BENEFITS OF BINAURAL AMPLIFICATION

IN PARTICIPANTS WITH

ASYMMETRIC HEARING IMPAIRMENT

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APRIL 2008

CERTIFICATE

This is to certify that this Master's Dissertation entitled **'BENEFITS OF BINAURAL AMPLIFICATION IN PARTICIPANTS WITH ASYMMETRIC HEARING IMPAIRMENT'** is a bonafide work in part fulfillment for the Master's degree (Audiology) of the student with **Registration no:** 06AUD012. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

I hereby declare that this Master's Dissertation entitled **'BENEFITS OF BINAURAL AMPLIFICATION IN PARTICIPANTS WITH ASYMMETRIC HEARING IMPAIRMENT'** is the result of my own work under the guidance of Mrs. P. Manjula, Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysore, and has not been submitted earlier to any other University for the award of any Diploma or Degree.

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CHAPTER -1

INTRODUCTION

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, binaural integration process is less effective and binaural advantages are correspondingly diminished or even lost (Davis & Haggard, 1982). This is true for an individual with unilateral hearing loss or an asymmetrical hearing loss.

The loss of hearing ability characterized by decreased sensitivity to sound in comparison to normal hearing is termed as hearing loss (Silman & 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 significant difference between ears; regardless of the magnitude, 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).

In individuals with asymmetric hearing loss, where speech input is degraded in one ear and more degraded in the other ear, individuals may experience more difficulty perceiving speech with both ears than with hearing through the better ear alone. This auditory phenomenon is termed 'binaural interference' (Jerger, Silman, Lew & Chmeil, 1993). Binaural interference occurs when the 'poorer ear' (ear with greater thresholds) has detrimental effects on perception by the 'better ear' (ear with lesser thresholds).

Colburn (1982), modeling binaural interactions in the impaired auditory systems, suggested that binaural processing might be limited when a signal from one ear that is degraded or distorted in frequency domain is compared to an 'intact' signal from the other ear. On the contrary, McCullough, and Abbas (1992) examined binaural syllable recognition ability in noise of five adults with symmetrical hearing loss who had interaural differences in speech recognition. Four of them demonstrated a slight binaural advantage over the best monaural condition.

Hearing aids make sounds audible to individuals with hearing impairment by amplifying them. Wearing two hearing aids (a binaural fitting) instead of one hearing aid (unilateral or monaural fitting) increase the range of sound levels for which binaural hearing is possible (Dillon, 2001). For listeners with bilateral hearing loss, there are numerous advantages to a binaural hearing aid fitting over a monaural hearing aid fitting. These include but are not limited to (1) elimination of the head shadow effect, (2) binaural summation, (3) binaural squelch, and (4) improved sound localization (Mueller & Grimes, 1993).

Studies have reported that factors such as age of listener, ear (left or right) that receives more degraded signal and the ability to understand asymmetrically degraded speech can influence binaural amplification (Rothpletz, Tharpe & Grantham, 2004). Studies have also shown that factors such as speech perception ability of the better or poorer ear, amount of asymmetry between the two ears, duration of deafness, duration of hearing asymmetry and age of onset of hearing loss have an effect on binaural speech perception (Gelfand, Silman & Ross, 1987).

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.

Need for the Study

Thus, 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.

CHAPTER - 2

REVIEW OF LITERATURE

Binaural hearing aids present an opportunity to preserve the speech recognition abilities in individuals with hearing impairment. Binaural amplification results in integration of loudness in the central auditory system (Noble & Byrne, 1990; Mulrow, Tuley & Aguilar, 1992; Sandlin, 2000). The studies indicate that binaural amplification increases the loudness from around 3 dB or lower near threshold to about 6 to 10 dB at higher intensity levels. This shows that binaural amplification may be advantageous in individuals with sensorineural hearing loss at higher degrees such as greater than moderate degrees of hearing loss (Sandlin, 2000). The process of recruitment seen in these individuals also indicates the excessive loudness growth at higher intensity levels (Silman & Silverman, 1991). Studies have shown that sound perception in two ears makes it possible for a person to localize the sound source in individuals with normal hearing or in individuals having symmetrical hearing loss (Naidoo & Hawkins, 1997; Dillon, 2001).

The use of binaural hearing aids is based on the assumption that the human auditory system functions best when both ears receive incoming acoustic information. There is evidence, however, that some elderly individuals perform better while using monaural as opposed to binaural amplification. The benefits of binaural amplification over monaural amplification in individuals with bilateral hearing impairment have been well documented in literature (Pittman & Stelmachowicz, 2003; Sammeth, Birman & Hecox, 1989; Whilby, Florentine, Wagner & Marozeau, 2006). Studies have also documented increased range of sound intensity with binaural amplification rather than monaural amplification (Moncur & Dirks, 1967; Nabelek & Pickett, 1974).

It has been shown that binaural amplification enables a person to understand more when speech signals are delivered in the presence of background noise. The ability to combine information at the two ears in order to listen to speech in the presence of noise is greater in the binaural amplification condition. The degree of hearing loss in both ears will reflect the amount of binaural advantage that is observed in participants with asymmetrical hearing loss (Nabelek & Mason, 1981; Dillon, 2001). The reason behind binaural amplification being better than monaural amplification may be due to head shadow effect, binaural squelch and binaural redundancy (Festen & Plomp, 1983). The binaural head shadow effect benefits individuals in conditions in which noise is present towards poorer ear side and signal is present towards better ear side (Bronkhorst & Plomp, 1989). The phenomenon of binaural squelch suppresses the effect of reverberation in individuals with hearing impairment, thereby improving the signal-to-noise ratio in these individuals. The phenomenon of binaural redundancy helps in better speech recognition abilities in quiet conditions (Kaplan & Pickett, 1981).

