ASSESSING LOCALIZATION ABILITY FROM INDIVIDUALS WITH HEARING IMPAIRMENT: A STUDY ON SIMULATED TRAFFIC ENVIRONMENT

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CERTIFICATE

This is to certify that this dissertation entitled **"Assessing Localization Ability from Individuals with Hearing Impairment: A Study on Simulated Traffic Environment"** is a bonafide work submitted in part fulfillment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD035. 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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This is to certify that this dissertation entitled **"Assessing Localization Ability from Individuals with Hearing Impairment: A Study on Simulated Traffic Environment"** has been prepared under my supervision and guidance. It is also being certified that this dissertation 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 **"Assessing Localization Ability from Individuals with Hearing Impairment: A Study on Simulated Traffic Environment"** is the result of my own study under the guidance of Dr. Hemanth N, 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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Abstract

Objectives: The present study was taken up to examine localization ability from subjective and objective methods in a simulated road traffic environment. The objectives were formulated as follows: a) To compare the localization errors between age matched control group and clinical groups b) To assess the localization function index using a standardized questionnaire from control and clinical groups c) To correlate and predict degree of error and localization function index with the audiological findings of participants of the study d) To find the relation between existing protocols in clinic to assess hearing fitness for driving license and to adopted test utilized in the current study.

Method: Forty participants within age range from 40 to 60 years were involved in the study. The participants were grouped into two groups namely control group and clinical group. Control group comprised of ten participants and all of them had normal hearing sensitivity. Clinical group were sub grouped into three, based on severity of hearing loss i.e. moderate to moderately severe hearing loss 40 to 70 dB HL (mean HL = 61.25 dB HL) (subgroup-1); severe hearing loss 70 to 90 dB HL (mean HL = 77.5 dB HL) (subgroup-2) and profound hearing loss > 90 dB HL (mean HL = 100 dB HL) (subgroup-3). Each subgroup comprised of ten participants. The participants were binaurally fitted with the digital BTE hearing aids. The target stimuli (Truck horn and automobile horn) were presented from five speakers and traffic noise (65 dB SPL and 75 dB SPL) was presented from four speakers as background noise to simulate traffic situation. The localization errors for each horn presented in low and high noise levels were assessed. In addition, localization functional index using the standard questionnaire was obtained from the participants of the study. Further aided SIS and aided audiogram were assessed in binaural condition.

Results: The results revealed a degree of localization error increased; LFI and SIS were significantly reduced with increase in degree of hearing loss. Further localization error significantly increased with high noise level than low noise level. LFI and DOE were significantly correlated with audiological findings. To be specific, LFI significantly decreased with increased degree of hearing loss; and hearing disability. In addition, LFI decreased significantly with reduced SIS. Further, DOE significantly increased with reduced localization functional index. A regression model was established through which DOE, LFI were predicted from the audiological findings. Interestingly, irrespective of degree of hearing loss, aided thresholds were within speech spectrum.

Conclusion: The findings of the study suggest to include localization test in a simulated road traffic condition rather aided audiogram in the present day protocol to issue hearing fitness certificate for hearing impaired individuals who seeks it for applying driving license. However, the eligibility criteria to issue certificate of hearing fitness for applying driving license is yet to be decided in the upcoming studies.

