EFFECT OF MICROPHONE DIRECTIONALITY ON HORIZONTAL LOCALIZATION AND SPEECH IDENTIFICATION IN NOISE IN CHILDREN WITH BINAURAL HEARING AIDS

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MAY, 2014

DEDICATED TO MY FAMILY,

TEACHERS & FRIENDS…

CERTIFICATE

This is to certify that this dissertation entitled **"EFFECT OF MICROPHONE DIRECTIONALITY ON HORIZONTAL LOCALIZATION AND SPEECH IDENTIFICATION IN NOISE IN CHILDREN WITH BINAURAL HEARING AIDS"** is the bona fide work submitted in part fulfillment for the degree of Master of Science (Audiology) student with Registration Number 12AUD024. This has been carried out under the guidance of a faculty of this institution and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"EFFECT OF MICROPHONE DIRECTIONALITY ON HORIZONTAL LOCALIZATION AND SPEECH IDENTIFICATION IN NOISE IN CHILDREN WITH BINAURAL HEARING AIDS"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This dissertation entitled **"EFFECT OF MICROPHONE DIRECTIONALITY ON HORIZONTAL LOCALIZATION AND SPEECH IDENTIFICATION IN NOISE IN CHILDREN WITH BINAURAL HEARING AIDS"** is the result of my own study under the guidance of Mrs. N. Devi, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CHAPTER 1

INTRODUCTION

Individuals with normal hearing acuity use binaural listening for different processes like better listening in noisy environment, localization of the sound source. Hence, bilateral stimulation through two separate hearing aids / cochlear implants or using both (bimodal stimulation) is becoming popular in rehabilitation of children with bilateral hearing impairment. The major claims of the advantages of bilateral amplification for hearing impairment are similar to binaural hearing which includes improved speech intelligibility, especially in an adverse listening condition, improved sound quality, ability to focus attention to the desired signal in presence of unwanted background noise (the squelch effect) and a higher level of localization ability (Koenig, 1950 & Dillon, 2001).

Auditory localization refers to the ability of a person to locate the sound source in space. It is very important in a daily life listening situations. It helps to alert a listener for getting awareness about a potential danger. For e.g. in traffic, it also helps in listening noisy environment, by aiding to find out the signal source and so the listener can give more attention to that source (Keidser et al., 2006; Devore et al., 2009).

According to Blauert, (1983) the inter aural differences in time, phase and level (ITD, IPD and ILD respectively) are the major cues in localization. ITD and IPD occur coincidently and IPD vary systematically with source azimuth and wavelength. IPDs dominate in localizing the low frequency sounds (up to 1.5 kHz). The head act as a barrier in transmission of sound from the side of one ear to the other ear and cause intensity difference in sound, called as Interaural Level Differences (ILDs). ILDs are the most prominent cue in localizing high frequency sounds (above 1.5 kHz) and can result in up to 20 dB a difference between the two ears at 6 kHz. The spectral cues are also there which are due to the shape of the head and the folds and convolutions of the pinna. These spectral cues help mainly for vertical localization of broadband high frequency sounds (4-12 kHz) (Moore, 1997)

A. Effect of Hearing Loss on Localization Abilities

The major impact of hearing loss on localization is the lack of audibility. The horizontal localization becomes poorer when the bilaterally averaged hearing threshold is about 50dB HL or above (Flamme, 2002). Other factor that affects localization ability includes distorted ILD and ITD cues, decreased frequency and temporal resolution. Macpherson and Cumming (2012) reported that even when audibility is compensated, individuals with low-frequency hearing impairment performed poorly in many localization tasks.

Localization performance improves when signals are presented at supra-threshold levels in sensorineural hearing loss and this improvement is higher when compared with conductive hearing loss. The transfer of a large amount of signal energy through bones and skull in conductive pathology causes signals through right and left ears reaches the respective cochleae at the same time. Hence, the Interaural differences become less effective in giving cues for localization. This is considered as the major reason for the disparity in localization performance between sensorineural and conductive hearing loss.

Noble, Byrne and Lepage (1994) studied the effect of configuration and type of hearing impairment on sound localization. The study was conducted in a group of 87 people with bilateral hearing impairment and checked both horizontal and vertical localization. The results had shown the effect of frequency dependent inter-aural difference cues in localization.

B. Effect of Hearing Aid on Localization Abilities

Theoretically, the localization ability should improve when bilateral hearing aids fitted. In terms of horizontal localization, the restoration of audibility can be taken a reason for this. Because, at least in case of mild to moderate sensorineural hearing loss, the decreased localization ability is mainly due to the reduced audibility of signal rather than difficulty in utilizing the localization cues that are at supra-threshold levels (Ibrahim, 2013).

For naive users of hearing aid, localization is likely to be disrupted because different signal processing features in the hearing aids distort the familiar localization cues. However, some evidences are there to support that adaptation can occur in hearing aid users for ITD and ILD distortions. The improvement can be seen within a few hours and continues for a few days and, to a lesser extent, for a few weeks (Bauer, Matusza & Blackmer, 1966; Byrne & Dirks, 1996; Ibrahim 2013). This improvement might be resulting from the fact that binaural hearing aids increase the amount of signal energy that is transferred via the air-conduction pathway, this in turn increase the cochlear isolation and making binaural differences more detectable and useful (Flamme, 2002).

Van den Bogaert et al. (2006) studied the effect of bilateral independent hearing aids in localization. The examination was done for both aided and unaided localization skills in subjects with hearing impairment. Normal hearing group was taken as reference. They found that subjects with binaural hearing aids poorer in localization task compared to subjects with normal hearing but, one half of hearing aid users had a near normal localization skills when tested with no hearing aids. In addition, for hearing aid group, the localization performance was significantly lower in noisy conditions. Based on this, they authors concluded that two hearing aids which are processing the signal independently are not able preserve cues for localization and the adaptive directional noise reduction can have an additional and significant negative impact on localization performance.

This findings inspired many researchers to think about the effect of different hearing aid parameters in sound localization. Such studies include effect of hearing aid technologies such as wide dynamic range compression (WDRC), microphone configuration (multi-band adaptive directionality), mismatched microphone mode, digital noise reduction algorithms etc. on horizontal sound localization and speech intelligibility.

Keidser et al. (2006) tested the effect of applying multi-band WDRC on the localization abilities of hearing aid users who had symmetrical hearing loss. The authors concluded that the distortion of ILDs and spectral cues caused by the multi-channel WDRC did not significantly affect the localization performance. It can be due to the unaffected ITD cues that helped preserve the localization performance. Further, the microphone mismatch between two hearing aids in binaural fitting also results in affected localization abilities. In this case, applying different directional microphone modes may cause more disruption to the interaural cues than would a pair of omnidirectional microphones. ITDs will be distorted because the internal time delays used to implement each specific polar pattern are different. ILDs are distorted as well because of two factors. first one is the changes in polar pattern response shapes due to head and the free-space directivity patterns and second one is the difference in gain frequency responses (which depends the location of sound source) between each side. Spectral cues will be affected also with a microphone mode mismatch between the two ears, as polar patterns tend to vary with frequency.

C. Effect of Hearing Loss on Speech Perception in Noise

Difficulty in understanding of speech especially in noisy conditions is one of the major complaints raised by individuals with sensorineural hearing loss. There are an ample of studies which shows even with mild sensorineural hearing loss , individuals faces a great difficulty in understanding speech in presence of noise than subjects with normal hearing (Plomp,1978 ; Plomp & Mimpen, 1979; Plomp & Duquesnoy, 1982). This difficulty may be attributed by an attenuation factor, which results in reduced audibility of both speech and noise and a distortion factor which cause reduced SNR. The variability in performance across individuals may be because of the variability in the different combination of attenuation and distortion factors. Different etiologies of hearing loss could result in different combinations of attenuation and distortion (Plomp& Duquesnoy, 1982).