Studies on binaural amplification relevant to the present research study are being reviewed under the following headings:

2.1. Binaural amplification and most comfortable level.

2.2. Binaural amplification and speech recognition abilities.

2.3. Auditory deprivation and binaural amplification.

2.1. Binaural amplification and most comfortable loudness level:

Degree of hearing loss and the type of amplification condition has an effect on the most comfortable loudness levels in individuals with hearing impairment (Sandlin, 2000; Dillon, 2001). Studies have been carried out regarding the effects of degree of hearing loss on the most comfortable loudness levels in participants with hearing impairment. Beattie, and Warren (1982) determined the effect of severity of hearing loss on the most comfortable loudness level (MCL) and the loudness discomfort level (LDL). They also assessed the efficacy of obtaining maximum intelligibility (PB max) at MCL and/or LDL. One hundred twenty-nine ears were tested from 74 elderly participants having mild to moderate sensorineural hearing losses. The results showed that mean MCLs and LDLs remained fairly constant as spondaic thresholds increased from 5 to 55 dB HTL. There was considerable inter-subject variability, which indicated that MCLs and LDLs could not be closely predicted from threshold. The study also indicated that measuring speech intelligibility at MCL approximated PB max (+/- 12 %) only about two-third of the time. It was concluded that decisions concerning auditory functioning might frequently be inaccurate if intelligibility is measured only at MCL. Neither can LDL be the single intensity at which speech intelligibility is measured, at least with elderly individuals. The findings also indicated that hearing aid users might not receive optimal benefit if their hearing aid was adjusted to MCL, and that improved intelligibility may be achieved at higher volume control settings.

Studies have also shown that the loudness levels depend on the degree of hearing loss. Shapiro (1979) assessed the relationship between hearing level and loudness discomfort level (LDL) for narrow-band noise in two groups of participants with sensorineural hearing loss. Group I had thresholds ranging from 25 to 60 dB

SPL and Group II's thresholds ranged from 65 to 100 dB SPL. LDLs were determined for narrow bands of noise centered at 500, 1000, 2000, and 4000 Hz. The LDLs for Group II were greater than those for Group I and the differences were statistically significant. It is speculated that one reason for others not finding differences as a function of hearing level may be the absence of severe to profound hearing loss in the test populations.

Studies have been carried out in order to investigate the effect of hearing impairment on loudness summation and reduction in most comfortable levels. Hawkins, Prosek, Walden, and Montgomery (1987) measured binaural loudness summation in 10 normally hearing and 20 bilaterally symmetrical high-frequency sensorineural hearing loss subjects. Stimuli consisted of 500- and 4000-Hz pure tones and a speech spectrum noise. It was observed that the hearing-impaired subjects demonstrated binaural summation that was not significantly different from the normally hearing subjects. The results suggest that a bilaterally symmetrical sensorineural hearing loss does not affect binaural loudness summation thereby leading to a reduced MCL.

Kamm, Dirks, and Mickey (1978) observed that, for pure tone and speech stimuli, median LDL and MCL levels were at relatively constant SPLs for subjects with hearing loss less than or equal to dB HL and at progressively higher SPLs with further increase in hearing loss. Blarney, Dooley, James, and Parisi (2000) observed reduction in the MCL due to loudness summation for the binaural stimuli. The results were consistent with observations for subjects with normal hearing and subjects with bilaterally impaired hearing. Hall, and Harvey (1985) observed that diotic loudness summation was present in cochlear-impaired ears, provided that the stimuli are presented sufficiently above threshold.

2.2. Binaural amplification and speech recognition abilities:

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).

Feuerstein (1992) evaluated forty-eight normal-hearing individuals for ease of listening, word recognition, and attentional effort tasks for speech in noise under binaural and two simulated unilateral conductive hearing loss (monaural) conditions. The two monaural conditions differed as a function of unoccluded ear orientation to the primary signal (monaural-near and monaural-far). Ratings on ease of listening and word recognition scores were significantly poorer during monaural listening and significantly affected by orientation of the ear to the speech signal. Attentional effort was not significantly affected by changing from binaural to monaural-near listening, but was significantly poorer in the monaural-far condition than in either of the other listening conditions. There was a significant correlation between ease of listening ratings and word recognition, but no correlation between attentional effort and either ease of listening or word recognition.

McCullough, and Abbas (1992) studied speech recognition in noise in five individuals with symmetrical hearing impairment, but having significant interaural differences in the speech recognition abilities. The study analyzed the relationship between interaural differences in speech-recognition performance and binaural advantage in these individuals. All participants repeated non-sense syllables in the presence of competing noise in monaural and binaural conditions. The binaural advantage was calculated as the difference in SNR that afforded 50 percent correct performance between the monaural and binaural conditions. Although the majority of the participants retained some degree of binaural advantage, a conclusive relationship between interaural differences in speech recognition and binaural advantage could not be established.

A study by Gatehouse, and Haggard (1986) showed that binaural amplification should be recommended only to people with symmetrical hearing loss. Davis, and Haggard (1982) suggested that for prognostic purposes the appropriate boundary of asymmetry should lie in the 12 to 15 dB ranges.

Henkin, Waldman, and Kishon-Rabin (2007) compared speech recognition in noise in adults with hearing impairment initially fitted with binaural hearing aids while they used monaural versus binaural amplification. They also investigated the association between performance with one versus two hearing aids and central auditory function as measured by a dichotic test, and evaluated the effect of increasing age on these two measures. Twenty-eight geriatric individuals with bilateral symmetrical mild-to-severe sensorineural hearing loss fitted with digital hearing aids, participated in the study. Speech recognition in noise was assessed in three conditions of aided right ear, aided left ear and aided binaurally, using the AB open-set monosyllabic word test at a signal-to-noise ratio of+10 dB. Speech stimuli were presented at 70 dB SPL via a loudspeaker located at 0° Azimuth and the noise were presented via a second loudspeaker located at 180° Azimuth. In addition, dichotic listening abilities were evaluated using the threshold-of-interference test. The results of the study indicated comparable mean group performance while using monaural versus binaural amplification. For most of the participants (71%), speech recognition in noise was better while using monaural amplification to the 'better' ear compared to binaural amplification. While the performance in the dichotic test was not correlated with speech recognition in noise with binaural versus monaural amplification, the performance in these two tests deteriorated significantly with increasing age. Results suggested that for elderly individuals, binaural amplification might not always be advantageous for speech recognition in noise. As most individuals continue to use binaural amplification, it is clear that there are listening situations in which binaural amplification provides benefit.