Chapter 1

Introduction

In India, a total of 18.9 % of population are hearing impaired from 2.21 % of total disabled population (NSSO-2011). Hearing impairment is found to be positioned first among other disabilities. According to Section 2(i)(iv) of the persons with Disability Act, 2016, (PWD) states that hearing disabled person is one who has the hearing loss of 60 dB or more in the better ear for conversational range of frequencies. A consequence of hearing loss can reduce traffic safety. Schmolz (1987) reported that hearing function is important while riding vehicle. It is known fact that although visual information place high demand while riding, hearing ability is partly involved in it (Henderson & Burg, 1974). A research report by Lundalv (2004) who stated that adult pedestrians and cyclists with moderate hearing loss are at high risk of being injured by a vehicle because they find it difficult to identify the direction of potential hazards. Thus, the majority of the states impose a few restrictions on the licensing of persons with hearing impairments for automobile driving. However, there has been a long history of concern about licensing to drive on people who cannot hear. To report a few, In United States, issuance of commercial license is prohibited if the hearing loss is worse than 40 dB or individual is unable to hear whispered speech at 5 feet. Contradictory to the previous statement a study by Sackey (2015) who had reported that deaf drivers drove better than normal hearing counterparts because they respected road safety regulations and used rear mirrors more effectively and use their other senses well to compensate the hearing loss. Thus, there is an equivocal response to issue driving license to the individual's with hearing disability and moreover there is no appropriate test to assess hearing ability in road traffic condition. Whereas, in India, the issue on driving license to hearing impaired has received relatively little attention in the literature. Recently, in 2011 Delhi high court has permitted deaf persons is entitled to receive driving license after passing a driving test. Till date, there is no standardized test to assess their hearing ability, especially in road traffic condition. In India at present scenario, aided threshold in quiet condition is obtained for the sounds presented at 0 degree azimuth. If the aided thresholds are within the speech spectrum then hearing fitness certificate has been provided to individual with hearing impairment who seeks to apply for driving license. Unfortunately this test does not quantify the hearing ability in a realistic traffic condition because visual cues provide cue on potential hazardous source when the incidence of sound energy is from 0 degree azimuth. Localization of sounds coming from rear side is of utmost important especially in a road traffic noise conditions rather the lowest level at which a person can detect the sound. The above explained fact is in consonance with research study conducted by Yokoyama et al., (2014) who reported that hearing impaired individuals finds it difficult to locate the direction of the vehicle horn or siren of ambulance while driving vehicle. In addition, Hausler et al., (1983) reported that hearing-impaired listeners have reduced performance on binaural functioning tasks. For instance localization in everyday environment is important to make the person hear from which direction sound is coming. Thus, in the present study, a standardized test protocol is adopted to assess localization ability for the horn sounds delivered from rear directions in the presence of traffic noise. Further, a localization error is computed from localization task (Ching, Incerti & Hill,

2004) on cohort of hearing impaired population who were classified based on severity of hearing loss.

1.1. Need for the study

Hearing system is one among the prime sense organs which augment to drive a vehicle safely. Because of difficulty in locating the sound source, individuals with hearing impairment may face problem while driving vehicle even with less severity, especially, when the vehicles are at rear. Locating a sound source is found to be important skill while driving. It is observed that according to the Motor Vehicle act, (1988) refused to give driving license to a hearing impaired individuals stating that hearing loss could be a source of danger to him/her, public and passengers. This judgment was questioned at Delhi high court in public interest litigation by a hearing impaired individual. The final verdict of the Delhi high court on 15 February (2011) stated that individual with hearing impairment are eligible to receive driving license. In one of the study reported by Henderson and Burg (1974) opined that vision makes up most of the driving task and hearing plays a small role in it. Although its role would be small, auditory system forms an integral part for a safe driving which provides cue for locating the sound source. As a hearing care professional there place a high demand of responsibility to assess hearing ability before they are entitled to receive driving license. In addition, it is imperative to quantify on how a hearing impaired individuals obtain cues of vehicle horns through hearing aid, especially in traffic noise. Furthermore, in the current day scenario aided audiogram has been in practice to certify hearing fitness certificate who seeks to apply for driving license. Detection of sound either by whisper test or performing aided audiogram does not help much concerned to hearing especially in driving. Indeed there is a need for standardized test to assess their hearing ability considering road traffic environment required for driving. Thus, in the present study an attempt is made to document the localization ability using subjective and objective methods from a cohort of hearing impaired with different degree of severity. These tests are performed in aided conditions to systematically trace their hearing ability in a laboratory situation, which closely simulate a traffic environment and further compared with the existing test protocol utilized in our clinic.

1.2. Aim of the study

The aim of the present study is to examine localization ability from individuals with hearing impaired using subjective and objective methods in a simulated road traffic environment.

1.3. Objectives of the study

1. To compare the localization errors between age matched control group and clinical groups
2. To assess the localization function index using a standardized questionnaire from control and clinical groups
3. To correlate and predict degree of error and localization function index with the audiological findings of participants of the study and
4. To find the relation between existing protocols in clinic to assess fitness for driving license and to adopted test utilized in the current study.