D. Effect of Hearing Aid Speech Perception in Noise

There are studies related to the effect of hearing aid features on speech intelligibility in noise. The effect of WDRC in speech in noise understanding has studied by different researchers, and most of them failed to give evidence for improved performance with WDRC. (Dillon, 1996; Moore et al., 1999; Souza et al., 2000). Souza et al. (2006) attempted to measure the acoustic effects of WDRC on speech intelligibility in noise and found that there is degradation in output SNR s when WDRC is used.

Another feature of hearing aid which is widely studied is the directional microphones in hearing aid. It has been proven that SNR improves with directional microphone mode (Kim & Bryan, 2011). The directional microphones have a positive effect on speech reception thresholds compared to unaided and omnidirectional microphone conditions (Boymans & Dreschler, 2000; Valente & Mispagel,2008; Quintino et al., 2010 ; Tawfik et al., 2010).

E. Binaural Benefits in Children with Bilateral Cochlear Implant and / or Hearing Aids

Several studies supports that there is an improvement in sound localization abilities and speech perception in noise with binaural cochlear implant or bimodal stimulation compared to unilateral cochlear implantation and unaided condition. The improvement were seen in many measures of binaural advantages such as minimum audible angle in localization, BMLD etc. (Litovsky, Johnstone & Godar, 2009; Beijen et al., 2010)

Need For the Study

Most of the studies mentioned above have been done in adult population with post-lingual hearing impairment. There is relatively longer time of normal hearing experience in adults before the acquisition of hearing loss may have a different effect in the localization and speech intelligibility in noise, even after the acquisition of hearing loss. Children who acquired hearing loss before developing most of auditory skills will have a lesser efficiency in using binaural cues with the hearing compared to adults with post-lingual hearing loss. Reviewing the literature, there is dearth of research, whether the children using binaural hearing aid receive a benefit from bilateral input and is there any effect of hearing aid features on utilizing binaural cues.

Aim of the Study

The aim of the current study is to find out the effect of microphone directionality on horizontal localization and speech identification in noise in children with binaural hearing aids.

Objectives of the Study

- To evaluate the effect of microphone directionality modes (directional Vs omnidirectional) in horizontal localization in children with binaural hearing aids.
- To evaluate the effect of microphone directionality modes in speech identification in noise in children with binaural hearing aids
- To compare localization abilities and speech identification in noise in children with binaural hearing aids and in children with normal hearing sensitivity of same age range.

CHAPTER 2

REVIEW OF LITERATURE

A. Horizontal Localization and Speech identification in noise

Localization may refer to the ability to judge the direction and distance of sound source in space (Moore, 1997). The "binaural" and the "monaural" cues (Yost & Gourevitch, 1987) provide this ability. Binaural cues are inter-aural time difference (ITD) or interaural phase difference (IPD) and interaural level difference (ILD) (Middlebrooks & Green, 1991). The head, body and pinna will cause changes in stimulus spectrum changes and this provide cue for localization.

The sound localization is affected in persons with hearing impairment because of the inability to utilize the above mentioned localization cues resulting from the limited availability of auditory information,

Another important advantage of binaural hearing is the easiness in perceiving speech in background noise. Two phenomena, i.e. head shadow effect and the binaural squelch helps to listen in noisy situations (Byrne, 1981). The ILD and ITD cues as well as many other factors such as nature and relative location of noise in space etc. also influence the speech perception in noise. As in case of localization, speech perception in noise is also affected in subjects with hearing impairment since the reduced audibility as well as distortion factor which cause reduced functional SNR.

B. Localization and speech perception in children Vs Adults

Children develops the ability to directly localize sound in all direction at the age of 21 to 24 months (Northern & Downs, 2002). However, many measures of horizontal localization performance become adult like at the age of 5 years as reported by Van Deun et al (2009).

Van Deun et al (2009) assessed the spatial hearing in children with normal hearing. There were 49 children of age range 4 years to 9 years. They have assessed sound localization, sound lateralization and binaural masking level differences. For sound localization they used a broadband noise (a bell ring) presented through one of 9 speakers arranged between +60^o to -60^o. Both Root Mean Square (RMS) error and Mean Absolute Error (MAE) were taken as a measure for localization. Median MAE for ages 4 years, 5 years and 6 years olds were 5^o, 2^o and 1^o respectively. For the RMS error, it was 10^o, 6^o, and 4^o. There was no significant difference among 5years, 6 years and adults in localization. Similar results were found in BMLD tasks also. However there was significant difference between adults and children of all three age groups in lateralization task. Litovsky and Godar (2010) also got similar degree of error in children with normal hearing. From these findings it is confirmed that some children may shows adult like localization at the age of 4-5 years and some may take little more time for adult like localization accuracy.

Litovsky and Godar (2010) studied the absolute localization for single source stimuli and for dual source lead-lag stimuli by comparing precedence effect in 4–5 year old children and adults. They have included nine children of age range 4.4 years to 5.8years old and 10 adults with mean age of 22 years. Pink noise bursts of 25 ms duration with 2 ms rise/fall times, presented at a rate of 4/s as stimulus. RMS error was calculated as a measure of localization. Two conditions were tested. Single source condition in which the task was to identify sound source and lead-lag (two sources) listener's Lister had to point the one of two speakers from which the lead or first sound is coming. In case of not hearing two different sounds, then task was similar to single source condition. Different delay timings (5, 10, 25, 50 and 100 ms) were introduced in lead-lag condition. For single source localization, the RMS error is clearly emerging and reaching near-adult performance in some of the children. For lead-lag conditions, both age groups had good localization at short delays up 10ms. This may suggest that the presence of the lag did not disrupt sound localization when the two sounds are heard as single sound.

D. Effect of hearing Loss on localization and speech perception in noise

Localization may be affected even in people with mild hearing impairments. It may due to the lack of audibility**.** The signal should be audible to get it localized in the space. So, audibility is highly important in localization. Studies have shown that the performance localization task remains essentially near normal until bilaterally averaged pure tone thresholds become around 50dB HL even in low SNRs. However, the localization performance becomes poorer as pure tone thresholds increases and this decrement cannot be attributed entirely to audibility (Flamme, 2002).

Noble, Byrne, and Lepage (1993) tested horizontal and vertical localization in 87 subjects with bilateral hearing impairment to find out the effect of configuration and type of hearing loss on localization. Hearing impaired group consisted of 66 subjects with sensorineural hearing loss and 21 subjects with conductive/mixed hearing loss. The control group includes 6 adults with normal hearing. Four different spatial regions viz. Frontal horizontal plane (FHP), Medial vertical plane (MVP),Lateral horizontal plane(LHP) and Lateral vertical plane(LVP) were taken for analysis. The analysis was done in both Sensorineural and conductive/mixed group also. In those with sensorineural hearing loss, it was found that deficits in localization could be related to different configurations of hearing loss. They also found that conductive component has a significant effect on localization. These findings revealed hearing loss and localization has at least a moderate correlation, suggesting that aspects of hearing impairment, in addition to simple attenuation, may also reduce auditory localization performance.

Noble et al (1994) reported evaluated the effect of hearing thresholds and the localization abilities in subjects with hearing impairment and in subjects with normal hearing. The study was done in two groups of subject. The first groups consisted of subjects with bilateral sensorineural hearing loss, mixed or conductive hearing loss and group 2 consisted subjects with normal hearing. Stimulus for localization task was pink noise bursts presented at maximum comfortable level and the average level of Hearing threshold and Maximum comfort level. Results showed a correlation between localization accuracy and hearing threshold was 0.3 to 0.4 in subjects with sensorineural hearing loss. Low frequency hearing had a slight effect on frontal plane localization and low and mid to high frequency hearing had effect on lateral plane horizontal localization. However, in general there was only a mild predictive power for hearing thresholds on localization performance. Other factors such as reduced frequency selectivity, intensity and temporal resolution and some pinna's physical properties may also plays role in localization performance.