Studies have been carried out to investigate the effects of amplification condition on the speech recognition scores in noise condition. Arsenault, and Punch (1999) studied perception of speech in noise in normal hearing as well as in individuals with hearing impairment. Syllables of the CUNY Non-sense Syllable Test were recorded in sound field at 0° Azimuth against a background of cafeteria noise at 270° Azimuth, at several signal-to-noise ratios using a binaurally equipped KEMAR manikin. The combination of inputs recorded at each ear was delivered to ten individuals with normal-hearing and eight individuals with sensorineural hearing impairment through insert ear phones to produce five experimental listening conditions: (1) binaural head shadow (HS), in which they studied the effect of head shadow in binaural amplification condition (2) binaural favorable (BF), in which the noise was presented to both ears, (3) monaural favorable (MF), in which the noise was presented only to the right ear, (4) monaural unfavorable (MU), in which the noise was presented only to the left ear, and (5) simulated monaural aided (SMA), in which the noise was presented to the right ear and noise attenuated by 20 dB relative to the HS condition was presented to the left ear. Results revealed that subject type, listening condition, and signal-to-noise ratio had significant effect on perception of speech in noise. Listeners with normal hearing showed 3.3 and 3.2 dB advantages respectively due to head-shadow and binaural squelch, over individuals with hearing-impairment. Results revealed that the binaural amplification condition might be better in terms of speech recognition abilities in individuals with hearing impairment. Results also showed that the monaural amplification condition was better when speech was presented towards the amplified ear and noise was presented towards unamplified ear. Results show that the type of amplification condition depends upon the presentation of signal and noise.

Another study with similar findings by Walden, and Walden (2005) compared monaural and binaural aided speech recognition in background noise in 28 individuals having asymmetrical hearing impairment being fitted with amplification. Aided Quick Speech-in-Noise test (QuickSIN) scores were obtained for binaural amplification and for monaural amplification in each ear. Results revealed that the vast majority of participants obtained better speech recognition in background noise on the QuickSIN from monaural amplification than from binaural amplification. There was a greater tendency for binaural amplification to have a deleterious effect among older participants. Results suggested that binaural amplification may not always be beneficial in every day listening environment when background noise was present, and it may be advisable for individuals wearing binaural amplification to remove one hearing aid or switch-off one hearing aid when difficulty is encountered understanding speech in background noise.

In participants with asymmetrical hearing loss 9 out of 10 demonstrated higher speech recognition scores in the better ear under earphones than when listening with both ears in the sound field (Arkebauer, Mencher & McCall, 1971). Shinn-Cunningham, Schickler, Kopco, and Litovsky (2001) examined speech intelligibility in adults with normal hearing using different target signal speaker azimuths and masker speaker azimuths. The investigators found some instances where binaural performance was equal to or worse than the performance of the better ear alone.

Rothpletz, Tharpe, and Grantham (2004) studied the effect of asymmetrical signal degradation on binaural speech recognition in 28 children and 14 adults. A sentence recognition task amidst multitalker babble was administered in three listening conditions: of monaural, with mild degradation in one ear; binaural, with mild degradation in both ears (symmetric degradation); and binaural, with mild degradation in one ear and severe degradation in the other ear (asymmetric degradation). Sentences and babble were degraded digitally to simulate mild and severe cochlear hearing loss. All participants demonstrated significant binaural advantage (average of 7 dB) when listening to symmetrically degraded signals as compared to when listening monaurally. In contrast, adults and children achieved little or no binaural benefit, on 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. In contrast to the speculations of the study, children did not show an overall demonstration of binaural interference. Ear (right or left) which received the more degraded signal did not influence relative performance in the binaural-asymmetric and the monaural conditions.

2.3. Auditory Deprivation and Binaural Amplification:

Another issue in aiding monaurally when there is asymmetrical hearing loss is that of auditory deprivation. Gelfand, Silman, and Ross (1987) studied the effect of auditory deprivation by comparing initial PB scores and audiometric thresholds with results obtained 4 to 17 years later for individuals with bilateral sensorineural hearing losses. Forty-eight individuals were monaurally aided, 9 were binaurally aided, and 19 were unaided. Thresholds decreased slightly for all groups, but aided and unaided ears did not differ significantly in this respect, revealing no acoustic trauma effect due to hearing aid use. PB scores decreased significantly only for the unaided ear of the monaurally aided individuals, but not for their aided ear, or for the binaurally aided or unaided groups. These findings suggest an auditory deprivation effect for the unaided ear of those wearing a monaural hearing aid. Changes in PB scores were not correlated with duration between the two test dates but correlated with degree of hearing loss only for the unaided group. Thus, even in individuals with asymmetrical hearing loss, the possibility of obtaining benefit from binaural amplification must be explored.

Many studies have reported a lack of amplification in adults with asymmetric sensorineural hearing impairment that leads to auditory deprivation (Silverman & Emmer, 1993; Arlinger, Gatehouse & Bentler, 1996). The auditory deprivation effect was more marked for the unaided poorer ears of persons with asymmetric sensorineural hearing impairment than for the unaided ears of monaurally fitted adults with bilateral, symmetric sensorineural hearing impairment (Silverman & Emmer, 1993). Arlinger, Gatehouse, and Bentler (1996) concluded that the auditory deprivation effect associated with monaural amplification of persons with bilateral hearing impairment was statistically significant. Hence they recommend binaural fitting for bilateral moderate or worse hearing impairment.

Silverman, Silman, Emmer, Schoepflin, and Lutolf (2006) investigated the performance on the pure-tone air-conduction threshold, speech-recognition threshold, and suprathreshold word-recognition tests over time in 21 monaurally aided (experimental group) and 28 unaided adults (control group) with asymmetric, sensorineural hearing impairment. The results revealed a significant decline on the mean suprathreshold word-recognition scores over time at one and two years post-baseline for the worse ears of the control participants; no declines occurred in the worse ears of the experimental participants or in the better ears of either group. A slight, significant increase in the pure-tone average occurred for the better ears of both groups. The findings are consistent with the presence of an auditory deprivation effect on suprathreshold word-recognition ability in the control group, suggesting that lack of amplification leads to decline in word-recognition performance over time in the worse ears of adults with asymmetric sensorineural hearing impairment.

Thus, from the above studies 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. The following section provides the details of the method used for the study.

CHAPTER - 3

METHOD

To evaluate the effect of different amplification conditions on the Most Comfortable Loudness levels (MCL), Speech Recognition Scores (SRS) and Speech Recognition Threshold in Noise (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 naive hearing aid users. All participants had Kannada as their native language. The participants satisfied the following criteria:

- Mild to severe degree of hearing loss.
- Flat audiometric configuration with a slope of < 5 dB rise or fall per octave (Lloyd & Kaplan, 1978).
- Speech recognition score of atleast 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

The following instruments were used for data collection:

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

Speech Material

The following speech materials were utilized in the study:

- A bi-syllabic phonemically balanced word lists in Kannada (Yathiraj & Vijayalakshmi, 2006). The test material recorded in a female voice on a CD. It consisted of eight lists with 25 words each (Given in Appendix A).
- 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 (Given in Appendix B).
- A passage in Kannada (Sairam, 2002). The passage was recorded in a male voice with normal effort on a CD (Given in Appendix C).