Chapter 2

Review of literature

Driving is the primary mode of travel in many developed countries and possession of a driver’s license in a number of societies is an important symbol of personal independence (Owsley and McGwin, 1999). However, driving is considered one of the most complex tasks in modern society (Groeger, 2000). For a normal hearing having skill in driving can entail to get license to drive. Road traffic information sensed by hearing and vision are of utmost import for safe drive. Though driver have normal vision, hearing loss in them have a significant effect on road safety. Hearing loss is a most common chronic condition having high prevalence. There are many studies focused on hearing loss and road safety. This is because hearing impaired individual have difficult to identify location of sound source (Lundalv, 2004). In addition, act concerned to road safety on hearing impaired has no consensus across country. A few countries act permits individuals with hearing impairment to drive and other countries considers them as defaulters. Further, there is no battery of test till now available to assess the hearing ability in traffic environment to locate the sound source. Thus, research conducted in these areas was thoroughly reviewed for appropriate research design. Research regarding this topic aims in identifying the best measure to assess the hearing ability for receiving driving license.

2.1. Effect of hearing loss and traffic safety

A deaf American reported 'deaf drivers did not have any history of accidents in a magazine. Supporting this statement there are research studies conducted in 60's who have reported deafness did not have a significant problem on driving performance (Finesilver, 1962; Norman, 1962; Grattan and Jeffcoate, 1968).In contrast to these findings, a case control study conducted by Coppin and Peck (1963) have reported that hearing impairment had a greater association with higher risk of motor vehicle accidents. They found that profound deaf drivers differed from those with normal hearing drivers by more number of road traffic accidents and violations of driving rules. The authors have realized limitation of their study by not considering age matched case and control groups. To overcome this lacuna, Coppin and Peck (1965) conducted an observational study where they reported that deaf males had a significantly higher number of road traffic accidents than normally hearing drivers. They concluded that male deaf drivers may spend more time driving in critical situations during rush hours of road traffics. Henderson and Burg (1973) provide the most specific and comprehensive look on relation between hearing and driving with respect to commercial motor vehicle operation. They incorporated driving task in the study which was given from the viewpoint of hearing and they defined four categories of auditory stimuli that might be important for the safety of truck driver. These categories included warning or attention-getting stimuli (horns, sirens, whistles); feedback stimuli (the response from the engine when acceleration is undertaken); other sounds that are quickly identifiable (e.g., air brakes) and other sounds that are not quickly identifiable (e.g., metal rubbing against a tire). These stimuli were then considered across three driving environments (high-noise, lownoise, and quiet), and driving behaviors that might occur in each of the scenarios above were rated for their importance to the driving task. The results suggested that the hearing makes its greatest contribution for driving especially during critical driving phases or emergency responses. It was reported that most important use of the sense of hearing while driving was to monitor the proper functioning of one's own vehicle and to a lesser extent to guide the use of the vehicle. In the similar line of experiment,Ivers et al., (1999) conducted a questionnaire based study in a larger population (n=2,326) on older population (≥49 years old). The questionnaire included the information on driving habits, previous road traffic accidents and degree of hearing impairment. The results of the study revealed that individuals with moderate hearing loss and hearing loss in the right ear although not significant but were associated with an increased crash risk. Severe hearing loss had increased likelihood of self-reported car accidents. They concluded that the relationship between hearing loss and road traffic accidents is directly related. Thorslund et al., (2013) conducted a study to investigate driving license defaulters and nondefaulters in a group of hearing impaired individuals. They administered a questionnaire on individuals with hearing loss in order to check the transport safety and mobility concerns. They involved 20 questions which were presented in three groups made based on degree of hearing loss. In their survey they also included information regarding driving license, avoidance of driving under certain conditions. They also obtained audiometric data for each respondent as a measure for hearing loss. From the results they found that there was an association between hearing loss and defaulter of driving license.

