Hogan & Turner, 1998).

Hence, from the present study it can be inferred that the degree of asymmetry of hearing loss upto 35 dB between the two ears might not have an effect on SRS in binaural amplification condition. In other words, binaural amplification results in similar speech recognition performance in participants with symmetric as well asymmetric hearing impairment.

C. Correlation of degree of asymmetry of hearing loss and SRS

Spearman's correlation analysis revealed no significant correlation between the degree of asymmetry of hearing loss and SRSbin ($\rho = 0.28$; $p>0.05$ for Group I, $\rho = 0.38$; $p>0.05$ for Group II and $\rho = 0.20$; $p>0.05$ for Group III). This implies that, SRSbin does not vary with the degree of asymmetry between the ears in individuals with bilateral hearing loss.

D. Correlation of asymmetry in aided monaural MCL between the two ears and SRS in binaural amplification condition.

Spearman's correlation analysis revealed a no significant correlation between the difference in aided monaural MCL of the two ears and SRS in binaural amplification condition for Group I and Group III ($\rho = 0.16$; $p>0.05$ for Group I and $\rho = 0.32$; $p>0.05$ for Group III) and a significant correlation for Group II ($\rho = 0.77$; $p<0.05$ for Group II). Thus, SRSbin does not vary with the difference between aided monaural MCL of the two ears in individuals with bilateral hearing loss, that is, increase in the difference between aided monaural MCL of the two ears does not lower the SRS.

III. Speech Recognition Threshold in Noise (SNR)

Previous studies have shown that individuals with sensorineural hearing loss have reduced speech recognition abilities in quiet condition. However, the problem becomes more complicated when speech signal is presented in background noise. Hence, individuals with sensorineural hearing loss may exhibit more problems of speech recognition in noise condition. The present study analyzed the effect of amplification conditions on the speech recognition threshold in noise in terms of SNR.

A. Comparison of SNR in three groups of participants in three amplification conditions

It can be observed from Figure 3 that a lower SNR was obtained in binaural amplification condition followed by amplification to better ear condition and then by amplification to the poorer condition in all three groups of participants. Lower SNR values indicate that the participants performed well even when difference between speech and noise was very lesser.

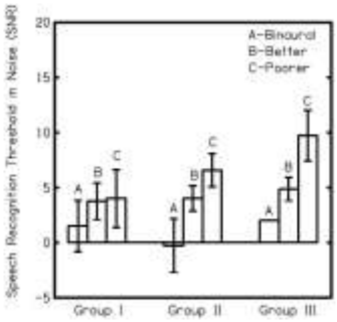

Figure 3: Mean and SD of SNR in A. binaural amplification condition (SNRbin), B. amplification to better ear condition (SNRb) and C. amplification to poorer ear condition (SNRp) in three groups of participants.

Group I (Symmetrical Hearing loss)

Repeated measures ANOVA indicated a significant difference between the SRS in the three amplification conditions [$F (2, 14) = 10.44$; $p< 0.01$]. Bonferroni post-hoc pair-wise analysis revealed a significant difference between SNRb and SNRbin ($p<0.01$) and between SNRp and SNRbin ($p<0.05$). However, there was no significant difference between SNRp and SNRb ($p>0.05$). Therefore, in individuals with bilateral symmetrical hearing loss the improvement of performance in noise with binaural amplification over monaural amplification did not reach statistical level of significance.

The results of the present study are in consensus with the earlier reports. The present study revealed that the signal to noise ratio was least in the binaural amplification condition compared to monaural amplification either to the better ear or to the poorer ear. These findings suggest that individuals with varying degrees of asymmetrical hearing loss (up to 35 dB of asymmetry) might still be able to take advantage of the binaural squelch phenomenon and hence are prospective candidates for binaural amplification.

Group II (Asymmetrical Hearing loss I)

Repeated measures ANOVA revealed a significant main effect of the amplification conditions on SNR [$F (2, 12) = 63.00$; $p< 0.001$] indicating a significant difference between the SRS in the three amplification conditions. The results of Bonferroni post-hoc pair-wise comparison revealed a significant difference between SNRb and SNRbin ($p<0.05$), between SNRp and SNRbin ($p<0.001$) and between SNRb and SNRp ($p<0.01$). This indicated that binaural amplification was better than either ear amplification alone and amplification to the better ear was better than amplification to the poorer ear alone.

Group III (Asymmetrical Hearing loss II)

Repeated measures ANOVA revealed a significant main effect of the amplification conditions on SNR [$F (2, 12) = 67.08$; $p< 0.001$] indicating a significant difference between the SRS in the three amplification conditions. The results of Bonferroni pair-wise comparison revealed a significant difference between SNRb and SNRbin ($p<0.05$), between SNRp and SNRbin ($p<0.001$) and SNRb and SNRp ($p<0.05$). Therefore, binaural amplification was better than either ear amplification alone and amplification to the better ear was better than amplification to the poorer ear alone.

It has been reported in the previous studies that the degree of asymmetry might have an on the speech recognition abilities in the presence of noise (Summers & Cord, 2007). Their results also suggested that amplification condition might affect subjective performance in noise and overall for listeners with varying degrees of mild to severe hearing loss when feedback was eliminated. However, in the present study, subjective preference was not considered. Inclusion of subjective preference would have provided additional information.