All the three material (in IPA format) are provided in the Appendix (A, B, C).

Test Environment

The testing was carried out in a sound treated double-room set-up with the ambient noise levels within permissible limits.

Procedure

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 softwares. The hearing aids were programmed to suit the hearing loss of the participant. 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 conditions. The procedure used for establishing MCLs was as follows.

The participant was instructed to rate the loudness of a recorded Kannada passage being presented based on the following seven-point rating scale (Cox, 1995):

1. Very soft
2. Soft
3. Comfortable, but slightly soft
4. Comfortable
5. Comfortable, but slightly loud
6. Loud but okay
7. Uncomfortable 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).

The speech recognition tasks were administered in three aided conditions.

1. Amplification to better ear.
2. Amplification to poorer ear.
3. Binaural amplification.

I. 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 & 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.

Thus using an adaptive procedure the maximum level of noise at which the participant could repeat at least 2 out of 3 words was measured. 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.

CHAPTER - 4

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 from the three groups of participants were subjected to statistical analysis using Statistical Package for Social Sciences (SPSS, version 14) software.

The results of the present study are discussed under the following headings:

I. Aided Most Comfortable Loudness Level (MCL)

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

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

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

II. Speech Recognition Scores (SRS)

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

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

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

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

III. Speech Recognition Threshold in Noise (SNR)

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

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

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

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

I. **Aided most comfortable loudness level (MCL)**

Individuals with hearing impairment have altered most comfortable loudness levels compared to normal hearing individuals (Dillon, 2000). The present study analyzed the aided most comfortable loudness levels in individuals having varied degrees of hearing loss in different amplification conditions.

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 most comfortable loudness levels with amplification to the better ear alone (MCLb) which inturn was better than amplification to the poorer ear alone condition (MCLp) (Table 4.1). This was true for all 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 that have reported the efficacy of binaural amplification condition in individuals with asymmetrical and symmetrical hearing impairment (Kamm, Dirks & Mickey, 1978; Verhey, Anweiler & Hohmann, 2006). Studies have shown that providing binaural amplification rather than monaural amplification increases the range of sound intensity for which binaural hearing is possible (Moncur & Dirks, 1967; Nabelek & Pickett, 1974). Thus, from the findings it can be implied that lower MCL in binaural amplification condition is an indication of better hearing with two hearing aids than one (Table 4.1) (Blamey, Dooley, James & Parisi, 2000; Whilby, Florentine, Wagner & Marozeau, 2006).

Table 4.1: Mean and standard deviation (SD) of the MCL with binaural amplification (MCLbin), amplification to better ear (MCLb) and amplification to poorer ear (MCLp) in three groups of participants

	Group I (Symmetric hearing loss)		*Group II (Asymmetric hearing loss I)*		*Group III (Asymmetric hearing loss II)*	
	Mean (dB HL)	*SD*	*Mean (dB HL)*	*SD*	*Mean (dB HL)*	*SD*
MCLbin	54.00	6.50	48.85	1.00	48.28	3.14
MCLb	57.75	6.71	52.57	1.90	52.28	3.35
MCLp	58.25	5.70	62.85	3.43	66.85	6.30

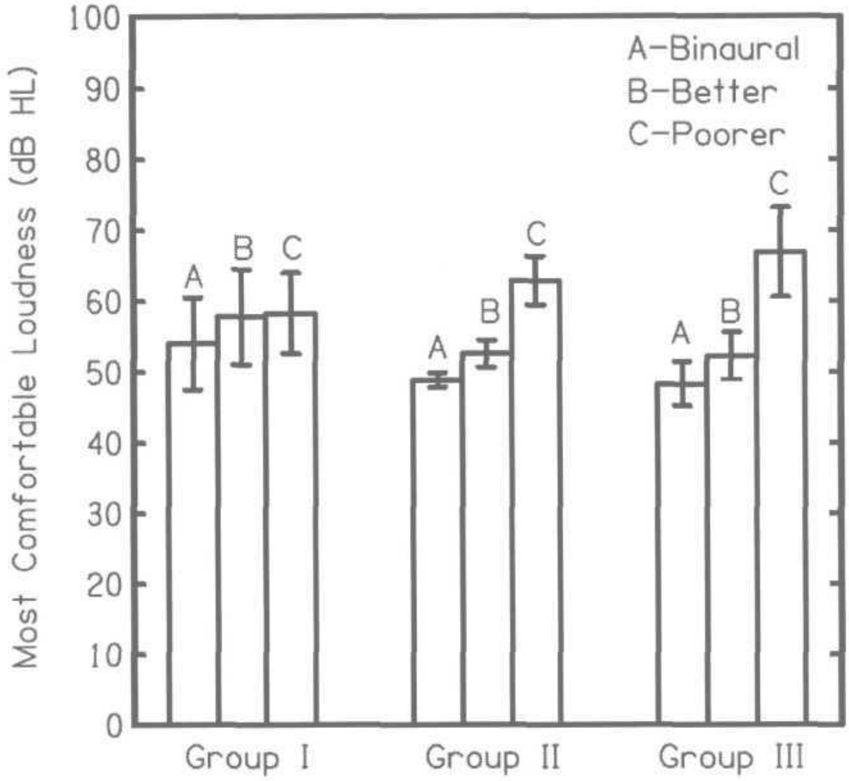

Fig. 4.1: Mean and standard deviation (SD) of the MCL with A. binaural amplification (MCLbin), B. amplification to better ear (MCLb) and C. amplification to poorer ear (MCLp) in three groups of participants.

To know if there was a significant main effect of amplification on MCL in each of the three groups of participants in the three amplification conditions 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.

Group I (Symmetrical Hearing loss)

To investigate if there was a main effect of amplification conditions on MCL, Repeated measures ANOVA was carried out. The results revealed a significant main effect of the amplification conditions on MCL [$F (2, 14) = 26.27$; $p < 0.001$]. This indicates 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 in the most comfortable loudness level between amplification to better ear and binaural amplification condition ($p<0.01$) and between amplification to poorer ear and binaural amplification condition ($p<0.01$). In both these pair-wise comparisons, the MCLbin was the lowest. However, there was no significant difference in the most comfortable loudness level between amplification to better ear and amplification to poorer ear conditions ($p>0.05$). This can be attributed to almost similar thresholds in both ears, as the participants in this group had symmetrical hearing loss (with difference in PTA between the two ears less than 15 dB).

