OBJECTIVE AND SUBJECTIVE MEASURES OF LOCALIZATION AND SPATIAL PERCEPTION IN HEARING IMPAIRED ADULTS

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CERTIFICATE

This is to certify that this dissertation entitled **"Objective and subjective measures of localization and spatial perception in hearing impaired adults"** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD031. This has been carried out under the guidance of faculty of the institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Objective and subjective measures of localization and spatial perception in hearing impaired adults"** is the result of my own study under the guidance of **Mr. Ganapathy M K,** 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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May, 2017

Dedicated to my

GRANDPARENTS

For their unconditional love and blessings

.....KORAN, YESHODA, KALYANI & KUMARAN

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ABSTRACT

Aim: The aim of the present study was to compare subjective and objective methods to localization and spatial hearing in individuals with hearing loss.

Objective: To compare the localization and spatial abilities of normal hearing individuals and individuals with hearing loss using the subjective and objective tests for localization. To find the correlation between subjective and objective tests used.

Participants: A total of 30 individuals participated in the study, in which 15 participants had normal hearing sensitivity and other 15 had bilateral symmetrical mild-moderate sensori-neural hearing loss.

Method: Objective and subjective tests for assessing localization and spatial abilities were carried out. The objective evaluation of localization abilities were assessed using phonetically balanced words recorded in child, male and female voice and music stimuli were presented through loudspeakers at different azimuths. For the subjective evaluation of the localization ability Spatial Hearing Questionnaire (SHQ) was administered.

Results: There was a statistically significant difference between the performance of normal hearing individuals and individuals with hearing loss in both subjective and objective tests. The individuals with hearing loss performed poorer than normal hearing individuals in both subjective and objective tests. The results showed that objective test for localization showed clinically significant results.

Conclusion: Even though individuals with hearing loss reported less difficulty in localizing sounds in subjective tests, more localization errors were found in the objective test for

localization. There is a practical clinical significance of objective sound localization test. Generally used SHQ tests spatial hearing; however the current localization test results warrants for objective test procedure to test localization and thus help in treatment of individuals with hearing loss.

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Chapter 1

INTRODUCTION

Hearing is one the fundamental system for successful communication. Locating the source of speakers is as equally important as perceiving the spoken conversation. Localization plays a vital role in perceiving speech in multi-talker situations for a person with hearing loss. The ability to understand speech in these situations has been attributed to the binaural processing used in the auditory system (Bronkhorst & Plomp, 1988). Localization helps individuals to locate the direction of new speaker when the conversation switches from one speaker to other so that each segment of the conversation is heard. Impaired localization probably plays a major role in speech communication difficulties than is usually appreciated.

An individual spatial orientation is affected by impaired localization and hinders the social functioning or even survival. Results of many experimental localization studies reveal that virtually all individuals with hearing loss have poor localization and they rate their localization lower than normal hearing individuals in daily life situations(Noble, Byrne, & Lepage, 1994). Better speech perception in noise is directly related to localizing (Hirsh, 1950). When compared to normal hearing individuals, individuals with hearing loss experience more difficulties in localizing sound source (Noble & Tyler, 1994). Further, localization abilities vary with degree of hearing loss. Localizing difficulties will be more prominent in individuals with more degree of hearing loss than with less degree of hearing loss. According to Noble,(1994) horizontal localization deteriorates for individuals with low frequency hearing loss (less than 1 kHz) and vertical localization gets affected mainly in high frequency hearing loss.

Hearing aid is the most important rehabilitative device for individuals with decreased hearing sensitivity. Researchers have reported contradicting results in terms of localization in hearing aid users. Van den Bogaert et. al, 2006 reported a significant negative impact on localization with bilateral hearing aids. However in this study elderly individuals were compared with young normal hearing individuals. These results could be because of the effects of ageing along with hearing loss. There had been a numerous studies evaluating the speech perception and localization abilities of hearing impaired, comparing aided and unaided performance. However, there have been only a very few studies correlating these objective results with a self assessment questionnaire addressing the various difficulty faced by the hearing impaired.

Spatial hearing is the ability of a listener to perceive sounds in more complex listening situations, which requires binaural processing of important auditory cues. The Spatial Hearing Questionnaire was developed by Tyler, Perreau, & Ji, (2009) to assess the difficulties faced by individuals with hearing loss. Studies showed good relation with various speech perception measures in normal hearing young adults (Tyler et al., 2009) and cochlear implant individuals(Litovsky, Parkinson, & Arcaroli, 2009).

Therefore, the present study was carried out to compare between young normal hearing adults with individuals with hearing loss. This study also compared between the scores obtained subjectively and objectively.

Need for the study:

The human auditory system perceives sounds based on the shape of outer ear, makes use of two input signal, from the left and right ear, which are combined in the auditory pathway. This binaural processing offers cues for spatial hearing and binaural selectivity (Dubno, Ahistrom, & Horwitz, 2002). The conventional technique uses only one microphone to assess the effects of noise (under headphones). In a complex listening condition, the human auditory system performs a selective analysis of the situation and separates the sources from each other. The conventional techniques to assess spatial hearing will give a summed up sound pressure levels of all signals. Therefore the present study with behavioral and psychoacoustical tests may provide further information on hearing problems in individuals using hearing aids.

Further, studies have reported that spatial-processing ability is seen to be reduced for individuals with reduced hearing when compared with normally hearing individuals (Arbogast, Mason, & Kidd, 2005; Gelfand, Ross, & Miller, 1988; Gordon-Hickey & Moore, 2008). There is dearth of literature on comprehensively understanding the effects of hearing loss on spatial processing and localization. Studies have been carried out in elderly individuals, whose results would also have effects of ageing. This study incorporates individuals with decreased hearing in age range that will allow for the effect of aging to be differentiated from the effect of hearing loss. The results from this study may help clinicians and researchers to take into account the spatial processing and localization into account in assessment and management of the individuals with hearing impairment.

AIM of the study:

The aim of the present study was to compare with subjective and objective methods the localization and spatial hearing in individuals with hearing loss.

Objective:

1. To access the localization and spatial hearing abilities in normal hearing individuals.
2. To access the localization and spatial hearing abilities in individuals with reduced hearing sensitivity.

3. To compare the localization and spatial hearing abilities between normal hearing individuals and in individuals with reduced hearing.
4. To find the relation between the localization abilities with results of spatial hearing questionnaire in normal hearing individuals and in individuals with reduced hearing sensitivity.

Chapter-2

REVIEW OF LITERATURE

The most important of all binaural auditory phenomenon is localization. The ability to indicate the sound source in an auditory space is called as auditory localization. Localization is considered to be crucial for human effectiveness and personal safety (Letowski & Letowski, 2012). It plays a major role in day to day life listening activities. One of the most important roles of localization is perception of speech in presence of noise, helping in environments like classroom, traffic, meetings, market; etc. Auditory localization makes use of binaural hearing (Kuhnle, Ludwig, Meuret, Küttner, Witte, Scholbach, & Rübsamen, 2013). Binaural hearing is critical for auditory space perception (Kuhnle, Ludwig, Meuret, Küttner, Witte, Scholbach, & Rübsamen, 2013). Impaired localization leads to poor communication skills (Kuhnle, Ludwig, Meuret, Küttner, Witte, Scholbach, & Rübsamen, 2013).

Acoustic cues important for auditory localization are i) Interaural level difference (ILD), ii) interaural time difference (ITD) iii) interaural phase difference(IPD).Time/phase dependent cues helps in localization of low frequency and level dependent cues help in localization of high frequencies. The diffraction of incoming sound waves around the head and pinna results in primary cues for localization that are frequency dependent patterns of interaural time and intensity differences (Macpherson & Middlebrooks,2002;Middlebrooks,Makous, & Green, 1989,Shaw, 1974).

Sound will reach the ear closer to source (near ear) than the ear which is far (far ear) this creates ITD cues. Inter aural time difference depends on size of the head and speed of the sound. Inter aural time difference is zero for frontally incident sounds and maximum for sounds coming from 90^0 with respect to the front. This time difference is important cue for localizing low frequency up to 1500 Hz sounds because low frequencies have wavelength longer than the path around the head, so it bends around the head (Gelfend, 2004)

Fedderson, Sandel, Teas, and Jeffress (1957) conducted experiment taking measurement on how ITD alter with changing azimuth around the head and their ITD measurements. Results revealed that there was no difference between the ears when the signal comes directly in front or behind (0^0 or 180^0), since the ears equidistant from the sound source in both cases. ITD developed as the loudspeaker moved around the head bringing it closer to one ear than the other. ITD increased to maximum when the loudspeaker was directly in front of the one ear (90^0 azimuth).