On the other hand, studies have reported the advantages of monaural amplification over binaural amplification condition in participants with hearing impairment. Carter, Noe, and Wilson (2001) evaluated four individuals who preferred monaural as compared with binaural amplification. For these individuals, the results of sound field testing using a speech in multitalker babble paradigm indicated that when listening in noise, there was a little difference between aided and unaided word-recognition performance, suggesting that binaural hearing aids originally fit for each individual were not providing substantial benefit when listening in a competing babble background.

Thus, the results of the present study are in consensus with the earlier reports which have inferred that, the speech recognition abilities in the presence of noise depends upon the amplification conditions, and that binaural amplification is better than monaural amplification conditions.

B. Comparison of SNR across the three groups of participants in binaural amplification condition

The present study analyzed the speech recognition threshold in noise in terms of SNR in binaural amplification condition across all three groups of participants (Table 3). One-way ANOVA revealed no significant main effect of degree of asymmetry on speech recognition abilities in all participants [$F (2, 19) =10.19$; $p>0.05$]. Thus, the performance of the participants in all the three groups was comparable on speech recognition in noise task with binaural amplification.

Table 3: Mean and SD of SNRbin in three groups of participants

Group	*SNRbin*	
	Mean (dB)	*SD*
I	1.50	2.32
II	-0.28	2.43
III	2.00	1.10

The speech recognition in noise does not depend on the degree of asymmetry in individuals with hearing impairment. The results of the present study are in consensus with that reported in earlier study regarding effect of degree of asymmetry on speech recognition abilities in noise (Posner and Ventry, 1977).

C. Correlation of degree of asymmetry of hearing loss and SNR

Spearman's correlation analysis revealed no significant correlation between the degree of asymmetry of hearing loss and SNR in binaural amplification condition ($\rho = 0.32$; $p>0.05$ for Group I, $\rho = 0.34$; $p>0.05$ for Group II and $\rho = 0.20$; $p>0.05$ for Group III). Thus, the speech recognition threshold in noise does not depend on and thus does not vary with the degree of asymmetry between the two ears.

D. Correlation of asymmetry in aided monaural MCL between the two ears and SNR in binaural amplification condition

For the analysis of the correlation between asymmetry of aided monaural MCL between the two ears and SNR in binaural amplification condition Spearman's correlation analysis was used. It revealed no significant correlation between the difference in aided monaural MCL of the two ears and signal-to-noise ratio in binaural amplification condition ($\rho = 0.00$; $p>0.05$ for Group I, $\rho = 0.75$; $p>0.05$ for Group II and $\rho = 0.32$; $p>0.05$ for Group III).

The results indicate that SNR does not vary with the difference in aided monaural MCL of the two ears in individuals with bilateral asymmetric hearing loss, that is, increase in the difference in aided monaural MCL of the two ears does not increase the SNR. This indicates that asymmetry of hearing loss does not have an effect on the speech recognition in noise presented under the binaural amplification condition.

Conclusions

The study evaluated the effect of degree of asymmetry between the two ears on the Most Comfortable Loudness levels (MCL), Speech Recognition Scores (SRS) and Speech Recognition Threshold in Noise in terms of signal to noise ratio (SNR). The important findings on the three parameters studied are as follows:

1. Aided Most Comfortable Loudness Level (MCL)

- Lowest MCL was obtained in the binaural amplification condition compared to the monaural amplification condition in all three groups of participants. This could be attributed to the binaural summation of loudness, in all the participants irrespective of the asymmetry between the two ears.
- For participants in Group II and Group III, amplification to both the ears yielded an MCL that was significantly lower than the MCL with amplification to the better ear alone ($p<0.05$), thus increasing the range of comfortable loudness.
- The results indicated that the degree of asymmetry (in the pure tone average between the two ears up to 35 dB between the two ears) did not influence the benefit in terms of MCL from binaural amplification, in participants with sensorineural hearing impairment.

2. Speech Recognition Scores (SRS):

- For speech recognition in quiet, it was found that providing binaural amplification did not result in significant improvement over monaural amplification for participants with bilateral symmetric hearing loss.
- In participants with asymmetric hearing loss (Groups II & III), providing binaural amplification resulted in improved speech recognition performance compared to monaural amplification either to better or poorer ear.
- Results indicated that SRS in binaural amplification condition did not vary with the difference between aided monaural MCL of the two ears in individuals with bilateral asymmetric hearing loss, that is, increase in the difference between aided monaural MCL of the two ears did not lower the SRS.

3. Speech recognition threshold in noise, in terms of, signal-to-noise ratio (SNR):

- The present study indicated that participants obtained higher speech recognition threshold in noise (SNR) with binaural amplification than monaural amplification to either better ear or poorer ear. These findings suggested that individuals with varying degrees of asymmetrical hearing loss might still be able to take advantage of the binaural squelch phenomenon with binaural amplification.

- Participants obtained higher speech recognition threshold in noise (SNR) with binaural amplification than with monaural amplification condition.

These findings imply that individuals with varying degrees of asymmetrical hearing loss, up to 35 dB, can be considered candidates for binaural amplification.

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