Group II (Asymmetrical Hearing loss I)

The main effect of amplification conditions on MCL was investigated using Repeated measures ANOVA. It revealed a significant main effect of the amplification conditions on MCL [$F(2, 12) = 128.86$; $p< 0.001$], that is, the mean MCLs in the three amplification conditions were significantly different from each other. Bonferroni post-hoc pair-wise analysis revealed a significant difference in the MCL between amplification to better ear and binaural amplification condition ($p<0.05$), between amplification to poorer ear and binaural amplification condition ($p<0.001$) and also between amplification to better ear and poorer ear amplification condition ($p<0.001$). The MCL was lowest in the binaural amplification condition followed by amplification to the better ear and followed by amplification to the poorer ear.

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 in the MCL between amplification to better ear and binaural amplification condition ($p<0.001$), between amplification to poorer ear and binaural amplification condition ($p<0.001$) and also between amplification to better ear and amplification to poorer ear condition ($p<0.01$). The MCL was lowest in the binaural amplification condition followed by amplification to the better ear alone and then by amplification to the poorer ear alone.

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, amplification to the better ear as well as the poorer ear yield an MCL that is much lower than MCL with amplification to the better ear alone, 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. This implies that a binaural amplification is better compared to either amplification to better ear or poorer ear alone condition, in all the three groups of participants. Therefore, it can be inferred that in individuals with bilateral hearing loss with an asymmetry (in the pure tone average between the two ears) extending upto 35 dB, the benefit from binaural amplification was in terms of lowered MCL.

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

The present study analyzed most comfortable loudness levels in binaural amplification condition across all three groups of participants. 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 (Beattie & Warren, 1982; Day, Browning & Gatehouse, 1988; Arsenault & Punch, 1999; Ricketts, 2000). Table 4.2 summarizes the mean and SD of the MCL in binaural amplification condition (MCL both) in the three groups of participants.

Table 4.2: 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

To know if there was a significant main effect of degree of asymmetry of hearing loss on the MCL in binaural amplification condition in three groups of participants One-way ANOVA was carried out. This did not reveal any significant main effect [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.

The results of the present study are in consensus with the earlier reports that the type of amplification condition affects the most comfortable loudness levels in individuals with hearing impairment (Sandlin, 2000; Dillon, 2001). Beattie, and Warren (1982) indicated that the hearing aid users might not receive optimal benefit if their hearing aid was adjusted to MCL, and that improved intelligibility may be achieved at higher volume control settings. The results indicated that the type of amplification condition had an effect on the most comfortable loudness levels in participants with sensorineural hearing impairment.

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). The present study analyzed the effect of the degree of asymmetry of hearing impairment on the most comfortable loudness level.

Spearman's correlation analysis revealed no significant correlation between the degree of asymmetry of hearing loss and the most comfortable loudness level in binaural amplification condition for participants in Group I, II and III ($p = 0.35$; $p>0.05$ for Group I, $p = 0.00$; $p>0.05$ for Group II and $p = 0.69$; $p>0.05$ for Group III). Therefore the results reveal that binaural amplification gives equal benefit irrespective of the degree of hearing loss in both ears.

The results indicated that the type of amplification condition had an effect on the most comfortable loudness levels, however, the degree of asymmetry (in the pure tone average between the two ears) in participants with sensorineural hearing impairment did not affect most comfortable loudness level.

II. Speech recognition scores (SRS)

The speech recognition abilities are adversely affected in individuals with sensorineural hearing impairment (Festen & Plomp, 1983). However, studies have shown that the speech recognition performance depends upon the extent of damage to the cochlea or degree of hearing loss (Revoile, Pickett, Holden-Pitt, Talkin & Brandt, 1987; Dubno, Dirks & Ellison, 1989). 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 (Table 4.3).

Table 4.3: Mean and SD of SRS in amplification to better ear condition (SRSb), amplification to poorer ear condition (SRSp) and binaural amplification condition (SRSbin)

	Group I (Symmetric hearing loss)		*Group II (Asymmetric hearing loss I)*		*Group III (Asymmetric hearing loss II)*	
	Mean (dB HL)	*SD*	*Mean (dB HL)*	*SD*	*Mean (dB HL)*	SD
SRSbin	21.87	2.16	22.85	1.34	23.14	1.21
SRSb	21.00	2.00	20.14	1.06	20.57	0.97
SRSp	20.87	1.64	17.42	0.97	15.71	0.75

The mean difference between SRSbin and SRSb or SRSp is highest in Group III followed by Group II and then by Group I.

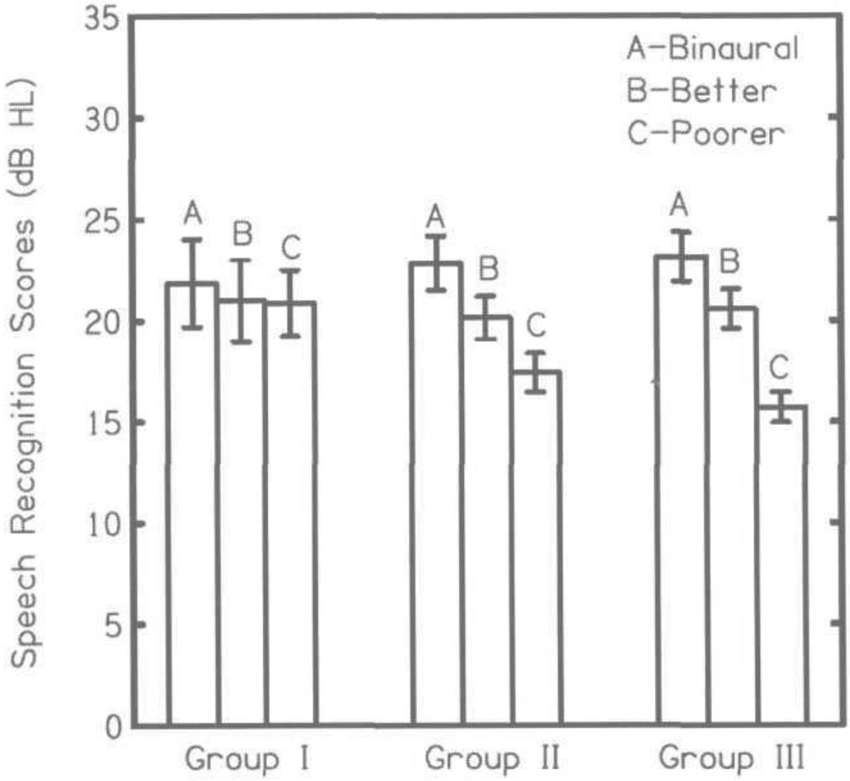

Figure 4.2: Mean and SD of SRS in amplification to better ear condition (SRSb), amplification to poorer ear condition (SRSp) and binaural amplification condition (SRSbin) in three groups of participants.