When the signal is reaching the far ear, there will be more amount of reduction in intensity for higher frequency components of the sound whereas the low frequency components will suffer smaller amounts of reduction, this creates IID cues. This reduction is attributed to the wavelength of the two types of components i.e. wave length of high frequency signal is shorter when compared to low frequency signals (Wright & Zang, 2009)

Fedderson, Sandel, Teas, and Jeffress, (1957) found that ILD depends both on frequency and Azimuth**.** As expected, ILD were negligible at 200 Hz, and increased with frequency to as much as about 20 dB at 6000 HZ. The ILD was 0 dB directly in front and behind because they were equidistant from both the ears. ILD increased as the loud speaker moved closer to side or the other, reaching a maximum where the loud speaker was directly in front of one ear (90^0).

Three spatial dimensions, where a source of sound can be localized are; horizontal plane, vertical plane and distance or range (Yost, 2006). According to Duplex theory by Rayleigh (1907), interaural time and intensity cues are important for horizontal plane localization for pure tones. The duplex theory states that ITDs are used to localize low frequency sounds, in particular, while ILDs are used in the localization of high frequency sound inputs. However, the frequency ranges for which the auditory system can use ITDs and ILDs significantly overlap, and most natural sounds will have both high and low frequency components, so that the auditory system will in most cases have to combine information from both ITDs and ILDs to judge the location of a sound source (Jan Schnupp, Israel Nelken and Andrew King, 2011). A consequence of this duplex system is that it is also possible to generate so-called "cue trading" or "time–intensity trading" stimuli on headphones, where ITDs pointing to the left are offset by ILDs pointing to the right, so the sound is perceived as coming from the midline. A limitation of the duplex theory is that the theory does not completely explain directional hearing, as no explanation is given for the ability to distinguish between sound sources directly in front and behind. Also the theory only relates to localizing sounds in the horizontal plane around the head (Gelfend, 2004).

Spectral cues are reported to be important for medial plane localization (Macpherson & Middlebrooks, 2002). Wightman and Kistler (1972, 1997) have investigated localization cues using virtual auditory space (VAS) techniques, which permit more-or-less independent manipulation of ITD, ILD, and spectral-shape cues. They demonstrated that ITDs dominate listeners' judgments of the location of broadband sound sources that contain low frequency components (Wightman & Kistler, 1992). In some cases, the influence of ITDs persisted even when stimulus spectra were limited to high frequencies, although the effect of high-pass filtering varied widely among listeners. Also, imposition of an interaural imbalance i.e., an ILD of 10–20 dB had surprisingly little impact on lateral location judgments by some listeners (Wightman & Kistler, 1997). Spectral-shape cues, which provide essential cues to the vertical and front/back location of broadband sounds, also vary with source azimuth and might contribute to the judgment of lateral localization. For instance, some congenitally monaural listeners, whose only cues to sound-source location derive from direction-dependent filtering by one external ear, show reasonably accurate localization in the horizontal dimension (Slattery and Middlebrooks, 1994).

ANATOMY AND PHYSIOLOGY BEHIND LOCALIZATION

Corresponding to the psychophysically-defined classical duplex theory, there are two parallel pathways in the auditory brainstem that are thought to encode ITDs and ILDs (Yin,1984; Batra 1989; Joris & Yin, 1995).The superior olivary complex (SOC) consists of several nuclei suited to separately encode the binaural cues to location: interaural time differences (ITDs), and interaural level differences (ILDs). These differential functions are related to the fact that the neurons within the SOC have different response patterns. Some demonstrate an excitatory response (i.e. a neuronal firing rate that increases above the spontaneous rate) while others demonstrate an inhibitory response (i.e. a neuronal firing rate that decreases below the spontaneous rate) or a response pattern that is unaffected by certain inputs (i.e. no change in the spontaneous rate) Goldberg & Brown, (1969)

The neural circuitry underlying the encoding of these binaural localization cues is well understood, and each of the cell types in the circuit has been well characterized physiologically. The circuit that encodes ITDs involves cells in the medial superior olive (MSO) (Goldberg & Brown, 1969; Yin & Chan, 1990), which receive excitation from large spherical bushy cells (SBCs) of the anterior ventral cochlear nucleus (AVCN) of both sides. The circuit that encodes ILDs involves cells in the lateral superior olive (LSO) (Boudreau &Tsuchitani, 1968), which receive excitation from the small SBCs of the ipsilateral AVCN(Warr, 1966; Glendenning, 1985; Shneiderman & Henkel, 1985;Cant & Casseday, 1986; Smith, 1993), and inhibition from the contralateral side relayed through inhibitory neurons in the medial nucleus of the trapezoid body (MNTB) (Morest, 1968;Warr, 1972; Tolbert, 1982; Glendenning, 1985; Smith, 1991). The MNTB cells receive excitatory input from the globular bushy cells (GBCs) of the contralateral AVCN. Thus all of the major inputs to these localization circuits in the SOC derive from the two classes of bushy cells in the AVCN which course out of the ventral acoustic stria, or trapezoid body, and project to the SOC.

FACTORS AFFECTING LOCALIZATION

i) Age

Vichweg and Campbell (1960) reported that localization abilities deteriorate with advancing age. According to Matzkaer and Springborn (1958) directional hearing decreases with increasing age. Nordlund (1964) reports no effect of age on localization for pure tones and white noise. Most of the studies suggest that biological aging leads to hearing loss in most of the individuals. Tremblay, Piskosz, and Souza (2002) reported impaired temporal coding in older adults, due to the reduction of simultaneous discharge of neurons. This leads to difficulty in understanding speech especially in noisy situation which can be attributed to the impaired localization ability (Willott, 1996). From all the studies discussed it can concluded that ageing affects the ability to localize.

ii) Auditory dys-synchrony

According to Zeng, Kong, Michalewski, and Starr (2005) neurological and electrophysical evidence suggests that disrupted auditory nerve activity is due to desynchronized or reduced neural activity or both. Psychophysical measures like temporal integration, intensity, and frequency discrimination, backward and forward masking, simultaneous masking, and monaural beat detection showed that the disrupted neural activity has minimal effects on sound localization using interaural level differences but it significantly impairs timing related perception such as sound localization using interaural time differences.

iii) Hearing Loss

Results of many experimental localization studies reveal that virtually all individuals with hearing loss have poor localization and they rate their localization lower than normal hearing individuals in daily life situations(Noble, Byrne, & Lepage, 1994). Due to lack of audibility even mild hearing impairment leads to localization difficulties. So, audibility is crucial in localization. Ricketts and Tharpe, (2004) demonstrated that children with mild to severe bilateral sensorineural hearing losses in classroom settings were more likely than their normal hearing peers to localize to utterances made by classmates (31% and 18% of the time, respectively). Although these authors did not have a definitive explanation, it was hypothesized that this difference may have resulted from a need for increased visual information for enhancing speech perception or for monitoring the environment in this population. Localization abilities are not impaired till bilateral pure tone average of 50 dB HL, even in presence of noise. However, localization abilities deteriorates as pure tone thresholds increases beyond this and this is not merely because of lack of audibility(Flamme,2002). Better speech perception in noise is directly related to localizing (Hirsh, 1950). When compared to normal hearing individuals, individuals with hearing loss experience more difficulties in localizing sound source (Noble et al., 1994). Further, localization abilities vary with degree of hearing loss. Localizing difficulties will be more prominent in individuals with higher degree of hearing loss than with less degree of hearing loss. According to Noble, Byrne, & Lepage (1994) horizontal localization deteriorates for individuals with low frequency hearing loss (less than 1 kHz) and vertical localization gets affected mainly in high frequency hearing loss.

Noble, Byrne, & Lepage (1994) evaluated the effect of thresholds and localization abilities. The subjects were divided into 2 groups. First group consisting of individuals with individuals with bilateral sensorineural hearing loss and mixed or conductive hearing loss. The second group consisted of individuals with normal hearing. Pink noise bursts were used as stimulus which was presented at Maximum comfortable level. Results reveal that there was a correlation of 0.3 to 0.4 between localization and hearing thresholds in subjects with sensorineural hearing loss. Frontal plane localization was slightly effected by low frequency hearing and lateral plane horizontal localization was effected by high frequency.