Prevalence of defaulters from driving license increased with higher degree of hearing loss. That is profound hearing impaired individuals had lesser chances of obtaining driving licence when compared to normal hearing, mild to moderate loss and severe hearing loss. The above mentioned study was either conducted by administering questionnaire to the participants sought on driving difficulty or using a one shot study design. To overcome this shortcome.Edwards et al (2016) studied association between hearing impairment (HI) and driving safety in a longitudinal study carried out for 3 years in older adults (63–90 years of age). The results indicated that older adults with moderate-to-severe hearing impairment are at higher risk for crash involvement, older adults with hearing loss are at increased risk for crashes and may be more likely to have difficultly driving in challenging situations. They also reported that older adults may not be more likely to significantly modify their driving habits over time and concluded that hearing impairment is independently associated with driving safety, but is not related to driving mobility. In connection to the hearing disability and road safety there are number of authorized departments. According to the National Highway and Transportation Safety Administration (NHTSA) (1999), reports suggest that individuals with vision, hearing problems, and CVA / dementia problems are defaulters to avail driving license. Department of Transportation Federal Highway Office of Motor Carriers Washington, D.C. (1993) reported that safe driving depends upon the driver's ability to receive messages from the environment, interpret them, and adjust to them. Four senses such as vision, hearing, touch, and smell are likely to influence the driver's ability to receive messages. The Federal Highway Administration concluded that hearing is important when a driver must act on emergency sounds.

From literature many of the studies have concluded that sound from the vehicle is not audible to drivers who have hearing loss. In addition, hearing impaired individuals are limited to hear warning signals, vehicle functioning problems and communication with road users, leading to collision.

2.2. Issue of driving licenses to hearing impaired individuals

2.2.1. In abroad countries. In 1920's deaf individuals were banned from driving in a number of U.S. states. The National Association of the Deaf protested against rule which was supported by accident statistics. With well-reasoned arguments ban from driving was successfully released. The procedure for licensing regulation for hearing impaired individual to drive worldwide appears to be somewhat different. After decades of prohibition, Department of Transport U.S. has agreed to 40 application filed by National association of deaf, allowing the deaf drivers from obtaining commercial driving license and also reported evidence that deaf drivers are safe. The Department of Transport now requires that a commercial driving license applicant should pass either the whisper test or an audiological test. Hearing impaired can also obtain intrastate commercial driving license from their state. Few states grant commercial driving license without hearing test that is valid only within state and not across country. Most states follow the U.S. Department of Transport and require a hearing test based on the federal requirements. Similarly, in New Jersey Dept. of Transport conducts Road test , Vision test, Knowledge test(50 questions written/oral) and a hearing impaired interpreter will also be provided. After passing vision and knowledge test, road test will be carried out. A minimum of 6 months of supervised practice driving is required, prior to a road test appointment. All out-of-country applicants must pass the knowledge test and a vision screening and may be required to pass a road test. Test results are valid only for two years. If an applicant fails the road test, he/she must wait at least two weeks before taking the test again. In New York, department of motor vehicle, medical review officer entitled to state that a person will be physically qualified to drive a commercial motor vehicle if that person first perceives a forced whispered voice in the better ear at not less than 5 feet with or without the use of a hearing aid or, if tested by use of an audiometric device, does not have an average hearing loss in the better ear greater than 40 decibels at 500 Hz, 1,000 Hz, and 2,000 Hz with or without a hearing aid when the audiometric device is calibrated to American National Standard (formerly ASA Standard) Z24.5–1951. When a hearing aid is used to meet the hearing qualification requirement, the hearing aid must be used while driving. The person will be disqualifying when he/she fails in both the forced whisper test and the audiometric test. Unlike in US, in most of the developed countries there appear to be no such rule to get license for driving. In the United Kingdom, people with a hearing loss are not currently required to report their sensory impairment to the Driver and Vehicle Licensing Agency unless they are a commercially employed driver (Driver and Vehicle Licensing Agency, 2012). There is no explanation as to why or what potential effect this type of sensory impairment may have on licensing. Similarly, in Australia, commercial drivers are the only group who need to declare their hearing loss, though it appears that this is more because of safety concerns. The legislation states that, drivers must have an awareness of changes in engine or road noise and external warning signals, and that this may be compromised by a hearing loss. Accordingly, commercial drivers must have a clinical evaluation and may only be granted a conditional license if their hearing reaches a certain standard, though hearing aids can be employed in order to reach this standard (Austroads and the National Transport Commission Australia, 2014).The licensing agency in Australia is mainly concerned with the problems of audibility for hearing impaired drivers, suggesting that they do not view milder forms of hearing impairment as a problem for driving. However in some of the developing countries profoundly deaf individuals are not allowed to drive. In a report for the World Federation of the Deaf and Swedish National Association of the Deaf, Haualand and

Allen (2009) surveyed 93 countries regarding their stance on deaf drivers. Although not all of the countries responded, 31 indicated that they did not allow profoundly deaf individuals to obtain a driving license. In some of these cases, there was no legislation written, but responses from respective countries indicated deaf people are not allowed to drive. This may be because the authorities saw deaf drivers as dangerous and prevented them from practicing this behavior.