Bronkhorst and Plomp (1988) assessed the speech intelligibility in noise indirectly by finding out the effect of hearing loss on ITD and ILD cues. They simulated unilateral hearing loss in subjects with normal hearing. Another group of subjects included listeners with hearing impairment. Their result showed more effect of noise on speech perception in listeners with hearing impairment than listeners with normal hearing. The relative gain due to the ITD was not significantly different in both groups. Binaural Intelligibility Level Difference (BILD: the difference in signal level in decibels between two binaural conditions for a given percent intelligibility) was used to get the contribution of ITD in speech perception task. The usefulness of ITD cues were varied within group of hearing impaired which suggests that there are other factors also present in determination ITD usefulness other than audibility. The poor performance of speech perception in noise with binaural hearing aided condition may indicate that the Hearing impaired listener's inability to take ILD cues effectively. In short, the listeners with hearing impairment fails to take ILD and ITD cues and perform poorly in speech perception in noise tasks when compared to normal hearing subjects who had a simulated hearing impairment.

Individuals with normal hearing require at least Signal to Noise Ratio (SNR) of +6 dB for perception of speech (Moore, 1997). Individuals with SNHL needs even better SNR. Children with hearing loss face more difficulty in low SNR compared to adults. (Sutter, 1985; Crandell & Smaldino, 2000 ;Ricketts,2001).

E. Effect of microphone directionality and other hearing aid technologies on Localization and speech perception in noise

One of the methods to improve SNR is directional hearing aids works based on the spatial location of the signal of interest relative to unwanted signals. Directional hearing aids can give approximately 3-6dB improvement; hence can give improved speech recognition across a range of noisy environments when compared to omni-directional amplification (Ricketts, 2001).

Speech recognition in fifty adults with mild to moderately severe sensorineural hearing loss was assessed by Valente, Fabry, and Potts (1995). All subjects were using behind the ear hearing aids. They have used Hearing in noise test (HINT) in two microphone modes with four programs. Single microphone-omnidirectional(with basic NAL-R frequency response and 'party' frequency response) and dual-microphone directional mode(with basic NAL-R frequency response and 'party' frequency response). The SNR at which 50% correct score obtained was taken as a measure. Comparison made across four conditions revealed that there is improvement in SNR for directional mode in both basic and party frequency response over omnidirectional mode. They reported an average SNR improvement of 7.4 to 8.5 dB in directional condition compared to omnidirectional mode. Similar results were obtained in In The Ear (ITE) type hearing aids also as reported by Valente, Schuchmant, Potts, and Beck (2000).

Gravel et al (1999) studied the speech recognition in noise in 20 children with mild to moderate severe hearing loss. They have checked two microphone conditions with binaural hearing aids. First, using omni-directional hearing aid and second, dual microphone hearing aid technology. The children were grouped in to 2 groups based on age, 4 to 6 years and 7 to 11 years. The test materials were words and sentences from Pediatric speech intelligibility (PSI) developed by Jerger and Jerger in 1984. The background noise was a multitalker babble. Speech stimuli presented from 0o azimuth and the noise presented from a speaker placed one meter behind the subject at 180 o azimuth. They found a significant difference between two microphone conditions, between the two age groups and the two stimuli types in terms of SNR that yielded 50% correct recognition both stimuli. There was a mean advantage of 4.7 dB SNR for dual microphone condition over omni-directional condition. Better SNRs are seen for older group of children irrespective of stimuli type and microphone conditions and for sentences irrespective of age group and microphone conditions.

Köbler and Rosenhall (2002) studied the horizontal localization and speech intelligibility with bilateral and unilateral hearing aid amplification in 19 adults with mild to moderate sensorineural hearing loss. The horizontal localization task includes an array of 8 loudspeakers in horizontal plane with 45o difference between them. Number of correctly identified sources was taken as measure of localization performance. 50% scores were obtained in both unaided and bilateral aided condition whereas in unilateral aided condition the performance was very poor, on an average only10%. Authors concluded that horizontal localization could not be improved by bilateral hearing aid fitting. However, bilateral hearing aid fitting has significant advantage on localization over unilateral hearing aid fitting. Speech in noise test with Swedish sentences by Hagerman, 1982 was used. It was measured as a percentage of correctly identified words. The poorest scores occurred in unaided condition. There was an improvement of 13% with unilateral aided condition and 18% with bilateral aided condition in speech intelligibility scores. The difference was statistically significant.

Keidser et al (2006) studied the effect of directional microphones, wide dynamic range compression and noise reduction strategies on horizontal localization. Participants were 12 adults with a median age 75 years and with a puretone 3 frequency average 46dB HL. Pink noise pulses with a duration of 750 ms used as a stimulus for different conditions with omnidirectional, cardioid and figure eight microphone setups.12 speakers were arranged in a circle with 18^{o} difference. Degree of error was obtained. They concluded that fitting a cardioid (directional) microphone on at least one ear could improve front/back discrimination. The reason could be the more amplification happens to the signals from front source and suppression of signals from rear due to the cardioids (directional) microphone, whereas there is an equal amplification to signals from front and rear sources in Omni-directional and figure eight microphone condition. The difference in amplification for front and back at least in one side may have an effect in front/back localization of sound. However, the authors also mentioned that, this effect was not present for all subjects because of some unknown factors. Their findings were correlated with the Inter aural difference measurements with KEMAR.

Van den Bogaert, Doclo, Wouters and Moonen (2008) studied the effect of multimicrophone noise reduction systems on sound source localization by users of binaural hearing aids. Two noise reduction techniques for binaural hearing aids namely, the binaural multichannel Wiener filter (MWF) and the binaural multichannel Wiener filter with partial noise estimate (MWF-N),and a dual-monaural adaptive directional microphone (ADM), which is a widely used noise reduction approach in commercial hearing aids were evaluated. Mean absolute error (MAE) taken as a measure of localization performance. MAE is defined as the sum of difference of stimulus azimuth and response azimuth divided by the total number of presentations. MAE were measured in different stimulus conditions such as noise and speech component presented separately(S,N); speech and noise components were presented simultaneously which resembled more a steady-state real-life listening situation(S+N). The results revealed that localization is highly influenced by noise reduction algorithms of hearing aid. The authors also concluded that the localization cues were preserved for certain stimuli such as speech and certain location signals such as front direction. For e.g. the localization is better for signal from front when using ADM, in which strategy very less noise reduction happened for sounds from front direction..

In another study, Keidser et al (2009) studied the effect of frequency dependent microphone directionality on horizontal localization in 21 adults. They compared the localization performance of subjects using hearing aid were compared with the normative data obtained from 30 adults with normal hearing. The spectral shape of signal will be altered based on the location of sound source in frequency dependent microphone directionality system. Five different stimuli with different spectral features were presented through loudspeakers arranged in a circular array. The localization task carried out in four conditions which includes without hearing aids, with hearing aids having no directionality, with hearing aids having partial (from 1 and 2 KHz) directionality and full directionality. There was only a small positive effect seen for full directionality in front/back localization and negative effect seen left/right localization. Partial directionality also improved front/back localization and did not show any effect on left/right localization. The performance was very poor for unaided condition and aided with no directionality conditions.

Lewis, Crandell, Valente and Horn (2004) compared the effect of directionality and FM system on speech perception in noise. Forty five subjects were taken from two sites and they had mild to severe sensorineural hearing loss. Hearing in Noise Test (HINT, by Nilsson et al, 1994) was used for assessing speech perception in noise. Correlated speech shaped noise was used as noise which is of typical acoustic spectra of every day listening situations. The reception threshold for sentences (RTS) was obtained.

The results revealed that there was improvement in mean RTS by approximately 5 dB in binaural hearing aid conditions with omnidirectional microphone mode compared to unaided condition. Also, the utilization of directional microphone gives an improvement of 1.2 dB in RTS over omnidirectional microphone mode. With FM system, there was significant improvement (of around 15.5 dB) in speech perception over any hearing aid conditions, even with the use of the directional microphone. Speech perception was even better by using two hearing aids in conjunction with two FM receivers rather than with just one FM receiver.