Noble, Byrne, and Lepage (1993) studied the effect of type and configuration of hearing loss on horizontal and vertical localization. The subjects were divided into two groups. The first group included 21 subjects with conductive hearing loss and 66 subjects with sensorineural hearing loss. The second group consisted of 6 subjects with normal hearing. Analysis was done for frontal horizontal plane, medial vertical plane, lateral horizontal plane and Lateral vertical plane. They concluded by saying hearing loss and localization have moderate correlation.

The results found in sensorineural hearing losses are interpreted as consequences of impaired or preserved spectral processing, sound localization impairments found in conductive hearing losses are interpreted as bone-conduction effects and the results in neurinomas are interpreted as impaired signal transmission in the auditory nerves, and the results of subjects with central involvements suggest that separate processors exist at some level in the central auditory system for the different localization cues.

Contradictory studies

Cochlear damage typically has little or no effect on binaural tasks, such as sound localization using interaural level and timing differences (Hall, 1984; Hausler, 1983; Hawkins & Wightman, 1980; Smoski & Trahiotis, 1986).

METHODS OF ASSESSING LOCALIZATION

i) Objective methods

Many studies have measured the sound localization abilities of normal hearing and/or hearing impaired people. A few studies have examined specifically how sound localization ability is affected by hearing loss (Noble, Byrne, & Lepage, 1994). Measurement methods have varied in detail but such variations do not alter any of the general findings to be reported in the following sections.

The arrangement used in some recent studies special equipment is an array of 20 loudspeakers. These are arranged in a horizontal arc and a vertical arc which form the circumference of a sphere. When the subject is seated with his or her head in the centre of the sphere, the mid-point of the head is 1.1 m from each loudspeaker. The horizontal arc contains 11 loudspeakers positioned from 90 degrees to the left of the subject to 90 degrees to the right. The vertical arc has only 10 loudspeakers as there is no loudspeaker in the position directly below the subject. The other items of equipment are: a tape recorder and a recording of interrupted pink noise (random noise with equal energy in each third-octave band), an amplifier, an attenuator, a computer-controlled switching box, and a personal computer. Other equipment consisted of an intercom unit and a video camera and monitor for observing and communicating with the subject. A test run consisted of presenting a 0.83 sec burst of pink noise. Test array used in several localization studies (Byrne, 1998 & Noble, 1998). A horizontal arc of loudspeakers forms the circumference of a circle with a radius of 1.1 m.

The subject will be seated on a chair with horizontal loudspeakers arranged at the ear level. There is a vertical arc of the same size but containing only10 loudspeakers as there is no loudspeaker directly below the subject. Bursts of noise are presented in random order from each loudspeaker and the subject judges which location was the sound source (Byrne, & Noble 1998 & Noble, Sinclair & Byrne, 1998).

The other methods the subject will be made to look towards the loudspeaker array or turning sideways from the speaker. Localization with hearing aids (pulsed four times) from each of the 20 loudspeakers in a random order. The subject's task was to say which of the loudspeakers; each identified by a number, and was judged to be the source of the sound (Byrne, & Noble 1998 & Noble, Sinclair & Byrne, 1998).

Other arrangements have used a single hidden loudspeaker that is mounted on a boom and is moved between sound presentations. In some studies (Orto & Preves, 1979) loudspeakers have been placed in a horizontal circle around the subject. That arrangement permits errors in judging sounds from the front to be from behind or vice versa.

Various forms of scoring have been used to characterize localization ability. The most simple method is to count the number (or percentage) of correct responses. A "horizontal "percent correct score is the percent of correct responses when sounds were presented from the loudspeakers in the horizontal arc. Similarly, the vertical score is the percent of correct responses when sounds were presented from the vertical arc of loudspeakers. This form of scoring takes no account of the size of errors. Therefore, a subject who makes small errors i.e. selects loudspeakers just one or two positions removed from the sound sources will get the same score as someone who makes an equal number of larger errors, i.e. is incorrect by three or four loudspeaker positions. To make the scoring more sensitive, most studies have used a scoring system that takes account of both the number and size of errors. Most of the recent studies use Degree of Error the adopted procedure of Ching, Incerti & Hill (2004). Degree of Error (DOE) corresponds to the difference in the degree of azimuth between the loudspeaker from which the target stimuli was presented and the loudspeaker to which the participants points to degree of error (DOE) as the measure.

ii) Subjective Methods

Multiple questionnaires are available for the self assessment outcomes from individuals with a hearing impairment, emphasizing mostly on hearing aid benefit and satisfaction (Cox & Alexander, 1995, 1999, 2001,2002; Dillon, James, & Ginis, 1997; Gatehouse, 1999; Tyler, Baker, & Armstrong-Bednall, 1983; Tyler & Smith, 1983)and general hearing disability and handicap (Giolas, Owens, Lamb, & Schubert, 1979; Newman, Weinstein, Jacobson, & Hug, 1990; Ventry & Weinstein, 1982). Despite numerous questionnaires assessing the social, emotional, and physical aspects of hearing loss, relatively few questionnaires stresses on spatial perception.

Patients with hearing loss often report difficulty in situations in which spatial hearing is emphasized, yet their hearing abilities in these complex situations are often not directly assessed either subjectively or objectively in routine audiological test battery.

Two questionnaires are available for measuring self reported localization ability, including the Speech, Spatial and Qualities of Hearing Scale (SSQ; Gatehouse & Noble, 2004) and the Spatial Hearing Questionnaire (Tyler, Perreau, & Ji, 2009). Although the questionnaires appear to overlap in their assessment, there are important differences in the SSQ and SHQ that may suggest use of one questionnaire over the other.

First, the SSQ is using an interview format between the participant and administrator (Gatehouse & Noble, 2004), whereas the SHQ was validated in a self-administered format (Tyler, Perreau, & Ji, 2009). Self administered format reduces the time and administrator bias. Various results suggested similar scores between the two administration methods, but lower test–retest reliability when the SSQ is self-administered, especially for the spatial subscale (Singh & Pichora-Fuller, 2010).

Second, the length of the SHQ is shorter with 24 questions, whereas the SSQ contains 49 questions. Therefore in a clinical setting SHQ is more advantageous. Finally, the two questionnaires assess different aspects of hearing disability. For example, the SSQ contains several general questions not specifically related to spatial hearing (i.e., “Does your own voice sound natural to you?” and “When you listen to music, can you make out which instruments are playing?”). The SHQ focuses specifically on spatial hearing and attempts to separate spatial hearing performance with stimuli of different frequency content (e.g. male voices vs. children’s voices).

Although normative data are available for the SSQ (Banh, Singh, & Pichora-Fuller, 2012), similar data with normal hearing have not been previously investigated using the SHQ. This could be a valuable contribution in the clinical utility of the tool in audiological assessment in several ways. In this way, performance from individuals with normal hearing can be compared with that of individuals with hearing impairment to gauge the overall differences in performance due to hearing loss. In addition, this also serves as a baseline for monitoring the performance following hearing aid and/or CI fittings.

The SHQ (Tyler, Perreau, & Ji, 2009) was specifically developed to measure an individual's subjective hearing abilities in situations in which binaural hearing is emphasized. Eight subscales were used to differentiate characteristics important for binaural hearing, including the perception of male voices (Items 1, 5, 9, 13, and 17),female voices (Items 2, 6, 10, 14, and 18), children's voices(Items 3, 7, 11, 15, and 19), music listening (Items 4, 8, 12, 16,and 20), sound localization (Items 13–24), speech perception in quiet (Items 1–4), speech perception in noise with target and noise sources from the front (Items 5–8), and speech perception in noise with target and noise sources spatially separate (Items 9–12). Previous psychometric evaluation has been performed for the SHQ using bilateral and unilateral CI users (Tyler, Perreau, & Ji, 2009). The results suggested high reliability (Cronbach's a = 0.98) and scores that loaded onto three factors that represent the subscales of Localization, Speech in Noise and Music, and Speech in Quiet and explain over 80% of the variance in scores (Tyler, Perreau, & Ji, 2009). Additionally, previous studies have revealed that the SHQ is well correlated to that of the SSQ (Potvin, Punte, & Van deHeyning, 2011; Tyler et al., 2009) as well as performance on objective test measures, including speech perception in quiet(e.g., consonant-nucleus-consonant monosyllabic words; Tillman & Carhart, 1966) and the Hearing in Noise Test(Nilsson, Soli, & Sullivan, 1994), speech perception in noise(i.e., an adaptive spondee word test; Tyler, Noble, Dunn, &Witt, 2006), and localization (i.e., a horizontal localization test using eight loudspeakers); Dunn, Tyler, & Witt, 2005.