To know if there was a significant main effect of the amplification conditions on SRS in each of the three groups of participants repeated measures ANOVA was carried out. Bonferroni post-hoc analysis was carried out to reveal any significant differences between scores of the three groups in three amplification conditions.

Group I (Symmetrical Hearing loss)

To know if there was main effect of amplification conditions on SRS repeated measures ANOVA was carried out. Results revealed no significant main effect of the amplification conditions on SRS [$F (2, 14) = 2.38$; $p > 0.05$]. That is that the 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 (Villchur, 1973; Ching, Dillon & Byrne, 1998). Since participants with symmetrical hearing loss had almost similar thresholds in both ears, binaural amplification did not result in significant difference among the three amplification conditions. Though the improvement may not be significant in quiet, improvement in the presence of noise should be studied. The benefit of binaural amplification in symmetrical hearing loss may also be reflected if auditory deprivation effect due to monaural amplification is also studied.

Group II (Asymmetrical Hearing loss I)

The main effect of the amplification conditions on SRS was investigated using the repeated measures ANOVA. The results 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 in 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 condition ($p<0.05$). Further, from Table 4.3 it can be noted that the SRS is best in the binaural amplification condition followed by amplification to the better ear and then followed by amplification to the poorer ear. Hence, it can be inferred that amplification in binaural condition 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 (Day, Browning & Gatehouse, 1988; Feuerstein, 1992; Gelfand, Silman & Ross, 1987). The results are in disagreement with the study by Rothpletz, Tharpe, and Grantham (2004) who observed the results in asymmetrical degradation condition, but not on individuals with asymmetrical hearing loss.

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 than compared to monaural amplification, either to better ear or poorer ear only condition. This finding 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. In their study, the participants achieved 17% to 18% better speech recognition in PB tests and a 2 to 3 dB lower SNR ratio in binaural condition compared to the 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 SRS in binaural amplification condition was better in Group III when compared to Group II, which in turn was better than Group I participants (Table 4.4).

Table 4.4: Mean and SD of the SRS in binaural amplification condition (SRSbin) in the three groups of participants

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

To know if there was a significant main effect of degree of asymmetry of hearing loss on the speech recognition scores in binaural amplification condition in three groups of participants, a One-way ANOVA was carried out. The results did not reveal any 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 preformed 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; Turner & Cummings, 1999).

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

The present study also analyzed the correlation between the degree of asymmetry of hearing impairment and SRS. Spearman's correlation analysis revealed no significant correlation between the degree of asymmetry of hearing loss and SRS in binaural amplification condition ($p = 0.28$; $p>0.05$ for Group I, $p = 0.38$; $p>0.05$ for Group II and $p = 0.20$; $p>0.05$ for Group III). This implies that, SRS in binaural amplification condition does not vary with the degree of asymmetry between the ears in individuals with bilateral asymmetric hearing loss.

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

For studying the relationship between asymmetry of aided monaural MCL between the two ears and SRS in binaural amplification condition Spearman's correlation analysis was used. It 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 ($p = 0.16$; $p>0.05$ for Group I and $p = 0.32$; $p>0.05$ for Group III) and a significant correlation for Group II ($p = 0.77$; $p<0.05$ for Group II). Thus, SRS in binaural amplification condition does 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 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. It is to be noted that lower values of SNR in participants indicate good speech recognition performance in the presence of noise. This is true even when the difference between the signal and noise is less. For establishing the SNR, the level of the speech is kept at a constant level and the level of noise is varied till at least 50% score is obtained on speech recognition task. A low SNR means that the recognition of speech signal occurs even when the noise levels are close to the levels of the signal. This can be attributed to the benefit obtained from binaural advantage including factors such as increased audibility and improved speech recognition abilities in the presence of noise.

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

It can be observed from Table 4.5 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. As mentioned earlier, lower SNR values indicate that the participants performed well even when difference between speech and noise was very lesser.

Table 4.5: Mean and SD of SNR in binaural amplification condition (SNRbin), amplification to better ear condition (SNRb) and amplification to poorer ear condition (SNRp)

	Group I (Symmetric hearing loss)		*Group II (Asymmetric hearing loss I)*		*Group III (Asymmetric hearing loss II)*	
	Mean (dB)	*SD*	*Mean (dB)*	*SD*	*Mean (dB)*	*SD*
SNRbin	1.50	2.32	-0.28	2.43	2.00	0.00
SNRb	3.75	1.66	4.00	1.15	4.85	1.06
SNRp	4.00	2.61	6.57	1.51	9.71	2.13

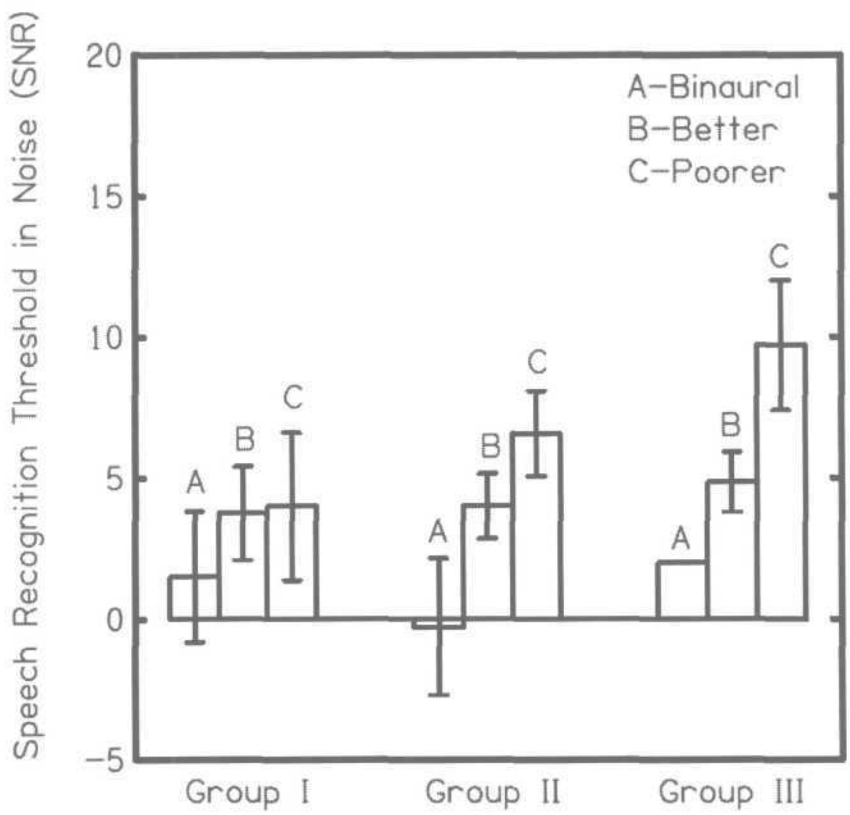

Figure 4.3: Mean and SD of SNR in A. binaural amplification condition (SNRbin), B. amplification to better ear condition (SNRb) and C. amplification to poorer ear condition (SNRp) in three groups of participants.