Chung, Neuman and Higgins (2008) investigated the effects of in-the-ear microphone directionality on sound localization in hearing protective device. Two groups of subjects participated in the study. The first group was taken as control group with 8 adults with normal hearing. The second group consisted of 8 subjects with symmetrical mild to severe Sensorineural hearing loss and had at least 6 months experience with binaural hearing aid. They tested horizontal localization performance with 16 speakers of a circular array with omnidirectional, cardioid, hypercardioid, supercardioid microphone conditions. The stimuli were recorded speech in quiet and in noise. They have compared the performance between directions versus omnidirectional microphone settings. The results showed significantly less errors with all directional microphones in quiet and noise conditions. The results also showed no degradation in performance of both normal and impaired listeners with directional microphones. The front-back and lateral localization errors were less with directional microphone compared to omnidirectional microphones.

F. Effect of asymmetry of directionality:

Some studies focused on the asymmetry in directionality of microphone (means one hearing aid with directionality and other hearing aid with no directionality in binaural hearing aid fitting).

Kim and Bryan (2011) investigated the effect of asymmetric directional microphone fittings on acceptance of background noise. Participants were 15 adults with symmetrical sensori neural hearing loss. Hearing-in-noise test (HINT; Nilsson et al, 1994) used as the stimuli for examining speech perception in noise. There were three microphone conditions i.e. binaural omnidirectional, right asymmetric, left asymmetric, and binaural directional. The presentation level was at the listener's MCL and Acceptable Noise Level (ANL) was obtained with HINT sentences. There was significant improvement in HINT scores for both the binaural directional and asymmetric directional microphone conditions compared to the binaural omnidirectional condition. ANL was worsened for the binaural omnidirectional fitting compared to two asymmetric directional conditions and the binaural directional condition. However, the scores were not significantly different for the binaural directional condition and the two asymmetric directional conditions. In addition, there was a improvement in ANL with binaural directional condition compared to asymmetric microphone condition as well as binaural omnidirectional condition. This may be due to the hearing aid's efficiency in responding to the signal and suppress background noise when both side hearing aids has directional microphone. It can be concluded that use of symmetrical directional microphone may increase the listener's ability to tolerate background noise.

G. Directional hearing aid: benefits in real life

There are some studies which focused on the benefits of directional hearing aid in real life. In such a study by Cord, Surr, Walden and Olson (2002) used telephone interviews and paper and pencil questionnaires for assessing the perceived performance with different microphone type in variety of listening situations. Initially, they have conducted a telephone interview with 112 patients and found out around 57 patients who are using both omni directional and directional microphone settings in daily living situations. They were likely to make reliable comparisons between both microphone settings. 44 patients participated for completing the Abbreviated Profile of Hearing Aid Benefit (APHAB, Cox and Alexander, 1995) and Microphone Performance Questionnaire (MPQ) developed by the authors. The analysis of both questionnaire scoring revealed that there is a strong disparity between the benefits of directional microphone technology for improved speech understanding in noise in controlled laboratory settings and that in real life situations. The patients who reported 'satisfaction' with their hearing aid during initial telephone interview does not report any difference in listening with both microphone settings in daily life.

The authors concluded that this disparity may be because of the complex and specific characteristics of the listening situations encountered in daily living. Also, there was strong preference for directional microphone when the laboratory conditions were closely matched with everyday listening situation (i.e., signal in front of and relatively close to the listener, spatial separation of the signal and the noise).However, it appears that this specific set of circumstances occurs less frequently in daily living than conditions that are less favorable to directional microphones or that actually favor omnidirectional microphone use. The findings are supported by another study by same authors in 2004. They compared the different audiological tests for speech intelligibility such as Hearing in noise Test and questionnaire score Listening Situations Survey (LSS). The results revealed a poor correlation between the laboratory findings and real life benefits regarding the microphone directionality.

Ruscetta, Palmer, Durrant, Grayhack and Ryan (2005) studied the Impact of Listening with Directional Microphone Technology on Self-Perceived Localization Disabilities and Handicaps. 50 adults were participated in this study. The first group included 20 subjects with unilateral severe-profound SN/mixed hearing loss and the second group consisted of 10 subjects with bilateral hearing loss having any degree of hearing loss. The third group included 20 subjects with normal hearing and kept as control group. There were three divisions based on the use of directional microphone. i.e. omnidirectional,directional and toggle-switch equipped amplification. They used self perceived localization disability measures and handicaps questionnaire. The results of psychometric evaluations on these revealed that any of the microphone schemes do not have a positive effect on self-perceived localization disability or handicap.

H. Spatial hearing performance in children with cochlear implants

Litovsky, Johnstone and Godar (2006) studied the benefits of bilateral cochlear implants and/or hearing aids in children ages from 4 years to 14 years. The total sample includes 20 children, among which 10 use bilateral cochlear implants and the rest 10 children use one Cochlear Implant in one ear and one Hearing aid in other ear. They measured the acuity of localization by the measure Minimum audible angle and speech intelligibility. Speech intelligibility is measured in both quiet condition and in presence of

2-talker competing speech.Speech intelligibility measured in both only CI and CI-CI/CI-HA condition shows a better SRT in bilateral aided condition. Effect was more significant in localization acuity. The Minimum audible angle is significantly lower (better) in CI-CI and CI-HA (bilateral stimulation) than unilateral cochlear implant condition. This study gives evidence about the effect of bilateral amplification in localization as well as speech intelligibility.

Van Deun et al (2009) checked RMS error in 30 children age ranges from 4 years to 15 years who used binaural cochlear implant. The error is smaller when both cochlear implants were activated. They found an rms error ranges from 13^{o} to 63^{o} which overlaps the range of normative data. Grieco- Calub and Litovsky (2010) also found similar findings in children with binaural cochlear implants. These studies had shown a marked improvement in localization in binaural cochlear implants condition.

Beijen, Snik, Straatman, Mylanus and Mens (2010) used MAA test for localization acuity is performed in bimodal and unilateral cochlear implant condition with different stimulus types (such as constant amplitude constant spectrum, roving amplitude constant spectrum etc.). They found a significant advantage in localization with bimodal condition only in worst/complex stimulus condition (roving amplitude and roving spectrum). In real life, amplitude and spectrum will not be constant. So this advantage of bimodal condition can be taken as a benefit of bimodal stimulation in real life situations.

CHAPTER 3

METHOD

The main purpose of current study was to find out the effect of microphone directionality on horizontal localization and speech identification in noise in children with binaural hearing aid.

A. Participants

Two groups of children will be taken for the study.

Group I includes 15 children in the age range of 5 years to 14 years.

Inclusion Criteria

- Children with pre-lingual sensorineural hearing loss with aided speech identification scores of 60% (open / closed task)
- Degree of hearing loss ranging from severe to profound and hearing threshold should be above 71 dB HL for frequency range 250Hz to 8000 Hz. (during the time of identification as well as testing) bilaterally
- Fitted with Digital BTE Hearing aids bilaterally
- Non progressive hearing loss
- No otological or neurological problems

Group II includes minimum of 15 children with hearing sensitivity within normal limits in both ears. The age ranges from 5 years to 14years.

Inclusion criteria

- No associated problems such as global developmental delay, visual impairment etc.
- Speech language and cognitive skills within normal limits

- No middle ear pathology or other otological signs/symptoms
- No neurological problem

A written consent from the parents regarding their willingness to participant their children for the study were taken before the test procedures.

B. Instrumentation

i. Testing environment:

All testing was carried out in a sound treated room designed based on ANSI S3.1.1991.

ii. Hearing aids

A pair of digital BTE type hearing aids (Audio service, Riva 2HP) which fit severe to profound hearing loss was taken. Hearing aids were programmed using Hi-Pro instrument with appropriate programming software in a personal computer.

iii. Clinical audiometer and Immittance audiometer

A dual channel clinical audiometer (OB922) with sound field measurement facility was used for pure tone audiometry, speech audiometry and Speech in noise testing. Immittance audiometry was done by a calibrated GSI tympstar.

iv. Instrumentation for horizontal localization task

Eight loud speakers were arranged in a circular array with a radius of 1 meter. The position of loud speakers is in 0^o, 45^o, 90^o, 135^o, 180^o, 225^o, 270^o, and 315^o Azimuth covering a range of 0^o to 360^o (figure 1). Each speaker were mounted on Iso-Pod™(Isolation position/decoupler™) vibration insulating table stand. The presentation of signals was through the software CuBase 6 which was installed in personal computer. All loud speakers were connected to the personal computer. For the localization task, speech shaped noise of duration 750ms is be used. Speech shaped noise is generated from long term average spectrum of 100 Kannada words using MATLAB 8.0.