2.2.2. In India. In 1989, motor vehicle act has disqualified/disagreed to provide driving license to hearing impaired individuals on the presumption that hearing impaired individuals are danger to public. The National Association of Deaf (NDA) in India has lodged complain against a rule of not issuing driving license to deaf individuals in Delhi high court. In their plea, documents to support that there are no evidence on hearing impaired individuals are dangerous to public. They argued to allow a deaf person to go through the test and drive if they are found capable. Recently in 2011, the legislation of India has agreed to provide driving license to deaf people only if they pass the driving test. Earlier, officials used to directly reject such applications or direct the applicant to provide an eligibility proof from the health department on his/her eligibility. However currently Government of India relaxes norms for hearing impaired to get driving license. The Union ministry of road, transport and highways has notified principal secretaries and transport commissioners of all states that loss of hearing does not impact the ability to drive (Bombay, 2013; Chennai, 2016). However it has been noted that driving essentially requires a visual function with little inputs from hearing, and also if the person is rehabilitated with hearing aid or cochlear implant, were he/she can hear reasonably well then there is only little reason to restrict him/her from obtaining driving license (Deputy ministry of RTO 2003). Based on this decision, RTO Bombay and Chennai has decided to receive the application from hearing impaired individuals, who can be considered to give learners driver's license without the necessary proof of his/her eligibility from the chief medical officer (CMO). They ask for documents, driving test in real traffic situation. If they pass the eligibility test, then they can be provided with driving license.

To summarize, some states in US agree to give driving license if the hearing impaired individuals pass the standardized hearing test (ex. Whispered test). In some other abroad countries department of road transport seek applicant to declare their hearing loss with only concern to road safety. In India, with different degree of hearing impairment is entitled to receive driving license if they pass hearing test. However, there is no standardized test to assess their hearing status to receive driving license.

2.3. Procedures utilized to issue driving license to Hearing impaired individuals

In Australian countries, the health professional perform test in assessing a patient's hearing fitness to drive. These drivers should have a reasonable level of hearing to ensure their awareness of changes in engine or road noises that may signal developing problems, rail crossings, emergency signals and sirens. In case of doubt about person's hearing, audiometry test is recommended. Australian National Acoustic Laboratory provided the standard to have an average hearing threshold of no less than 40dBA in the better ear, measured across the lower frequencies of 500Hz, 1000Hz, 2000Hz and 3000Hz Hz to obtain driving license. However, for obtaining commercial driving license hearing impaired drivers must wear hearing aid. In countries such as Luxembourg, Netherland, Malaysia, Melbourne they should undergo a medical examination and fitness examination in which they assess eyesight, hearing, cardiovascular disorders, endocrine disorders, diseases of the nervous system, mental disorders, alcoholism, drugs and medicines, blood disorders and diseases of the genitourinary system and also possible hearing loss measured by audiological testing that is performed by certified personnel. If the hearing impaired person has an unaided average (500Hz, 1000Hz, 2000Hz and 3000Hz) hearing threshold level of equal to or greater than 60 dB in the better ear the hearing impaired person will not be qualified for licensing. In India, a certified audiologist assesses a hearing status after fitting with a hearing aid. If the aided thresholds are within the aided speech spectrum from frequencies 250 Hz to 4 kHz (in octave) then individuals with hearing impaired are entailed to receive the driving license from regional transport office. It is reported from literature though aided thresholds help to assess ability to identify a soft sounds, they tend to have localization difficulty which is utmost important for safe driving.