There had been a numerous objective and qualitative studies evaluating the speech perception and localization abilities of hearing impaired. However, there have been only a very few studies correlating these objective results with a self assessment questionnaire addressing the various difficulty faced by the hearing impaired. Therefore, the present study will be carried out to compare spatial abilities between young normal hearing adults with individuals with hearing loss. Also this study will compare between the scores obtained subjectively and objectively.

Chapter 3

METHOD

The present study was done to compare localization performance between normal hearing individuals and individual with bilateral mild-moderate sensorineural hearing loss

3.1. Participants

The study included 15 participants with bilateral mild to moderate sensorineural hearing loss (Group I) and 15 participants with bilateral normal hearing sensitivity (Group II). The participants were in the age rang**e** of 18 to 45 years. This age range was chosen as it has been reported that psycho-acoustic (Werner, & Gray, 1998) and cognitive abilities (Hale, 1990) in normal listeners reach a plateau by the age of 15 years. Further, deterioration in temporal processing abilities has been reported after 40 years (Kumar & Sangamanatha, 2011). All the participants were native speakers of Kannada- a south Indian langauge. Entire study was carried out according to the ethical guidlines of the institute (Venkatesan, 2009) and an informed consent was taken from each participant. The age and gender of both the groups are given in Table 3.1

Table 3.1

Age and gender of the Mild to Moderate SNHL and normal hearing peers

Groups	*Gender*		*Age range (Years)*	*Mean age (Years)*	*STD deviation*
	M	F			
Mild to Moderate SNHL	7	8	18-45	33.33	5.3
Normal hearing peers	4	11	18-45	23.8	9.2

3.2. Procedure for the selection of participants

The participants in the group I had been selected on the following criteria:

- Participants in this group included Mild –Moderate (26-55 dB HL) sensorineural hearing loss. The average pure tone threshold of hearing impaired individuals were 45.6 dB HL (range between 40 dB HL to 51 dB HL) with air bone gap < 10 dB.
- They had normal middle ear functioning based on immittance evaluation.
- Retro cochlear pathology was ruled out based on auditory brainstem responses and transient evoked Otoacoustic tests.

The participants in the group II had been selected on the following criteria:

- Hearing sensitivity was within normal limits i.e., pure tone average of < 15 dB HL in both ears for octave frequencies between 500 Hz to 8 KHz.
- Immittance evaluation showed normal middle ear functioning with ‘A’ type of tympanogram and presence of acoustic reflexes at 500, 1000 and 2000 Hz

-
- Normal auditory brainstem responses with and TEOAE's were present in all subjects

3.3. Instrumentation

Detailed audiological evaluation was carried out for all the participants. Pure-tone thresholds were obtained via the modified Hughson and Westlake procedure (Carhart & Jerger, 1959), using a calibrated diagnostic two channel Grason Stadler - 61 clinical audiometer for estimation of air/bone conduction pure tone thresholds. . A calibrated middle ear analyzer (GSI tympstar) was used to evaluate the middle ear status and an Oto acoustic emission analyzer (ILO Version 6) was used to check the status of outer hair cells.. Speech identification scores were obtained using a phonemically balanced word test in Kannada, developed by Yathiraj and Vijayalakshmi (2005). Bio-Logic Navigator Pro System will be used to record Auditory Brainstem Response (ABR) to rule out the presence of any retro cochlear dysfunction.

For localization task**,** Cubase software along with Lynx Aurora 16 sound card and signal router loaded with Hewlett-Packerd workstation was used .Eight calibrated Galvanic 8020B loud speakers delivered sounds from different azimuth. Six loud speakers arranged in a circle 0^o, 45^o, 135^o, 180^o, 215^o, 315^o Azimuth covering a range of 0^o to 315^o were used for delivering the stimuli. Two loudspeakers separated by 10^o from the loudspeaker kept at 0^o (Front) and 180^o (Back) were used for delivering the noise. Each speaker was mounted on Tri-Pod™ (Isolation position/decoupler™) vibration insulating table stand. It was ensured that center of the head of each participant was equidistant from each loudspeaker about 2 meters away from the center.

b. Sound level meter (Sound level meter type 2260, Br€uel &Kjær Sound & Vibration Measurement, Denmark) was used to calibrate the target test signals from the loud speaker.

c. Spatial hearing questionnaire were administered to assess the spatial hearing abilities of the participants.

3.4. Material

For localization task Phonemically balanced word test in Kannada, developed by Yathiraj and Vijayalakshmi (2005) were recorded in child, adult female and adult male voice using Motu mic in acoustically treated room and musical stimuli (mayamalavagowla raga violin) for the localization task..Adobe audition version 3 loaded in the workstation was used to normalize the recorded signal and to generate speech spectrum shaped noise to assess the speech in noise abilities. All these stimuli were presented at 40 dB SL.

3.5. Environment

The initial tests for subject selection were done in a sound treated two-room situation *as per* ANSI S3.1, (1999). The localization was carried out in a semi-sounded treated room. The participants were seated in the chair which was placed equidistant from the loud speakers. The loudspeakers were placed 1 meter away from the child at 0^o, 45^o, 135^o, 180^o, 225^o, and 335^o azimuths.

3.6. Procedure

The study was carried out in two phases:

3.6.1. Administration of spatial hearing questionnaire (SHQ)

Spatial Hearing Questionnaire (SHQ) was administered (William & Noble, 2006; Tyler, Perreau, & Ji, 2009). This is a questionnaire addressing questionnaire addressing the disability and handicap associated with impaired localization and other binaural hearing abilities. The

SHQ has 24 questions (see Appendix). Patients score each question on a scale from 0 to 100. 0 (zero) indicates that the situation is very difficult and 100 indicates that the situation is very easy. The questionnaire represents eight different characteristics that are likely to be important in binaural hearing: Male voices, Female voices, Children's voices, Music, Source localization, Understanding speech in quiet, Understanding speech in noise with target and noise sources from the front, Understanding speech in noise with spatially separate target and noise sources. The total score was obtained by combining scores from all 24 questions.

3.6.2. Localization

Localization and speech in noise tasks was carried out using six loud speakers arranged in a circle 0^o, 45^o, 135^o, 180^o, 215^o, 315^o Azimuth covering a range of 0^o to 315^o. Two loudspeakers separated by 10^o from the loudspeaker kept at 0^o (Front) and 180^o (Back) were used for delivering the noise. The presentation of signals was through the cubase software installed in personal computer. All loud speakers were connected to the personal computer. The output of each loud speaker was calibrated according to the standards using a sound level Meter (Sound level meter type 2260, Br€uel &Kjær Sound & Vibration Measurement, Denmark). Each speaker was calibrated for the different stimulus and levels before testing.

Stimuli was presented in 3 different conditions

- Source localization and understanding speech in quiet.
- Understanding speech when the target stimulus and noise was coming from the front.
- Understanding speech when the stimulus and noise was spatially separate(10 dB SNR).

The stimulus was presented at 40 dB SL randomly through the speakers. The task of the subject was to indicate the perceived direction of the stimulus by pointing towards the respective speaker and to verbally repeat the words heard. The localization ability and error was analyzed.

Localization ability was calculated by number of correctly identified sound source. Degree of Error was computed by the adopted procedure of Ching, Incerti & Hill (2004). Degree of Error (DOE) was calculated separately for each loudspeaker. DOE corresponds to the difference in the degree of azimuth between the loudspeaker from which the target stimuli was presented and the loudspeaker to which the participants points to. For example, if the target stimulus was presented through second loudspeaker (45^0) and participant points it to 5th loudspeaker (180^0) then the degree of error is 135^0 ($180^0 - 45^0$). The calculated degree of error was squared. DOE^2 was calculated for five iterations in each speaker were summated and then divided by number of stimulus presented. The average DOE^2 computed for five speakers were summated and divided by number of speakers used to present the stimuli. The resultant value was square rooted to obtain the degree of localization error. Similar procedure was used to identify DOE for each stimulus presented in the presence of noise. Degree of error was calculated using the following formula.

$$DOE = \sqrt{(DOE1)2 \; + \; (DOE2)2 \; + \cdots \ldots \ldots + (DOEn)2 \; / \; N}$$

DOE_1: Degree of error in the speaker no. 1

DOEn: Degree of error in the nth number of speaker

RMS: Root Mean Square

N= number of stimuli presented from each loudspeaker/ overall loudspeaker

3.7. Statistical Analysis

The data on degree of error and percentage rating across different stimulus in different azimuth and conditions were tabulated. The data were analyzed to find the RMS degree of errors and statistical analysis software SPSS (Statistical Package for Social Sciences (Version 17.0) for analyzing the localization trend of experimental and control groups and on localization performance. Descriptive statistics was carried out. The Shapiro-Wilk test was used to check for normality of the data. Based on normality test results One sample Wilcoxon's test, Friedman test, Spearman's rank correlation coefficient and Wilcoxon sign rank test were administered.