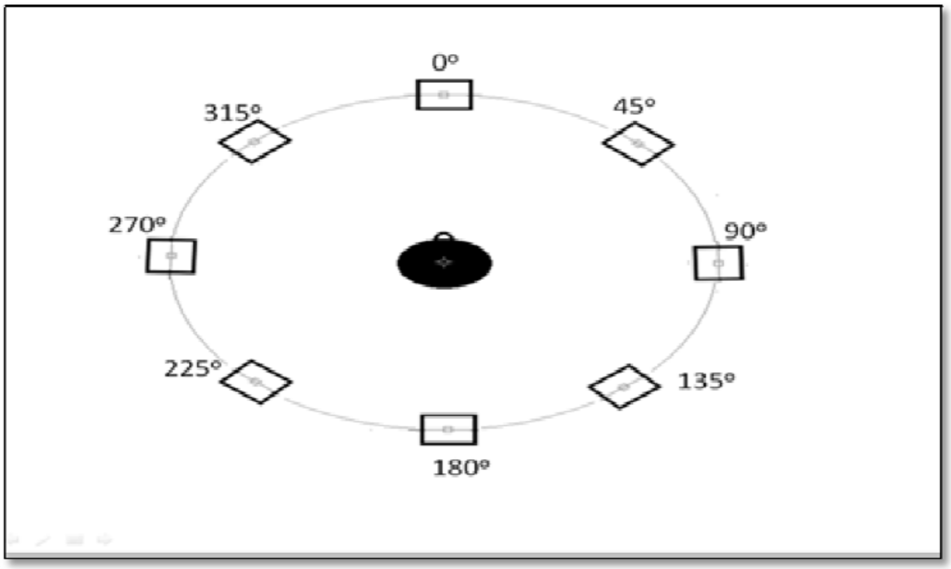

Figure 1: Arrangement of loudspeakers for horizontal localization task

v. Instrumentation Speech in noise testing

A calibrated clinical audiometer (OB922) with free field facility was used for speech in noise testing. There were two speakers one placed at 0^o azimuth and other at $+45^o$ azimuth. Speech was presented lively through the speaker at 0^o azimuth and speech noise from $+45^o$ azimuth (figure 2).

Signal to noise ratio-50 (SNR-50) was used to measure the speech identification in noise performance. A list of bi-syllabic words developed by Saghal (2005) was used to find SNR 50. The list has 3 set of 40 words. These are the words with a combination of low-mid, low-high and high-mid frequency.

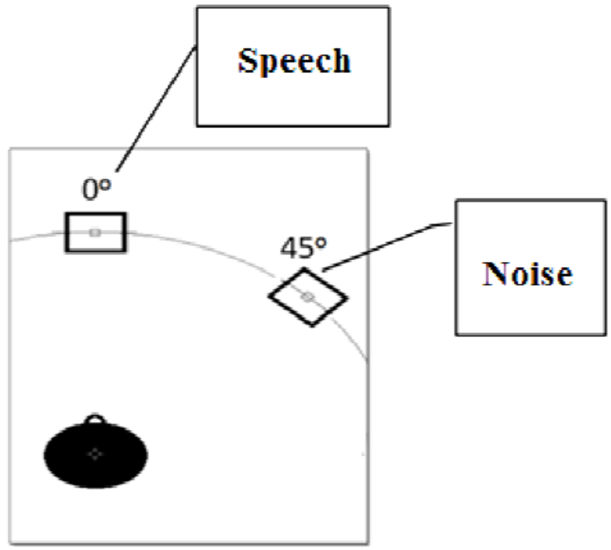

Figure 2: Loudspeaker arrangement for speech identification in noise test

C. Procedure

i. Programming of hearing aid:

The program which was fed in child's own hearing aids was transformed to the hearing aids used in the study. In case of unavailability of current program, programming was done with the latest audiogram and appropriate changes were made according to the child's needs. Two programs were fed; first with omnidirectional mode and the second with directional mode. The examiner changed the programs during the tests using push button.

ii. Horizontal localization task

The speech shaped noise of 750ms duration was taken as stimulus for horizontal localization. Each segment of noise was randomly assigned for different loudspeaker leading to have 3 stimuli per loudspeaker. The subject's task was to orally indicate the source of stimulus from the array of speakers. The inter stimulus interval were changed according to each child's reaction time. Child's task was to point the speaker from which he/she heard the stimulus. Degree of error was used to measure the accuracy of localization. The formula for calculating the root mean square DOE (Ching, Incerti & Hill, 2004) is given below.

$$\text{rms DOE} = \sqrt{\frac{(DOE)_1^2 + (DOE)_2^2 + (DOE)_3^2 + \ldots + (DOE)_8^2}{8}}$$

Where, DOE_{1-8}= Degree of Error of the eight loud speakers;

DOE=Stimulus azimuth-response azimuth

For eg. If child pointed loudspeaker at 45^o for a sound from 90^0 azimuth., then DOE = 90-45=$45^{o.}$ and rms DOE = Root mean square degree of Error.

Same procedure was done for both the microphone setting i.e. Directional and Omnidirectional in the group 1 as well as in both groups of children (Group I &Group II).

iii. Speech identification in noise:

Signal to noise ratio-50 (SNR-50) was used to measure the speech identification in noise performance. Kannada bi-syllabic word list (Sahgal, 2005) was presented through the audiometer to the loud speaker located at one meter distance from the participant at $\pm 45^o$ azimuth. The noise was presented at 0^oazimuth. The presentation level of speech was kept constant at 65dBHL. Speech noise increased from an initial level of 30 dB by 5 dB steps till participant correctly repeat 50% of the words that is presented. Three words were presented at each level of speech noise. Then, found out the highest level of speech noise at which the participant can repeat 50% of the words. 4 to 5 reversals will be obtained. The final signal to noise ratio difference was taken as SNR-50.

The above procedure was carried out for both the conditions, omnidirectional mode and directional mode as well as in both groups.

CHAPTER 4

RESULTS AND DISCUSSION

The aim of current study was to evaluate the effect of microphone directionality on horizontal localization and speech perception in noise in children with binaural hearing aids. Two groups of children participated in the study, first group included 15 children with normal hearing and group II includes 15 children with severe to profound hearing loss fitted with binaural hearing aid. Speech perception in noise using SNR50 (SNR at which 50% correct score in speech identification task) and horizontal localization task were administered. SNR50 (speech in noise) and rms degree of error/ rms DOE (localization ability) were calculated for both the groups and also for two microphone conditions in group II (children fitted with hearing aids).

A. Comparison of SNR50 scores

i. Comparison of SNR50 scores between group I and group II

Two comparisons were made from the mean, median and standard deviation between groups, one between SNR50 of children with normal hearing and that of children using binaural hearing aids with omnidirectional mode. Second comparison was between SNR50 of children with normal hearing and that of children using binaural hearing aids with directional mode. The mean, standard deviation and median were given in the table 1.

Table 1

Mean, Median and Standard deviation of SNR50 for group I and group II

Participants	Microphone directionality	SNR50		
		Mean	Std. Deviation	Median
Group I	-	-.13	1.55	.00
Group II	Omnidirectional	14.13	2.69	15.00
	Directional	14.33	2.52	14.00

The mean SNR50 is very high in both microphone conditions in group II and essentially there was no difference observed in SNR50 between two microphone conditions within group II. Since the standard deviation is very high in group I, non parametric test Mann-Whitney test was used to see the difference between two groups.

Table 2

Comparison of SNR50 between group I and group II

Participants	Z	Asymp. Sig. (2-tailed)
Group I SNR50 Vs Group II SNR50OMNI	-4.685	.000
Group I SNR50 Vs Group II SNR50DIRE	-4.688	.000

Note: Group II SNR50OMNI: SNR50 in omnidirectional microphone condition
Group II SNR50DIRE: SNR50 in directional microphone condition

As shown in the table 2, Mann-Whitney U test results revealed that there was a significant difference between two groups with Z for =-4.68 (Omnidirectional mode) and Z = -4.69, $p < 0.05$ (directional mode) i.e. the performance of the speech in noise was the same irrespective of the direction of the microphone being selected in children fitted with binaural hearing aids.