2.4. Hearing loss and localization ability

Hearing loss is not simply a problem of sound attenuation. It is a problem of sound distortion. Such distortion may have serious effect on interaction at neural level for sounds coming from two ears. Localization of sound by human listeners has been studied extensively over 100 years. Stevens et al., (1936) studied the localization of pure tones and reported that a person can localize a tone in space primarily because the sound differs at the two ears in intensity, frequency or in phase, or in combination. Localization is basically locating a sound source by utilizing interaural time difference (ITD) and interaural level difference (ILD) cues between ears. ILD provides localization cues for high frequency sounds, whereas, ITD provides localization cues for sounds that are low in frequency. It is been reported by Wightman and Kistler (1992) that listeners use ITD cues for frequencies up to 1000 Hz –1500 Hz, and ILD for frequencies above 4000 Hz .Macpherson and Middlebrooks (2002) measured the ILD, ITD and spectral cues in localization of wideband, low-pass and high pass noise bursts. From the findings it was noted that ITD cue utilized was more to locate low pass stimuli than ILD cue. ITD majorly arise due to the head shadow which acts as an obstacle between two ears. The wavelengths of low frequency is greater than the head circumference which leads to time difference between two ears. That is in ITD the distance travelled by the sound in reaching near side takes less time than the farer ear. Thus, ITDs are directly proportional to the size of the head and it depends on frequency and intensity of the stimuli. Practically ITDs are found to be larger for low frequencies (<1500 Hz) and diminishes as the frequency increases (Bernstein and Trahiotis, 1982).Stevens and Newman (1936) showed that localization performance is worse for tones between 2000 Hz and 4000 Hz than at higher or lower frequencies. This is because both ITD and ILD cues are weak in this region. The ITD cues are partly intensity dependent. At below 40 dB SL the ITD cues utilized increased with increase in intensity. However, locating sound source in utilizing ITD cues saturates at 70 dB SL (David and Stephens, 1974).

Localization accuracy of multiple simultaneous sources was studied by Good and Gilkey (1996) in which they asked the listeners to localize the square wave stimuli delivered from 239 azimuth in the presence of SNR of 23 dB . From the results it was found that localization accuracy decreased as SNR reduced. At low SNRs, listeners did more frontback confusions. Localization was found to be difficult in vertical azimuth. This is due to reduced pinna cue. The RMS errors were approximately 12^0 in quiet, 18^0 at 0 dB signalto-noise ratio (SNR), and almost 40^0 at −10 dB SNR. In similar line of experiment study, Lorenzi, Gatehouse and Lever (1999) studied the effect of SNR on location of sound source. The task given to the participants was to localize a train of click in frontal and horizontal plane in quiet and in the presence of white noise. The SNR was varied from -9 dB to + 18 dB presented in +90, 0 or -90 azimuth. They found that regardless of masker location, localization ability was not affected by noise until 0 to 6 dB SNR, however, localization ability decreased at reduced SNR. However in any SNR the effect of noise was more when it was presented at +/- 90 azimuth compared to 0 azimuth. To be specific low frequency cues were less affected by noise than high frequencies when it was presented from +/- 90 azimuth. Brungart et al., (1999) assessed auditory localization of nearby sound source less than 1 meter from listeners head. They reported that the interaural level difference increased as the sound source approached towards the head whereas the interaural time delay is roughly independent of distance. The point of the sound source was moved randomly within 1 meter of subject and the subject was instructed to respond by pointing to the perceived location of the sound with an electromagnetic position sensor. Azimuth error increased slightly as the sound source approached the head. This is because of increased diffraction caused by head. In the recent study conducted by Wood and Bizley (2015) who measured localization task at spatial resolution at 15^0fixed intervals. Listeners were instructed to discriminate the relative location of two sequentially presented sound sources. To make it more natural, noise was presented from multiple speakers. Three experiments were carried out, localization in presence of noise, localization in presence of BBN (broad band noise), LPN (low pass noise), BPN (band pass noise) which restricted the ITD and ILD cues. From the results it was noted that with decreasing the SNR there was impaired performance throughout auditory space. The localization ability at high SNR level was better for BBN than LPN followed by BPN. They concluded that the SNR and auditory space interaction was present indicating that with increased SNR the performance in locating sound source was improved.

To summarize, ITD is a cue in locating low frequency sound source. Hearing impaired individuals' finds it difficult to locate sound source due to impaired auditory input. The hearing loss creates distortion and unable to effectively integrate the sounds from two ears.