CHAPTER-4

RESULTS

The present study aimed at comparing subjective and objective methods of localization and spatial hearing in individuals with hearing loss. A total of thirty individuals were assessed, 15 individuals with bilateral mild to moderate sensorineural hearing loss and 15 individuals with normal hearing sensitivity.

The results of the study are provided under the following heading:

4.1 Comparison of localization and spatial hearing abilities in normal hearing individuals.

4.2 Comparison of localization and spatial hearing abilities in individuals with reduced hearing sensitivity.

4.3 Comparison of localization and spatial hearing abilities between normal hearing individuals and individuals with reduced hearing sensitivity.

4.4 Correlation of localization abilities with results of spatial hearing questionnaire in normal hearing individuals and individuals with reduced hearing sensitivity.

The data on degree of error and percentage rating across different stimulus in different azimuth and conditions were tabulated. The data obtained were subjected to statistical analysis using Statistical Package for Social Sciences (SPSS) software (SPSS version 20). Descriptive statistics was carried out to estimate the mean and standard deviation. Prior to the analysis of the data, Shapiro Wilk test was administered to assess the normality of the data. The results indicated that they were not normally distributed. Hence, the data were subjected to non parametric analysis. One sample Wilcoxon's test was carried out to see the significance between normal hearing individuals and individuals with reduced hearing individuals. The Friedman's test was carried out to see the significant difference across stimuli for a particular loudspeaker azimuth. Wilcoxson's signed rank test was carried out for finding the pairs of stimuli having significant difference in parameters that had significant difference in the Friedman's test. Spearman's rank correlation coefficient was done to check the correlation between behavioral measure and questionnaire.

The localization error for the two groups was calculated by finding the difference in angle between the loudspeaker through which the stimulus were presented and the loudspeaker which the participant localized. Degree of error (DOE) corresponds to the difference in the degree of azimuth between the loudspeaker from which the target stimuli was presented and the loudspeaker to which the participants points. The root mean square of the degree of errors for each of the stimuli that were presented, were calculated after noting the responses on a spread sheet.

4.1 Comparison of localization and spatial hearing abilities in normal hearing individuals

Initially localization abilities across different stimuli were calculated and then the spatial hearing abilities were calculated by obtaining the average of the ratings for each condition.

4.1.1 Objective test for localization across different stimuli in quiet

The error in localizing (DOE) for each stimulus was calculated by obtaining the average localization response for each of the stimulus i.e. 3 phonetically balanced words per 6 speakers in child, male, female voices and 1 musical stimuli per 6 speakers as depicted in Table 4.1

Table 4.1

Mean error in localization for each stimulus in quiet condition in normal hearing individual

Stimuli	*Mean RMS degree of error*
Child voice	0^0
Female voice	0^0
Male voice	0^0
Music	0^0

4.1.2 Objective tests for localization in the presence of noise

Localization error was also calculated for speech in noise condition (spatially separate and same direction). The results are depicted in Table 4.2.

Table 4.2

Mean error in localization for each condition in the presence of noise in normal hearing individual

Stimuli	*Mean RMS degree of error*
Spatially separate	0^0
Same direction	0^0

From Table 4.1 and Table 4.2 it can be noted that there were no localization error across different stimuli (child, male and female) in quiet and noisy conditions (Spatially separate and same direction). This indicates that individuals with normal hearing sensitivity had no difficulty in localizing sounds both in quiet and noisy situation.

4.1.3 Qualitative assessment of localization and spatial hearing in normal hearing individuals

Assessment was done by calculating the average of percentage rating done by individuals with normal hearing in all seven conditions as depicted in the Table 4.3

Table 4.3

Average of percentage rating for seven conditions in normal hearing individual

Question	*Mean percentage rating*
Child voice	100
Female voice	100
Male voice	100
Music	100
Localization	100
Spatially separate	100
Same direction	100

0-Very difficult, 25-Can do sometimes, 50-Can do half of the times, 100-Very easy

From Table 4.3 the mean score in normal hearing group shows that all the seven conditions were rated 100 (“VERY EASY”) by all the subjects. This indicates that individuals with normal hearing did not have any difficulty in localization tasks in quiet and as well in the noisy conditions.

4.2 Comparison of localization and spatial hearing abilities in individuals with reduced hearing sensitivity

The localization abilities across different stimulus was calculated and then the spatial hearing abilities was calculated by obtaining the average of the ratings for each condition for the individuals with mild-moderate sensorineural hearing

4.2.1 Objective test for localization across different stimuli in quiet

The mean error in localizing each stimulus was calculated by obtaining the average localization response for each of the stimulus i.e. 3 phonetically balanced words per 6 speakers in child, male, female voices and 1 musical stimulus per 6 speakers as depicted in the Table 4.4

Table 4.4

Mean error in localization for each stimulus in quiet condition in individuals with hearing loss

Stimuli	*Mean RMS degree of error*
Child voice	29.77^{0}
Female voice	20.63^{0}
Male voice	23.37^{0}
Music	5.10^{0}

To check for significant difference across different stimulus a non parametric Friedman's test was carried out and it rendered $\chi^{2=}$25.7 which was statistically significant ($p<0.05$). Further analysis was carried out using Wilcoxon signed rank test, to identify pairs of stimuli that were significantly different from each other. The Wilcoxon's test results indicated that there was a statistically significant difference ($p<0.05$) in the following pairs: music and child voice; music and female voice and music and the male voice as depicted in the Table 4.5

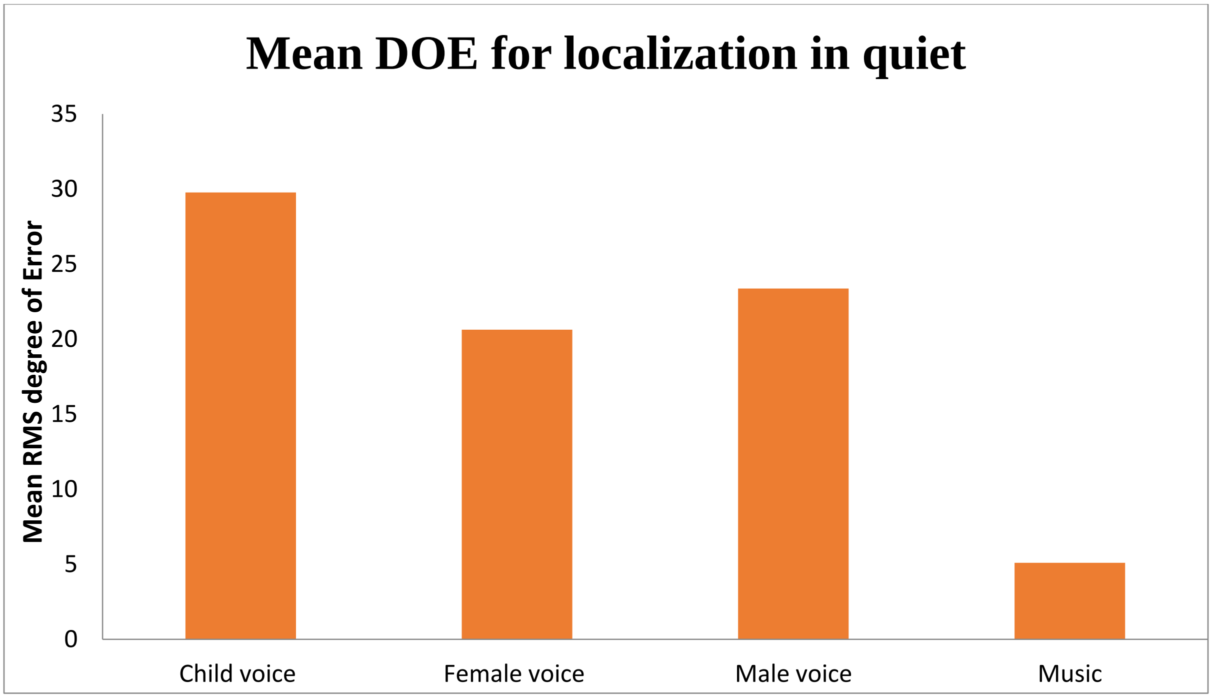
Table 4.5

Results of Wilcoxon's signed rank test

Stimulus pairs	z value	p value
Music & child voice	-3.408	0.001*
Music & female voice	-3.111	0.002*
Music & male voice	-3.358	0.001*
Child & female voice	-2.217	0.027
Child & male voice	-0.852	0.394
Male & female voice	-1.060	0.289

* =significant difference ($p<0.05$)

The results from Table 4.4 and 4.5 indicates that individuals with hearing loss have more difficulty localizing child voice than male and female voice. Music stimuli had the least DOE compared to other stimulus and hence the easiest among the entire stimulus to localize as depicted in the Figure 4.1.