The findings of current study support the results of study by Ching et al (2011). The spatial release from masking was evaluated as a measure of speech perception in difficult to listening conditions. Subjects were children of 3 to 12 years including both normal hearing and fitted with hearing aid. They results revealed that there was about 3 dB improvement in SRT for children with normal hearing due to spatial release from masking whereas children with hearing aid did not show any improvement. This result suggests that the benefits of hearing aid fitting for speech perception is very limited in back ground noise or adverse listening conditions.

ii. Comparison of SNR50 scores within group II

A paired t test was used to see whether there is any significant difference between omnidirectional and directional microphone modes within the group II. There was no significant difference between the two microphone conditions with $t = -0.612$, $p > 0.05$.

This result is correlating with the results of Cord, Surr, Walden & Olson (2002). They reported that there was no effect of directional microphone on speech perception in real life situation when assessed through questionnaire. However, result of current study is against the conclusions of many studies done on adult subjects. There was a significant difference in speech perception in noise when compared between the omnidirectional and directional microphone settings. Lewis, Crandell, Valente and Horn (2004) reported a significant improvement in sentence recognition threshold in noise with directional (adaptive) microphone over omnidirectional microphone settings in adults. In another study in adults by Valente and Mispagel (2008) reported a significant advantage of directional microphone over omnidirectional microphone. They have tested with speech perception in noise using sentences. Further, they found no significant difference between the unaided and omnidirectional performance. The differences in results may be attributed to the difference in subjects, difference in the test material and test conditions. In the current study, children with pre-lingual hearing loss were tested. Their listening ability and language skills are poor compared to children with normal hearing as well as adults with post lingual hearing loss. This in turn results in reduced speech intelligibility in noise in children with binaural hearing aid when compared to normal hearing peers and adults with post-lingual hearing loss. In the study by Valente and Mispagel (2004) as well as Lewis et al (2008), they have used sentences for the testing, whereas in the current study Kannada words were used. This difference also attributed to the difference in the results within group comparison of microphone directionality.

B. Comparison of Horizontal Localization performance

i. Comparison of Horizontal Localization performance between group I and group II

The rms DOE was calculated for assessing horizontal localization performance in both groups. The comparisons were made between group I and group II with omnidirectional mode as well as group I and group II with directional microphone. Table 3 shows the mean, standard deviation and median of group I and the group II with both microphone modes.

Table 3

Mean, Median and Standard Deviation of rms DOE in localization in group I and group II

Participants	*Microphone Directionality*	*rms DOE in localization*		
		Mean	Std. Deviation	Median
Group I	-	11.85	6.12	12.80
Group II	Omnidirectional	73.57	18.55	70.99
	Directional	68.66	17.34	65.19

Note: rms DOE: root mean square of degree of error in localization task

It can be inferred from the table 3 that the mean as well as the median for rms DOE of group I is lower than that of group II. Within group II, the rms DOE is lesser in omnidirectional microphone condition than directional microphone condition. Mann-Whitney U test was done to check if there is any significant difference between the groups with both microphone directionalities.

Table 4

Comparison of rms DOE in localization between group I and group II

Participants	Z	Asymp. Sig. (2-tailed)
Group I rms DOE Vs Group II rms DOE-OMNI	-4.678	.000
Group I rms DOE Vs Group II rms DOE-DIRE	-4.678	.000

Note: rms DOE-OMNI: root mean square of degree of error in Omnidirectional condition

rms DOE-DIRE: root mean square of degree of error in Directional condition

Table 4 reveals that there is a significant difference between the groups with both microphone directionalities. The z values were -4.68 for both microphone modes (p <

0.05) (table 4). There is a difference in localization between participants of group I and group II. The group I had lesser rms DOE compared to both the microphone conditions of the participants in group II who had bilateral sever to profound hearing loss.

Dillon (2001) reports advantage of binaural hearing aids is more prominent in moderate to severe degree of hearing loss, since the audibility can be restored using hearing aids. In sever to profound hearing loss the advantage of audibility restoration may be not effective. This may be one reason for the poor performance in localization. Also, as reported by Macpherson and Cumming (2012), poor frequency and temporal resolution also affects the localization ability in children with binaural hearing aids.

ii. Comparison of Horizontal Localization performance within group II

a. Comparison of Horizontal Localization performance within group II across microphone conditions

Localization performance was compared within the group II between two microphone conditions. There was no significant difference between two microphone modes, i.e. omnidirectional and directional. The paired t test results are shown in the table 5.

Table 5

Results of paired t test for within group comparison of rms DOE across microphone conditions

Group II	T	Df	Sig. (2-tailed)
rmsDOEOMNI Vs rmsDOEDIRE	1.190	14	.254

Note: rmsDOEOMNI- root mean square of degree of error in omnidirectional condition
rmsDOEDIRE: root mean square of degree of error in directional condition

As in speech perception in noise, the studies evaluating effectiveness of microphone directionality on localization in real life situations revealed similar findings. Ruscetta, Palmer, Durrant, Grayhack & Ryan (2005) concluded that there was no effect for microphone directionality in 'Self-Perceived Localization Disabilities and Handicaps'. Results of current study are against some other studies done in adults. Keidser et al (2006) reported improvement in localization performance with cardioids (directional) microphone in many of their adult participants with mild to moderate hearing loss. However, Keidser et al (2006) reported that the same effect was not seen in all the participants which may due to some unknown factors. The participants of current study were children with severe to profound hearing loss.

As quoted by Ibrahim (2013), reported that the distortion factor and the attenuation factor cause the reduced speech intelligibility in hearing loss. This will results in inability to utilize the ITD and ILD cues which are important in speech detection and intelligibility as well as localization of sounds. These two factors should be overcome by hearing aid fitting. The functional gain measurement indicates that the attenuation factor or audibility could be retained by giving sufficient gain of hearing aids. However, the distortion factor due to the auditory system damage could not be overcome by hearing aid fitting. In addition, the variety of signal processing in the hearing aid distorts the fine cues (ILD and ITD) (Bogaert et al, 2006). So, these two distortions results in reduced speech intelligibility in noise as well as the localization performance even though the audibility is retained or attenuation factor is overcome by sufficient amount of amplification. The ineffectiveness of microphone directionality in horizontal localization in children with hearing aids may also be due to the distortion of binaural cues caused by hearing aid and hearing loss.

b. Comparison of Horizontal Localization performance within group II across sound sources

Further, comparisons were made between front and back sources as well as right and left sources. Mean, standard deviation and median for right-left and front-back sources for both group I and group II were given in the table 6.

Table 6

Mean, Median and Standard deviation of rms DOE in localization for front- back and right-left speakers in both microphone directionalities within group II

Participants	*Microphone Directionality*		*rms DOE in Localization*			
			Front	Back	Right	Left
Group I	-	Mean	7.65	9.62	8.57	7.57
		Median	8.66	8.66	7.50	7.50
		SD	6.05	5.70	4.99	3.88
Group II	Omnidirectional	Mean	62.29	72.13	62.19	69.62
		Median	56.35	72.43	55.48	65.06
		SD	24.65	26.96	19.73	18.28
	Directional	Mean	43.29	72.27	44.27	69.95
		Median	41.77	65.07	41.04	69.15
		SD	14.79	24.36	17.92	18.92

Note: rms DOE: root mean square of degree of error

It can be inferred from the table that the mean rms DOE across sound sources were essentially equal in group I. however, the values are variable in group II across both microphone conditions.

Right and left as well as back and front comparisons within the group I showed no significant difference in rms DOE between right and left speakers as well as front and back speakers in repeated measure of ANOVA testing.