2.5. Amplification and Localization

The potential of binaural hearing is that the information is processed through both the ear and linked to binaural centers for the interpretation. In order to restore audibility hearing aids are used by hearing impaired listeners. Recent research on localization shows that aided localization is poorer than unaided (Noble and Byrne, 1990). It is been reported that naturally available cues are altered by hearing aid processing due to bilateral asynchrony (Keidser et al., 2006). Others have opined that independent working digital signal processing (DSP) circuits in the right and left hearing aids could interfere with the naturally occurring binaural cues (Bogaert et al. 2006; Keidser et al., 2006; Keidser et al., 2011). This interference could increase the localization errors especially in noisy backgrounds. Dillon et al., (2001) evaluated on binaural cues provided by two hearing aids on localization revealed that when two hearing aids are working independently with its own time delay and noise reduction strategies, it can bring a destructive effect on binaural cues for localization performance and further degrade the detection of environmental sound perception. It was found that compression in hearing aid found to have serious problem on localization of sound source. This is because the sound reached at near ear has high intensity, thereby reducing the gain, whereas, sound reaching at the far ear has low intensity in which amplification was provided and results in reduced inter aural intensity difference (Hansen, 2002). However, inter-aural intensity difference was maintained in slow acting compression and linear hearing aid circuit. Thus sound processed by slow acting amplification keeps the same gain for long term input even though the input to hearing aid increase or decreases. It was also noted that localization ability depends on style of hearing aid. Noble and Byrne (1990) investigated localization ability within the vertical and horizontal planes based on microphone placement. Three styles of hearing instruments were examined: behind the ear (BTE) with microphones at ear level above the pinna, in the ear (ITE) with microphones in the concha and in the canal (ITC) with microphones in the opening of the ear canal. Listeners were tested in omnidirectional microphone configurations. No significant difference was noted between unaided and aided performance across hearing aids. Thus, the findings of this study reported that localization ability did not improve with BTE, ITE, or ITC hearing instruments in omnidirectional microphone configurations regardless of microphone location. However, several studies have reported that BTE hearing aids deteriorate localization performance more than custom hearing aids (Hausler, Colburn and Marr 1983; Westerman and Topholm, 1985). This may be noted due to the microphone location of BTE hearing aids are more likely disrupting the spectral cues important for front/back discrimination. A few authors have reported many potential solutions to overcome the problem of localization difficulties, such as providing open fit by large vents, thus creating a direct sound path to the ear canal. By doing this it helps in improving direct sound transmission to ear canal but remains limited only to higher frequencies (Byrne et al., 1998; Noble et al., 1998; Drennan et al., 2005; Keidser et al., 2006). Open fit hearing aid on the other hand had caused an confusion in localization especially in individuals with high frequency hearing loss (Nobl, Sinclair & Byrne, 1998). The low frequency sounds are reasonably normal in which the natural sounds and amplified low frequency sounds are mixed leading to change in phase resulting in distorted interaural time difference.

To summarize, hearing aids can upset the balance of the acoustic cues delivered binaurally, if its parameter is not utilized optimally. In such circumstances use of hearing aid leads to less natural hearing experience and result in poorer localization. Thus in the present study binaural hearing aid from the company was used just to have similar processing delay. Slow release time compression circuit was opted as gain remain same for long term input.