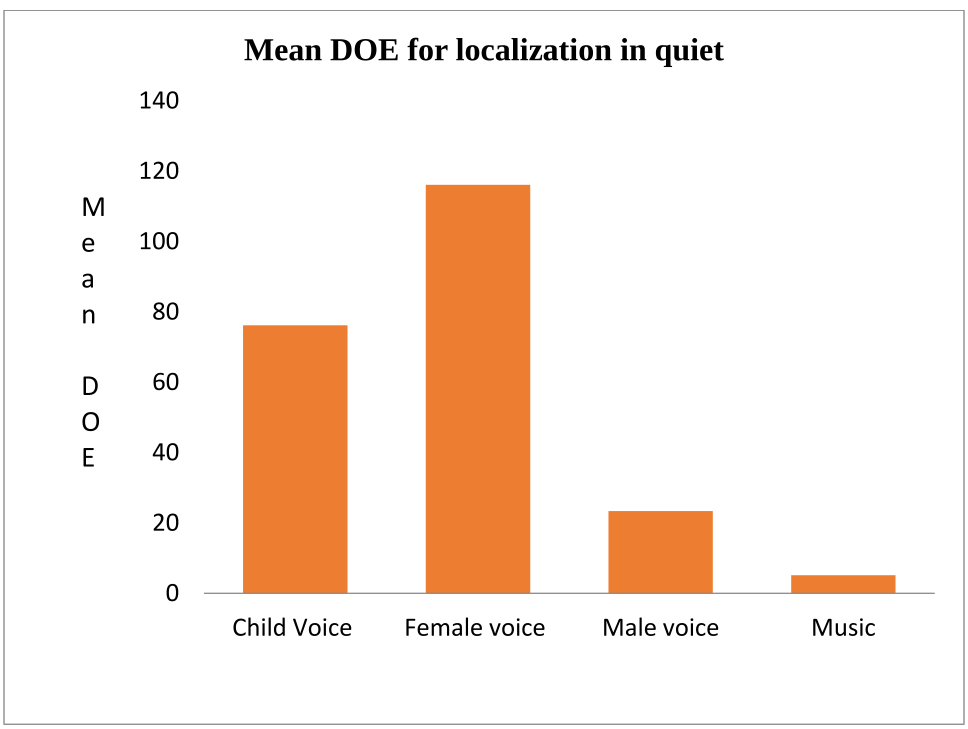


Figure 4.1 Mean Degree of error for localization in quiet condition

4.2.2 Objective tests for localization in the presence of noise

The mean localization error was also calculated for speech in noise condition (spatially separate and same direction) as depicted in the Table 4.6

Table 4.6

Mean error in localization for each condition in the presence of noise in individuals with hearing loss

Condition	*Mean RMS degree of error*
Spatially separate	76.15^0
Same direction	116.09^0

Wilcoxon signed rank test was done to identify significant difference between the spatially separate and same direction condition. The Wilcoxon's test results indicated that the difference was not statistically significant $Z=1.667$ ($p>0.05$). The results from Table 4.6 indicate that individuals with hearing loss have more difficulty localizing when speech and noise were presented from the same direction. This result is depicted in Figure 4.2 given below.

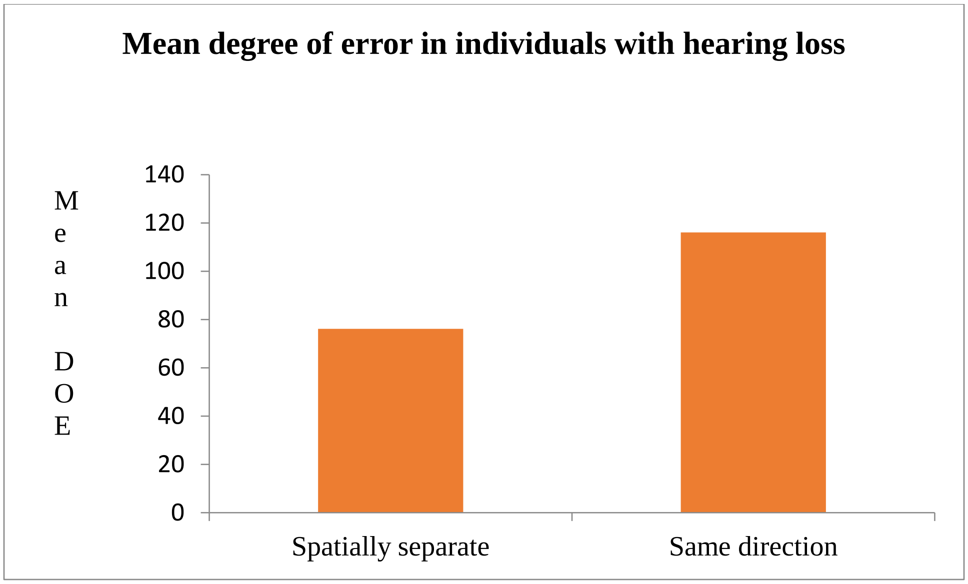


Figure 4.2 Mean degree of error in individuals with hearing loss in the presence of noise

4.2.2 Qualitative assessment of localization and spatial hearing in individuals with hearing loss

Assessment was done by calculating the average of percentage rating done by individuals with normal hearing in all seven conditions as depicted in the Table 4.7

Table 4.7

Average of percentage rating across 7 conditions in individuals with hearing loss

Question	*Mean percentage rating*
Child voice	72.7778
Female voice	77.7778
Male voice	88.8832
Music	84.3333

Localization	88.8832
Spatially separate	82.5310
Same direction	84.4817

0-Very difficult, 25-Can do sometimes, 50-Can do half of the times, 100-Very easy

To check for significant difference across different conditions Friedman's test was carried out and it rendered χ^{2}=5.540 which was not statistically significant (p>0.05). These results indicate that localization difficulties are almost same across the 7 conditions and the percentage ratings ranges from 70-80 as depicted in the Figure 4.3.