In group II, two way repeated measures of ANOVA was done to see the difference between the right and left as well as between front and back speakers in the rms DOE. It showed a significant effect of microphone directionality with $F(1, 14) = 5.889$, $p<0.05$,right and left speakers with $F(1, 14) = 16.8$, $p< 0.01$ and also significant interaction between microphone directionality and right-left speakers with $F(1, 14)= 7.06$, $p<0.05$.

Since there was a significant interaction effect, paired t test has been done which showed significant difference between degrees of error in right speakers and left speakers with directional microphone mode where $t(1, 14) = -5.47$, $p<0.01$. Also there was a significant difference between the rms DOE of omnidirectional and directional microphone in the right side sources ($t(14) =3.9$, $p<0.01$.) (Table 7)

Table 7

Results of paired t test for comparison of rms DOE in localization across sound sources in both microphone directionalities within group II

	rms DOE in localization		
Conditions	T	Df	Sig. (2-tailed)
OMNIRIGHT – OMNILEFT	-1.271	14	.23
DIRRIGHT – DIRLEFT	-5.470	14	.00
OMNIRIGHT – DIRRIGHT	3.962	14	.001
OMNILEFT – DIRLEFT	-.060	14	.95

Note: rms DOE: root mean square of degree of error
OMNIRIGHT: rms DOE of right side speakers with omnidirectional mode.
OMNILEFT: rms DOE of left side speakers with omnidirectional mode.
DIRRIGHT: rms DOE of right side speakers with Directional mode.
DIRLEFTT: rms DOE of leftt side speakers with Directional mode.

Similarly, two way repeated measures ANOVA have been done for the rms DOE for front and back speakers. There was a significant difference between front and back rms DOE with F (1, 14) = 9.30, p<0.01.

The significant discrepancy in rms DOE between right and left as well as front and back sound sources can be taken as an implication for the necessity of synchronized or co-ordinated binaural hearing aids (Ibrahim, 2013). Many studies have been shown that the use of fine binaural cues are affected by independently working digital signal processing in two hearing aids of binaural fitting (Bogaert et al. 2006; Keidser et al., 2011). In the present study, the hearing aids for binaural fitting were programmed independently and no synchronization facility was available.

CHAPTER 5

SUMMARY AND CONCLUSION

The main objectives of the study were to compare the horizontal localization and speech identification in noise in children with normal hearing and children using binaural hearing aids and to find the effect of microphone directionality in horizontal localization and speech identification in noise in children with binaural hearing aids.

SNR50 used to measure the speech identification in noise and rms degrees of error (DOE) for eight different angles were calculated to measure the horizontal localization performance. Both evaluations were done in both group of children and in both microphone conditions within experimental group, i.e. group II. The scores of SNR50 and rms degree of error (DOE) in localization were tabulated and analyzed using Statistical Package for Social Sciences version 17 (SPSS). Descriptive statistics, Mann-Whitney U test, Wilcoxon signed rank test, paired t test and two way repeated measure analysis of variance (ANOVA) were used for the analysis of data. The results revealed that:

1. There was a significant difference in SNR50 between children with normal hearing and children with binaural hearing aid with omnidirectional microphone as well as with directional microphone. This may be attributed to poor listening and language skills of children with hearing impairment, distortion factor related to hearing loss which disturbs the use of fine binaural cues and distortion of ILD/ITD cues due to hearing aid processing.

2. There was no effect for microphone directionality on SNR50 in children who are pre lingual severe to profound hearing loss with binaural hearing aids.
3. There was a significant difference in rms degree of error (DOE) between children with normal hearing and children with binaural hearing aid with omnidirectional microphone as well as with directional microphone. The main cause of this difference could be the distortion factor due to hearing loss and the distortion of ILD and ITD cues due to hearing aid processing.
4. There was no effect for microphone directionality on rms DOE in children with pre lingual severe to profound hearing loss who are using binaural hearing aids.
5. There was significant difference between the rms DOE for right and that for left speakers, and this may be due to the independent programming and functioning of two hearing aid. So, synchronized binaural hearing aid functioning may be important in getting binaural advantages (such as speech identification in noise and localization) for hearing aid wearers.
6. There was significant difference between the rms DOE of front speakers and that of back speakers. This may be due to the loss of pinna advantage when using a behind the ear type hearing aids.

Implications of the study

The hearing aid will not be beneficial in terms of speech perception in noise for children with hearing impairment in school set ups. Hence, alternatives like FM devices should be used along with hearing aid in order to get adequate SNR. Training for localization also need to be included in auditory training of children with binaural hearing loss.

Future directions for research

1. Effect of microphone directionality on speech in noise and localization can be evaluated in children with mild to moderate degree post lingual hearing loss
2. This study can be further extended to find out the effect of microphone directionality in more number of participants
3. Effect of other hearing aid features (such as noise reduction strategies, compression strategies etc.) on localization as well as speech in noise in children with binaural hearing aid can be explored.
4. Horizontal localization and speech in noise can be compared between adults and children with similar degree of hearing loss and the effect of hearing aid features on them.

REFERENCES

Beijen, J., Snik, A. F. M., Straatman, L.V., Mylanus, E. A. M., & Mens, L. H. M. (2010). Sound localization and binaural hearing in children with a hearing aid and a cochlear implant. *Audiology Nerotology,15*(1),36-43.

Bauer, R. W., Matusza, J. I., & Blackmer, R. F. (1966). Noise localization after unilateral attenuation. *Journal of the Acoustical Society of America, 40*, 441-444.

Blauert, J. (1969). Sound localization in median plane, *Acoustica, 22*(4), 205-213.

Blauert, (1983). *Spatial hearing: The psychophysics of human sound localization.* Cambridge, MA: MIT Press.

Boymans, M., & Dreschler, W. (2000). Field trials using a digital hearing aid with active noise reduction and dual microphone directionality. *International journal of Audiology, 39*(5), 260-268.

Bronkhorst, A. W., & Plomp, R. (1988). The effect of head-induced interaural time and level differences on speech-intelligibility in noise. *Journal of the Acoustical Society of America, 83*(4), 1508-1516.

Byrne, D., & Dirks, D. (1996). Effects of acclimatization and deprivation on non-speech auditory abilities. *Ear and Hearing, 17*(3 Suppl), 29S-37S.

Byrne, D. (1981). Clinical issues and options in binaural hearing-aid fitting. *Ear and Hearing, 2*(5), 187-193.

Chung, K., Neuman, A. C., & Higgins, M. (2008). Effects of in-the-ear microphone directionality on sound direction identification. *Journal of Acoustic Society of America,123*(4), 2264-22275.

Crandell, C. C. & Smaldino, J.J. (2000). Classroom acoustics for children with normal hearing and with hearing impairment. *Language ,Speech, and Hearing Services in schools,31*.362-370.

Cord, M. T., Surr, R. K., Walden, B. E. & Olson, L. (2002). Performance of directional microphone hearing aids in everyday life. *Journal of American Academy of Audiology, 13*, 295-307.

Cord, M. T., Surr, R. K., Walden, B. E. & Olson, L. (2004). Relationship between laboratory measures of directional advantage and everyday success with directional microphone hearing aids. *Journal of American Academy of Audiology 15*, 353-364.

Devore, S., Ihlefeld, A., Hancock, K., et al. (2009). Accurate sound localization in reverberant environments is mediated by robust encoding of spatial cues in the auditory midbrain, *Neuron, 62*(1), 123-134.

Dillon, H. (1996). Compression? Yes, but for low or high frequencies, for low or high intensities, and with what response times?. *Ear and Hearing, 17*, 287-307.

Dillon, H. (2001). *Hearing aids.* New York, NY: Thieme Press.

Flamme, G. A. (2002). Localization, hearing impairment, and hearing aids. *Hearing Journal,* 55(6), 10-20.

Gagana, M .S., & Manjula, P. (2013). '*Effect of frequency compression in speech identification in noise and localization in individuals with hearing impairment'*. (Unpublished master's dissertation), Department of Audiology, AIISH, Mysore.

Gravel, J.S., Fausel, N., Liskow, C. & Chobot, J. (1999). Children's speech recognition in noise using omni-directional and dual-microphone hearing aid technology**.** *Ear and Hearing, 20(1),*1-11.