To investigate if there was a significant main effect of the amplification conditions on SNR in the participants in the three groups, repeated measures ANOVA was carried out.

Group I (Symmetrical Hearing loss)

To examine if there was a significant main effect of the amplification conditions on SNR, repeated measures ANOVA was carried out. This 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 in SNR between amplification to better ear and binaural amplification condition ($p<0.01$) and between amplification to poorer ear and binaural amplification condition ($p<0.05$). However, there was no significant difference between amplification to better ear and amplification to poorer ear condition ($p>0.05$). 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. Previous studies have reported the benefits of providing audible speech to listeners with sensorineural hearing loss when the speech is presented in a background noise. 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. This indicates that the participants obtained lower SNRs with binaural amplification than monaural amplification to either better ear or 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)

To investigate the main effect of amplification conditions on SNR repeated measures ANOVA was carried out. Results 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 in SNR between better ear amplification and binaural amplification condition ($p<0.05$), between poorer ear amplification and binaural amplification condition ($p<0.001$) and between better ear amplification and poorer ear amplification condition ($p<0.01$). This indicated that binaural amplification was better than either ear amplification alone. In the monaural condition, amplification to the better ear was better than amplification to the poorer ear alone.

Group III (Asymmetrical Hearing loss II)

To investigate the main effect of amplification conditions on SNR, repeated measures ANOVA was carried out. It 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 in SNR between better ear amplification and binaural amplification condition ($p<0.05$), between poorer ear amplification and binaural amplification condition ($p<0.001$) and between better ear amplification and poorer ear amplification condition ($p<0.05$). The findings indicated that binaural amplification was better than either ear amplification alone. In the monaural condition, amplification to the better ear was better than amplification to the poorer ear alone.

Previous studies have reported the effect of degree of asymmetry on the speech recognition abilities in the presence of noise (Plyler & Fleck, 2006; 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 compared to binaural amplification condition in participants with asymmetrical 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 the binaural hearing aids originally fit for each individual were not providing substantial benefit when listening in a competing babble background. Word-recognition performance when aided monaurally in the better ear was superior to the performance when aided monaurally in the poorer ear and when aided binaurally. This may be attributed to the fact that the participants had a higher degree of asymmetry and the poorer ear speech recognition abilities were deteriorated even in the presence of monaural amplification. However, speech recognition abilities were better when monaural amplification was provided to the better ear only. Binaural amplification, in this case, did not provide much benefit due to the binaural interference.

Henkin, Waldman, and Kishon-Rabin (2007) compared speech recognition in noise in elderly individuals with bilateral symmetrical mild-to-severe sensorineural hearing loss. They were initially fitted with binaural hearing aids while they used monaural hearing aid. The results of their study indicated comparable mean group performance while using monaural versus binaural amplification. For most of the individuals (71%), however, speech recognition in noise was better while using monaural amplification to the 'better' ear compared to binaural amplification. The results suggested that for elderly individuals, bilateral amplification might not always be advantageous for speech recognition in noise.

Walden, and Walden (2005) suggested that bilateral amplification may not always be beneficial in daily listening environment when background noise is present, and it may be advisable for individuals wearing bilateral amplification to remove one hearing aid when difficulty is encountered understanding speech in background noise.

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. One-way ANOVA carried out to find if there was a significant main effect of degree of asymmetry of hearing loss on SNR in binaural amplification condition in three groups of participants. Results revealed that there was 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 4.6: Mean and SD of SNR in binaural amplification condition (SNRbin) in three groups of participants

Groups	*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 upon the degree of asymmetry in individuals with hearing impairment. The results of the present study regarding effect of degree of asymmetry on speech recognition abilities in noise are in consensus with that reported in earlier study (Posner & Ventry, 1977).

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

In the present study, the correlation between the degree of asymmetry of hearing impairment and SNR was also analyzed. Spearman's correlation analysis revealed no significant correlation between the degree of asymmetry of hearing loss and SNR in binaural amplification condition (p = 0.32; p>0.05 for Group I, p = 0.34; p>0.05 for Group II and p = 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 ($p = 0.00$; $p>0.05$ for Group I, $p = 0.75$; $p>0.05$ for Group II and $p = 0.32$; $p>0.05$ 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.

The results of the present study are summarized in the form of a table (Table 4.7) given below.

Table 4.7: Significance levels for different groups of participants for different amplification conditions

Group	*Amplification Conditions*	*Most Comfortable Level (MCL)*	*Speech Recognition Scores (SRS)*	*Speech Recognition Threshold in Noise (SNR)*
I	Binaural-Better ear	**	-	**
	Binaural-Poorer ear	**	-	*
	Better-Poorer ear	-	-	-
II	Binaural-Better ear	*	***	*
	Binaural-Poorer ear	***	***	***
	Better-Poorer ear	***	*	**
III	Binaural-Better ear	***	***	*
	Binaural-Poorer ear	***	***	**
	Better-Poorer ear	**	***	*

Note. * : $p<0.05$; ** : $p<0.01$; *** : $p<0.001$; -: $p>0.05$

From Table 4.7, it may be inferred that, among the amplification conditions, the performance of all participants was significantly superior in the binaural amplification condition than in the monaural amplification conditions (either better ear or poorer ear). Among the monaural amplification conditions, the performance of all the participants was significantly superior with amplification in the better ear compared to amplification in the poorer ear.

CHAPTER - 5

SUMMARY AND CONCLUSION

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 specific objectives of the study were:

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.

Twenty-two participants with varying degree of asymmetrical sensorineural hearing loss were included in the study. The participants were assigned to one of the following three groups based on the degree of hearing loss in the ears.

Group I consisted of participants having symmetrical sensorineural hearing loss with the difference between the pure tone average (PTA for 500 Hz, 1000 Hz, and 2000 Hz) of the right and left ears within 15 dB.