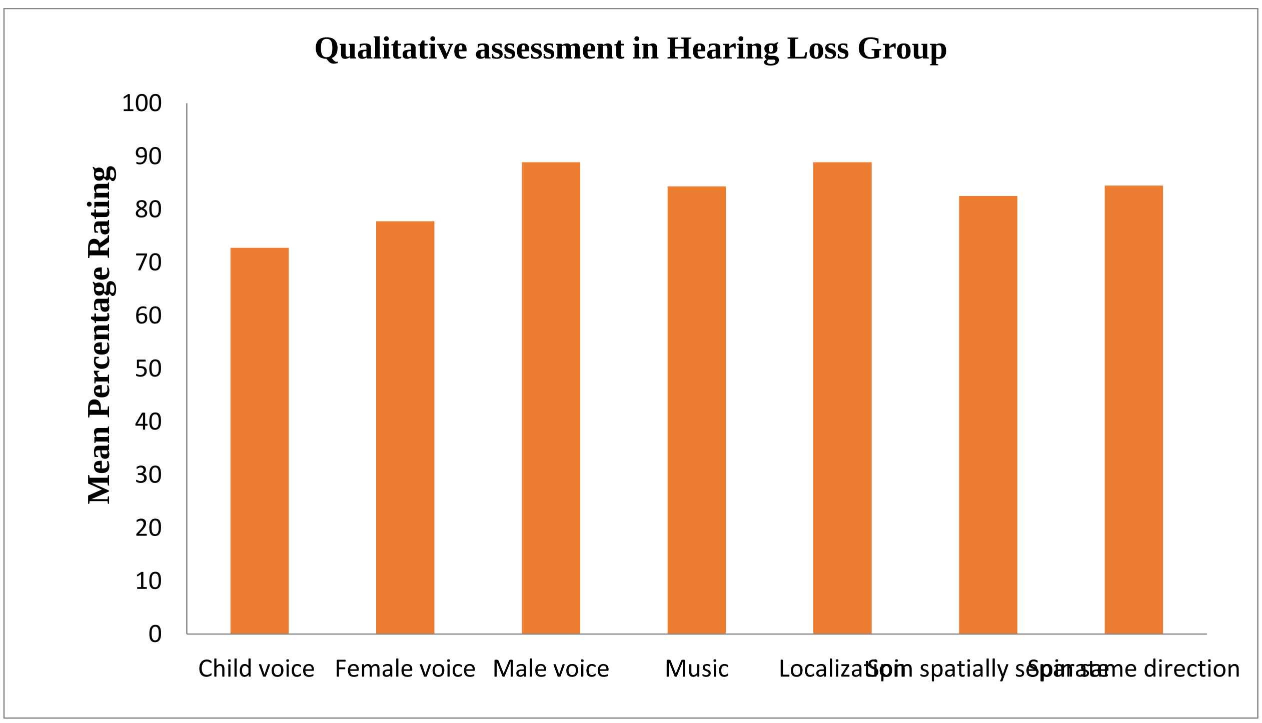


Figure 4.3 Mean percentage ratings of individuals with hearing loss in SHQ

4.3 Comparison of localization abilities between normal and hearing impaired individuals.

The second group (normal hearing) had same scores across all stimulus and conditions; therefore one sample wilcoxon's test was carried out to see significance between two groups.

4.3.1 Comparison between normal and hearing impaired group for localization task across different stimuli.

The normal hearing group had 0 degree of error for all stimulus condition and hence 0 was taken as single value for the group and was compared with hearing impaired group using 1-sample Wilcoxon's test. The results reveal that a statistically significant difference ($p<0.01$) was observed in all the stimuli: child voice, female voice, male voice and music.

The Spatial abilities when speech and noise was in same direction had a statistically significant difference (p value < 0.01) and when noise and speech was spatially separate also had a statistically significant difference (p value < 0.01) as depicted in the Table 4.8

Table 4.8

Results of 1-sample Wilcoxon's test in objective test.

Stimuli/Condition	*p value*
Child voice	0.001*
Female voice	0.001*
Male voice	0.001*
Music	0.017*
Speech & noise in same direction	0.001*

Speech & noise spatially separate	0.007*

* =significant difference (p<0.05)

From the Table 4.8 it can be noted that individuals with hearing loss had more difficulty in localization when compared to normal hearing individuals in all conditions in the objective test.

4.3.2 Comparison between normal and hearing impaired group for the qualitative data (Questionnaire)

The normal hearing group had rated all the questions with a rating of 100 for all stimulus condition and hence 100 was taken as single value for the group and was compared with hearing impaired group using 1 sample wilcoxon's test and there was a statistically significant difference (p <0.05) in all conditions, except for localization as depicted in the Table 4.9

Table 4.9

Results of 1 sample Wilcoxon's test in subjective test

Conditions	*p value*
Child	0.005*
Female	0.003*
Male	0.007*
Music	0.007*
Speech & noise in same direction	0.002*
Speech & noise spatially separate	0.002*

Localization	0.078

*****= significant difference ($p<0.05$)

These results indicate that the individuals with hearing loss had more difficulty in localizing child, male, female and music stimuli in quiet condition when compared to normal hearing individuals. Difficulty in localizing speech in presence of noise (spatially separate and same direction) was noted in individuals with hearing loss.

4.4 Correlation of localization abilities with results of spatial hearing questionnaire (SHQ) in individuals with hearing loss

To find the correlation between the localization ability and results obtained from the SHQ in individuals with hearing loss one sample Spearman's correlation was done and the results are as shown in the Table 4.10

Table 4.10

Results of Spearman's rank correlation

Pairs(Behavioural and subjective)	r_s	*p value*
Child	-6.42	0.10
Female	-5.27	0.44
Male	-0.54	0.84
Music	-0.53	0.85
Speech & noise in same direction	-2.92	0.29
Speech & noise spatially separate	-4.77	0.72

The results revealed that there was no significant difference ($p>0.05$) found in any pairs. These results indicate that there was no correlation between subjective and objective test done.

Summary of the results

The normal group individuals had 100% scores in both the objective and subjective tests. In the objective tests done the individuals with hearing loss had more difficulty localizing child voice. Music stimuli were easy to localize when compared to child, female and male voice in quiet situation. The individuals with hearing loss had more difficulty localizing speech in noisy condition, when speech and noise was presented through same direction. When localization skills of hearing impaired was assessed subjectively, the difficulty to localize was same in all conditions. Further when normal hearing individual's performance was compared with individuals with hearing loss in objective test, individuals with hearing loss had more difficulty to localize in speech in presence of noise. The same result was found in subjective test also i.e. individuals with hearing loss had more difficulty localizing male, female, child and music stimuli in quiet and speech in noisy condition than individuals with normal hearing. There was no correlation between objective and subjective test. Even though individuals with hearing loss reported less difficulty in localizing sounds in subjective tests, more localization errors were found in the objective test for localization.

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Chapter-5

DISCUSSION

The aim of the present study was to compare subjective and objective methods of localization and spatial hearing in individuals with hearing loss. Subjective and objective tests to measure localization and spatial hearing abilities were administered in individuals with normal hearing and individuals with mild-moderate sensorineural hearing loss. The results are discussed under the following heading.

5.1 Localization and spatial abilities of normal hearing individuals

Individuals with normal hearing performed highly accurately in both objective and subjective tasks for localization. The normal hearing individuals had 0 degree of errors in localizing in quiet condition and also in the presence of noise in all the conditions. The normal hearing individuals also scored 100 % in all the sections of SHQ questionnaire, indicating no difficulty in localizing sound in both quiet and noisy condition. The results are in agreement with the findings of Makous and Middlebrooks (1990), Butler, Humanski and Musicant (1990) and Noble (1994).

5.2 Localization and spatial abilities of individuals with hearing loss

5.2.1 Objective test for localization across different stimuli in quiet

The individuals with hearing loss had difficulty in localization task. This may be due to the lack of auditory information as a result of hearing loss. The mean scores of male and female voices were reduced in the localization task. These results could be due to the reduced audibility in these individuals (Noble & Tyler, 1994). Further, it was noted that the individuals with hearing loss had highest degree of error for stimuli with child's voice when compared to male, female voices or music stimuli. The differences may be attributed to anatomical and morphological differences in the vocal-tract geometry, less precise control of the articulators, higher fundamental and formant frequencies, greater spectral variability and higher variability in speaking rate (Potamianos, & Narayanan, 2007). This can also be implied to the lack of availability of interaural level difference cues that helps in localizing the higher frequencies (Fedderson, Sandel, Teas, & Jeffress 1957).

5.2.2 Objective tests in the presence of noise.

In presence of background noise the mean differences between localization tasks for noise and stimuli from same and different directions were not statistically significant. However, the individuals with hearing loss had more difficulty localizing when speech and noise was presented through the same direction. According to Good and Gilkey (1996) localization accuracy is not greatly affected in the presence of noise until the signal and the noise are presented through same speaker. Further, Jacobsen (1976) reported similar results that the spatial acuity deteriorates when target sound and the noise are presented simultaneously. Better speech perception in noise is directly related to localization (Hirsh, 1950), hence the results may indicate that hearing impaired individuals have more problem in understanding speech when noise and speech are from the same direction.

5.2.3 Subjective test using Spatial Hearing Questionnaire in quiet condition

The mean SHQ scores in quiet condition were reduced; however there were no significant differences between listening conditions (Child voice, Male voice, female voice and music). Similar results have been reported by Delphi, Abdolahi, Tyler, Bakhit, Saki & Nazeri, (2015) that the mean difference of SHQ between child, female and male was not statistically significant. The reduced scores seen in hearing impaired individual in SHQ in quiet condition could be due to lack of audibility (Noble & Tyler, 1994) and thus individuals in the present study could have rated reduced localization ability.

5.2.4. Subjective test using Spatial Hearing Questionnaire in presence of noise

There was no significant difference in the localization abilities for speech stimuli when noise was spatially separate and in same direction conditions. Flamme (2002) reported that localization abilities are not impaired till bilateral pure tone average of 50 dB HL, even in presence of noise. In the present study the pure tone average of the individuals were not greater than 51 dB HL. Further, Flamme (2002) reported that localization ability deteriorates as pure tone thresholds increases beyond 50 dB HL. Studies can be carried out in individuals with hearing loss greater than moderate degree. However as seen in the results of objective test, the spatially separate and same direction speech identification in noise were affected, this warrants use of objective tests to understand hearing impaired individuals hearing abilities in noise.