Grieco-Calub, T. M., & Litovsky, R. Y. (2010). Sound localization skills in children who use bilateral cochlear implants and in children with normal acoustic hearing. *Ear and Hearing, 31*(5), 645-56.

Ibrahim, I. (2013).'*Effects of coordinated bilateral hearing aids and auditory training on sound localization and speech intelligibility in noise'*.(doctoral thesis) retrieved from http://ir.lib.uwo.ca/etd/1166/.

Johnstone, P. M., Náb̆elek, A. K., & Robertson, V. S. (2010). Sound localization acuity in children with unilateral hearing loss who wear a hearing aid in the impaired ear. *Journal of American Academy of Audiology, 21*(8), 522-34.

Keidser, G., Rohrseitz, K., Dillon, H., Carter, L., Rass, U., & Convery, E. (2006). The effect of multi-channel wide dynamic range compression, noise reduction and the directional microphone on horizontal localization performance in hearing aid wearers. *International Journal of Audiology, 45*, 563-579.

Keidser, G., O'Brien, A., Hain, J., McLelland, M., & Yeend, I. (2009). The effect of frequency dependent microphone directionality on horizontal localization performance in hearing-aid users. *International Journal of Audiology, 48*, 789-803.

Kim, J. S., & Bryan, M. F. (2011). The effect of asymmetric directional microphone fitting on acceptance of background noise. *International Journal of Audiology, 50* (5), 290-296.

Köbler, S. & Rosenhall, U. (2002). Horizontal localization and speech intelligibility with bilateral and unilateral hearing aid amplification. *International Journal of Audiology*, *41(7),* 395-400.

Koenig, W. (1950). Subjective effects in binaural hearing. *The Journal of the Acoustical Society of America, 22*(1), 61-62.

Lewis, M. S., Crandell, C. C., Valente, M. & Horn, J. E. (2004). Speech perception in noise: directional microphones versus frequency modulation (FM) systems. *Journal of the American Academy of Audiology, 15*(6), 426-439.

Litovsky, R. Y., Johnstone, P. M., Godar, S., Agrawal, S., Parkinson, A., Peters, R., & Lake, J. (2006). Bilateral cochlear implants in children: localization acuity measured with minimum audible angle. *Ear and Hearing, 27*(1), 43-59.

Litovsky, R. Y., Johnstone, P. M., & Godar, S. P. (2009). Benefits of bilateral cochlear implants and/orhearing aids in children. *International Journal of Audiology, 45*(supl.1), S78-S91.

Litovsky, R. Y., & Godar, S. P. (2010). Difference in precedence effect between children and adults signifies development of sound localization abilities in complex listening tasks. *Journal of acoustic society of America,128(4)*, 1979-1991.

Macpherson, E. A., &Cumming, M. A. (2012). Loss of sensitivity to dynamic sound Localization cues in listeners with impaired low-frequency hearing. *Association for Research in Otolaryngology* 35th Midwinter Meeting, San Diego, CA.

Middlebrooks, J. C., Green, D. M., (1991). Sound localization by human listeners. *Annual of Revolution of Psychology*. 42, 135-159.

Moore, B. C. J. (1997), An Introduction to the Psychology of Hearing (4h Ed.), California, Academic Press.

Moore, B. C., Peters, R.W., & Stone, M. A. (1999). Benefits of linear amplification and multichannel compression for speech comprehension in backgrounds with spectral and temporal dips. *Journal of Acoustic Society of America,105*, 400–411.

Noble, W., Byrne, D., & Lepage, B. (1994). Effects on sound localization of configuration and type of hearing impairment. *Journal of the Acoustical Society of America, 95*(2), 992-1005.

Northern, J. L. & Downs, M. P. (2002). Hearing in children (5th Ed.), USA, Lippincott Williams & Wilkins

Plomp, R. (1978). Auditory handicap of hearing impairment and limited benefit of hearing aids. *Journal of the Acoustical Society of America, 63*(2), 533-549.

Plomp, R., & Mimpen, A. M. (1979). Speech-reception threshold for sentences as a function of age and noise-level. *Journal of the Acoustical Society of America, 66*(5), 1333-1342.

Plomp, P. R., & Duquesnoy, A. J. (1982). A model for the speech-reception threshold in noise without and with a hearing aid. *Scandinavian Audiology,* (Suppl. 15), 95-111.

Quintino, C. A., Mondelli, M. F. C. G., Ferrari, D.V. (2010). Directivity and noise reduction in hearing aids: speech intelligibility and benefit. *Brazilian Journal of Otorhinolaryngology, 76*(5), 630-638.

Ricketts, T. A., (2001), Directional Hearing aids. *Trends in Amplification,5(4),* 139-276.

Ricketts, T. A., & Hornsby, B. W. Y. (2003). Distance and reverberation effect on directional benefit. *Ear & Hearing, 24*(6), 472-484.

Ruscetta, M. N., Palmer, C. V., Durrant, J. D., Grayhack, J., & Ryan, C. (2005). Validity, internal consistency, and test/retest reliability of a localization disabilities and handicaps questionnaire. *Journal of American Academy of Audiology, 16*, 585-595.

Sahgal, A., & Manjula, P. (2005). *'Comparative study of proprietary and generic prescriptive procedures for nonlinear hearing aids'*, Unpublished, Department of Audiology, AIISH, Mysore.

Senn, P., Kompis, M., Vischer, M., & Haeusler, R. (2005). Minimum audible angle, just noticeable interaural differences and speech intelligibility with bilateral cochlear implants using clinical speech processors. *Audiology and Neurotology,10*, 342–352.

Simon, H. J. (2005). Bilateral amplification and sound localization: then and now. *Journal of Rehabilatation Research and Development, 42*(4), 117-132.

Souza, P., Jenstad, L., & Richard, F. (2000). Using multichannel wide-dynamic range compression in severely hearing-impaired listeners: effects on speech recognition and quality. *Ear & Hearing, 26*(2), 120-131.

Souza, P., Jenstad, L., & Boike, K. (2006). Measuring the acoustic effects of compression amplification on speech in noise. *The Journal of the Acoustical Society of America. 119(1),* 41-44.

Sutter, A.H. (1985).Speech recognition in noise by individuals with mild hearing impairments. *Journal of Acoustics Society of America, 78(3),* 887-900.

Tawfik, S., El Danasoury, I., AbuMoussa, H., & Naguib, M. (2010). Enhancement of speech intelligibility in digital hearing aids using directional microphone/noise reduction algorithm. *The Journal of International Advanced Otology, 6(1), 74-82.*

Valente, M., Fabry, D., & Potts, L. G. (1995). "Recognition of speech in noise with hearing aids using dual microphones". *Publications*. Paper 20. Retrieved from http://digitalcommons.wustl.edu/audio_hapubs/20

Valente, M., Schuchman, G., Potts, L., & Beck, L. (2000). Performance of dual-microphone in the-ear hearing aids. *Journal of the Acoustical Society of America, 11*(4), 181-189.

Valente, M. & Mispagel, K. M. (2008). Unaided and aided performance with a directional open-fit hearing aid. *International Journal of Audiology,* 47(6), 329-336.

Van den Bogaert, T.V., Klasen, T. J., Moonen, M., Deun, L. V., & Wouters, J. (2006). Horizontal localization with bilateral hearing aids: without is better than with. *Journal of Acoustic Society of America,119*(1), 515-526.

Van den Bogaert, T. V., Doclo, S., Wouters, J., & Moonen, M. (2008). The effect of multimicrophone noise reduction systems on sound source localization by users of binaural hearing aids, *Journal of Acoustic Society of America.124*(1), 484-497.

Van Deun, L. et al .(2009). Sound localization, sound lateralization, and binaural masking level differences in young children with normal hearing. *Ear and Hearing, 30*(2) 178-190.

Van Deun et. al (2010). Earlier intervention leads to better sound localization in children with bilateral cochlear implants. *Audiology and Neurotology,15,* 7–17

Yost, W. A., & Gourevitch, G. (1987). Directional Hearing. N Y, Springer-Verlag.