Group II consisted of participants having a lesser extent of asymmetrical sensorineural hearing loss with the difference in the PTA of the right and left ears between 16 dB and 25 dB.

Group III consisted of participants having a greater extent asymmetrical sensorineural hearing loss with the difference in the PTA of the right and left ears between 26 dB and 35 dB.

The data were collected in two phases:

In the first phase, digital BTEs were programmed for each participant and aided MCL were established in three amplification conditions (binaural amplification, amplification to the better ear, amplification to the poorer ear). In the second phase, speech recognition scores and speech recognition threshold in noise in terms of SNR were measured in three amplification conditions (binaural amplification, amplification to the better ear, and amplification to the poorer ear).

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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APPENDIX - A

Phonemically Balanced Word List Developed by Yathiraj and Vijayalakshmi (2005).

raita	tʃukki	huḷu	va:tʃu
anna	hagga	su:dzi	hoṭṭe
mola	batta	roṭṭi	do:ṇi
tʃa:ku	mantʃa	gu:be	vadzra
tuṭi	bekku	akka	va:ṇi
me:ke	lo:ṭa	e:ḷu	tale
ha:vu	ba:la	vi:ṇe	katte
kattu	dze:bu	dimbu	me:dzu
bi:ga	manḍi	vaḍe	na:ji
o:du	noṇa	go:li	ba:lu
baḷe	maḷe	ha:lu	ni:li
mu:ru	ṭi:vi	amma	gombe
ra:ṇi	di:pa	dzana	ka:ge
kappu	rave	ravi	adu
ta:ra:	moḷe	tande	dra:kʃi
braʃu	railu	rakta	bæ:gu
hasu	ka:ru	suttu	kaʃta
dzaḍe	divja	ja:va	paisa
nalli	a:ru	tʃandra	mara
kivi	pu:ri	ja:ke	hu:vu
kaʃta	haddu	ʃa:le	tinnu
ja:ru	suʃma	aidu	iḍli
da:na	ta:ji	nadi	ke:ḷu
ʃampu	dana	uppu	sara
ili	ʃa:lu	kriʃna	pada

APPENDIX-B

Word list with a combination of low-mid, low-high and high-mid frequency speech sounds

	Low-Mid	Low-High	High-Mid
1)	/gu:be/	/nalli/	/tʃa:ku/
2)	/me:ke/	/sɛ:bu/	/ko:Li/
3)	/bi:ga/	/mola/	/la:ri/
4)	/mu:gu/	/bassu/	/d̪a:ra/
5)	/rave/	/baLe/	/kivi/
6)	/kaNNu/	/d̪ana/	/tʃikka/
7)	/ni:ru/	/tʃindi/	/i:ruLLi/
8)	/mara/	/ni:vu/	/kuTTu/
9)	/kone/	/mi:se/	/tʃakra/
10)	/pu:ri/	/t̪inDi/	/ʤinke/
11)	/bekku/	/haNa/	/raʤa/
12)	/ganTe/	/suma/	/si:re/
13)	/ru:pa/	/biLi/	/gaŋTe/

14) /nid̪re/	/tand̪e/	/kat̪t̪i:/
15) /kabbu/	/tʃenDu/	/giNi/
16) /magu/	/d̪o:Ni/	/vitʃa:ra/
17) /kappu/	/dʒi:pu/	/se:ru/
18) /bi:ru/	/To:pi /	/ko:ti/
19) /na:ri/	/bila/	/tʃikka/
20) /mu:ru/	/ ba:vi /	/rutʃi/
21) /kemmu/	/ni:li/	/suk^{h}a/
22) /pad̪a/	/baTlu/	/i:ruLLi/
23) /ravi/	/d̪i:pa/	/kelasa/
24) /reppe/	/Dabbi/	/katte/
25) /buguri/	/ hind̪e/	/KuLLi/
26) /kombe/	/ivanu/	/roTTi/
27) /ra:Ni/	/bi:dza/	/ko:su/
28) /ma:rga/	/baTTe/	/iruve/
29) /pennu/	/moLe/	/sari/

30) /gamana/	/tamma/	/guDi/
31) /rama/	/meTlu/	/gedʒdʒe/
32) /be:ru/	/beTTa/	/railu/
33) /maŋga/	/me:dʒu/	/rasa/
34) /guNa/	/ba:Le/	/ka:su/
35) /pa:naka/	/no:vu/	/ke:Lu/
36) /kappe/	/bassu/	/kelavu/
37) /nu:ru/	/ma:tre/	/tʃakli/
38) /gombe/	/noDu/	/kaDDi/
39) /ramja/	/haNNu/	/ka:fi/
40) /nuŋgu/	/beTTa/	/go:De/

APPENDIX - C

suḷḷina p^{h}ala

ondu haḷḷijalli obba kuruba huḍuga va:sava:giddanu. avanu mundza:neje: ka:ḍige ho:gi allije: dz^{h}arijalli sna:na ma:ḍi sandzejavarege kurijannu me:jisi, sandze haḷḷige va:pa:sa:guttidda. omme avanu kuri me:jisuva:ga iddakkiddanteje: hattirada holadalli kelasa ma:ḍuttidda raitarannu tama:ʃe ma:ḍa be:ku endu konḍa. anteje: avanu ajjo! huli! huli! ka:pa:ḍi endu ku:ga toḍagida. idannu ke:ḷida raitaru k^{h}aḍgagaḷannu tegedukonḍu hulijannu kollalu sidd^{h}ara:gi o:ḍi bandaru. idannu noḍida huḍuga nakku biṭṭa. raitaru ko:pagonḍu va:pa:sa:daru. huḍuga ide: ri:ti aida:ru ba:ri ma:ḍida. raitaru a: huḍugana me:lina nambike kaḷedu konḍaru.

omme suma:ru hanneraḍu g^{h}anṭe, bisilu ta:ḷala:rade huḍuga tʃ^{h}atri jannu hiḍidu kuḷittidda. iddakkiddante nidzava:giju ṭ^{h}akka huli bande: biṭṭittu. huḍuga matte ka:pa:ḍi! ka:pa:ḍi ! endu tʃi:rida. a:dare ja:ru saha avana saha;jakke baralilla. huliju avana saṇṇa saṇṇa kurigaḷannu kollala:ramb^{h}isitu. adannu ka:pa:ḍalu ho:da a: huḍugana mele a: huli ha:ri, avanannu konditu.
i: kat^{h}eja ni:ti enendare “suḷḷuga:ranige ʃikʃe tappadu".