5.3 Comparison of localization and spatial abilities between normal hearing individuals and individuals with hearing loss

5.3.1 Objective test

Overall the individuals with hearing loss had more difficulty in localization when compared to normal hearing individuals in all conditions in the objective test. When compared to normal hearing individuals, individuals with hearing loss experience more difficulties in localizing sound source. The difficulty was also more in localizing child, male, female and music stimuli in quiet condition when compared to normal hearing individuals. Similar results were also reported by Noble, and Tyler (1994), Gardner (1973), Humanski, and Butler (1988). Difficulty in localizing speech in presence of noise (spatially separate and same direction) was noted in individuals with hearing loss. Subjects with hearing loss have significantly poorer speech understanding, especially in competing noise contexts (Tyler, & Noble, Dunn, & Witt 2006). Hausler, Colburn, and Marr (1983) reported that spectral and intensity information are very important for spatial discrimination and for localization, as spectral information is degraded and intensity information is lost due to the cochlear damage hearing impaired individuals have impaired localization. Hausler and Colburn (1983) reported subjects with poor spectral performance complained of difficulties, even with good interaural time and interaural intensity discrimination; whereas subjects with good spectral performance did not complain even if the interaural time and interaural intensity information was poor. Also these difficulties could be due to degeneration of auditory nerve fibres which could be secondary to longer duration of cochlear hearing loss (Chisolm, Willott, & Lister, 2003). The auditory nerve fibres change the rate-level function of Auditory Nerve fiber affecting the spectral shape representations (Reiss, Ramachandran, & May, 2011) and localization performance (Macpherson, & Sabin, 2013). According to Moore, (1995), the cochlear gain as well as spectral resolution of the auditory system gets affected due to cochlear damage thus diminishing the beneficial modulatory effects of the descending efferent system on localization performance in noise (Andéol, 2011; May, Budelis, & Niparko, 2004).

5.3.2 Subjective test

In the subjective tests individuals with hearing loss had significantly poorer performance than normal hearing individuals. The individuals with hearing loss have poor localization and they rate their localization lower than normal hearing individuals in daily life situations (Noble, Byrne, & Lepage, 1994). A questionnaire assessing disability and handicap associated with impaired localization and other binaural abilities was developed by Tyler, Noble, Dunn, & Witt, (2006) and the results showed that the subjects with hearing loss had significantly more difficulty localizing sound than listeners with normal hearing; handicapping effects reported by the subjects with hearing impairment, although minimal, were related to experiences of confusion of sounds in busy places, subsequent loss of concentration, and a desire to escape these challenging situations; and subjects with hearing loss reported significantly poorer speech understanding, especially in group conversations and competing noise contexts.

5.4 Correlation between subjective and objective tests of localization in hearing impaired individuals.

The results reveal that there was no correlation between objective test for localization and subjective test SHQ. Even though individuals with hearing loss reported less difficulty in localizing sounds in subjective tests, more localization errors were found in the objective test for localization. This may be because the localization difficulties go unnoticed by the individuals with hearing loss and do become apparent when people are asked to do task related to localization specifically. Although there have been some reports of complaints of localization difficulties, such problems do not often figure prominently in the spontaneous complaints of hearing-impaired people (Stephens, 1972; Hausler et al, 1983).

These results also point out at the clinical significance of objective sound localization test. By carrying out objective tests the audiologist can decide on the benefit of the hearing aid or in fitting of hearing aid. Also this objective assessment will help in fitting Assistive Listening Devices (ALDs) and in other rehabilitation such as listening training can be carried out.

Chapter 6

SUMMARY AND CONCLUSION

The aim of the present study was to compare localization and spatial abilities of normal hearing individuals and individuals with hearing loss using subjective and objective tests for localization. The study also looked into the correlation between subjective and objective tests.

A total of 30 individuals participated in the study, in which 15 participants had normal hearing sensitivity and other 15 had bilateral symmetrical Mild-moderate sensori-neural hearing loss. For objective evaluation of localization abilities, phonetically balanced words recorded in child, male and female voice and musical stimuli were presented through loudspeakers at different azimuths. For the subjective evaluation of the localization ability Spatial Hearing Questionnaire (SHQ) was administered.

The individuals with normal hearing had 100% scores in both the objective and subjective tests. But individuals with hearing loss had difficulty localizing sounds in all the test conditions in the objective test. The individual with hearing loss rated their spatial abilities much lower than the normal hearing individual in subjective test. In the objective tests done the individuals with hearing loss had more difficulty localizing child voice. Further they had more difficulty localizing speech in noisy condition, when speech and noise was presented through same direction. These results may be due to the lack of audibility and poor spectral resolution as a result of cochlear damage. Even though individuals with hearing loss performed poorer than normal hearing individuals, their performance was not poor as expected, this indicates that apart from the physical cues available from both the ears for localization there could be a separate processes that exists at some level in the central system for the localization cues.

There was no correlation between objective and subjective test that was carried out. Even though individuals with hearing loss reported less difficulty in localizing sounds in subjective tests, more localization errors were found in the objective test for localization. Therefore, performing only subjective tests to assess localization may not give the clear understanding of localization problems in individuals with hearing loss.

There is a practical clinical significance of objective sound localization test. Generally used SHQ tests spatial hearing; however the current localization test results warrants for objective test procedure to test localization and thus help in treatment in SNHL.

Implication of the study:

This study will help audiologist to understand the difficulties faced by individuals with hearing loss in daily listening situations. The findings can be utilized for assessment and management strategies. Also the results may help in modification/selection of the amplification devices/programming strategies/prescribing assistive listening devices for better speech perception in noisy situations and to reduce the rejection of hearing aids. These localization and spatial perception tests may be used to assess the success of hearing aid fitting or other rehabilitative strategies to alleviate localization difficulties. Also including localization testing in conventional audiometric test battery will be helpful for better demonstration of benefits of bilateral vs. unilateral fitting to hearing impaired individuals. The results from this study may help clinicians and researchers to take the spatial processing and localization into account in assessment and management of the individuals with hearing impairment.

Appendix:

The Spatial Hearing Questionnaire:

Name: ________________________________

Date: ________________________________

Please respond to each question with a number from 0 to 100. Number 0 means the situation would be very difficult. Number 100 means the situation would be very easy.

0 = Very Difficult   100 = Very Easy

1. A man talking to you is standing in front of you. It is a very quiet room. How well can you understand him?
2. A woman talking to you is standing in front of you. It is a very quiet room. How well can you understand her?
3. A child talking to you is standing in front of you. It is a very quiet room. How well can you understand the child?
4. You are listening to music that is comfortably loud coming from in front of you. It is a very quiet room. How easy or difficult is it to hear the music clearly?
5. A man talking to you is standing in front of you. There is a loud fan directly behind him. How well can you understand him?
6. A woman talking to you is standing in front of you. There is a loud fan directly behind her. How well can you understand her?
7. A child talking to you is standing in front of you. There is a loud fan directly behind them. How well can you understand the child?
8. You are listening to comfortably loud music coming from in front of you. There is also a loud fan in front of you. How easy or difficult is it to hear the music clearly?
9. A man talking to you is standing in front of you. There is a loud fan off to one side. How well can you understand him?

10. A woman talking to you is standing in front of you. There is a loud fan off to one side. How well can you understand her?

11. A child talking to you is standing in front of you. There is a loud fan off to one side. How well can you understand the child?

12. You are listening to comfortably loud music coming from in front of you. There is also a loud fan off to one side. How easy or difficult is it to hear the music clearly?

13. How well are you able to determine the location of a man’s voice when you cannot see him?

14. How well are you able to determine the location of a woman’s voice when you cannot see her?

15. How well are you able to determine the location of a child’s voice when you cannot see the child?

16. How well are you able to determine the location of a music source, say a radio, when you cannot see it?

17. How well are you able to determine the location of a man’s voice when he is behind you?

18. How well are you able to determine the location of a woman’s voice when she is behind you?

19. How well are you able to determine the location of a child’s voice when the child is behind you?

20. How well are you able to determine the location of a music source, say a radio, when it is behind you?

21. How well are you able to determine the location of a flying airplane when you cannot see it?

22. You hear a car off in the distance, but you cannot see it. How accurately can you tell where it is coming from?

23. If you were to stand beside a road and close your eyes, how well could you tell what direction a car was going as it passed by?

24. You are in a room in a house and hear a loud sound. How easily can you tell how far away the sound was?

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