2.6. Localization handicap checklist

Estimation of hearing disability is the part of audiological research. Self-rating procedures and behavioral performance task have been used to check the hearing disability. The percentage of disability is obtained on basis of pure tone average, speech recognition scores and also by speech identification scores and can be predicted by audiological parameters. However limitation of this is the representation of daily life. There are few studies suggesting the measure of self-reported data along with audiological evaluation and suggesting that the behavioral test results to be compared with the self-reported data in order to know the hearing disability. Earlier literature reports hearing disability is a one-dimensional scale. It fails to accommodate various functions of hearing into account faced by a individuals with hearing impairment (Lutman et al., 1987). Noble et al., (1970) reported that the hearing impairment is not only associated with speech but also associated with sound localization. Noble et al., (1995) reported a questionnaire based study on localization ability in normal and hearing impaired individuals (N=104) with mean age of 71 years in which they assessed everyday disabilities in sound localization, possible handicap that are associated with everyday life particularly an ability to detect the distance, discrimination of sound and their correlation with localization disability were assessed. From the results it was noted that the localization ability of hearing impaired individual was poorer than normal. They have reported a closer correlation of localization and handicap other than speech recognition and handicap. Questions related to detecting distance of sound and discrimination was severely affected in hearing impaired individuals thus they concluded that hearing impairment was associated with localization disability. Previously reported studies have not used standardized audiometric measurement in conjunction with questionnaire rather have relied only on functional measures (Appollonio et al., 1996) or self-report to determine hearing status (Cacciatore et al., 1999). Thus in order to know the impact of hearing loss on quality of life in older adults with hearing impairment, study by Dalton et al., (2003) in which audiometric thresholds were obtained and The Hearing Handicap Inventory for the Elderly (HHIE) was administered. They reported that severity of hearing loss was significantly associated with having a hearing handicap and with selfreported communication difficulties. The results indicated that HHIE-screening tool is more robust way to identify hearing handicap in elderly irrespective of audiometric results. In yet another study Kramer et al., (1995) wherein they documented hearing disability using a questionnaire format. Thirty questions were framed considering intelligibility in noise and quiet, localization of sound, detection and discrimination of sound. This questionnaire was administered on 274 hearing impaired individuals. In addition auditory thresholds and speech recognition scores were obtained on the same participants on whom questionnaire was administered. The results revealed that scores on questionnaire was lower with increased threshold and reduced speech recognition scores. It infers localization handicap was well correlated between questionnaire and audiometric data. It clearly indicates that even questionnaire related to source location is a sensitive tool to identify the quantity of handicap in localization in hearing impaired population. Noble, Ter-Horst and Byrne (1995) assessed disabilities and handicaps associated with hearing impairment, a questionnaire was used as a part of this study which assessed sound localization difficulty in everyday situation and deleterious effect of localization impairment. Individuals with symmetrical hearing loss using bilateral hearing aids were given with questionnaire and results showed that hearing impaired individuals related their localization skills as significantly poorer than control groups not having hearing loss.

To summarize from the studies indicate that questions related everyday localization was correlated with audiometric data. However, there is a dearth of literature on subjective measure to assess localization function index in those individuals who were fitted with hearing aid.

Literature suggests that hearing impairment is considered hazardous to public and few countries prevent hearing impaired individuals from driving while others provide a license on the basis of few basic audiometric testing. But there is no standardized protocol to certify hearing status for procuring driving license. Driving requires localization skill rather hearing a tone at different frequency. Thus, in the present study a study design was formulated by including subjective questionnaire to evaluate localization ability and objective test to assess degree of localization error in a cohort of hearing impaired population. The findings of the study may suggest a change in protocol to assess hearing status for those who seeks certificate from health professional.

Chapter-3

Method

A standard group research design was utilized to assess the localization ability in a simulated traffic environment using an objective and subjective methods. The entire study was carried out in two phases. The two phases are:

Phase-1.Experiment to objectively assess localization ability

Phase-2.Qualitative measures to assess the localization ability

3.1. Selection of Participants

Forty participants within age range of 40 to 60 years (mean age =50.67) were recruited in the study. The participants were grouped into two groups namely control group and clinical group. Control group comprised of ten participants and clinical group comprised of thirty participants. Further the participants in the clinical group were sub grouped into three based on severity of hearing loss i.e. moderate to moderately severe hearing loss 40 to 70 dB HL (mean HL = 61.25 dB HL) (subgroup-1); severe hearing loss 70 to 90 dB HL (mean HL = 77.5 dB HL) (subgroup-2) and profound hearing loss > 90 dB HL (mean HL = 100 dB HL) (subgroup-3). Figure 3.1. Audiogram of each participant of control and clinical groups. A) Participants of normal hearing, B) moderate group to moderately severe, C) severe group and D) profound group. Each subgroup comprised of ten participants. Those participants in each clinical group who were diagnosed as bilateral symmetrical sensorineural hearing loss and had either no prior experience or experienced with hearing aid usage were included in the study. As a prerequisite for the present study all the participants involved were required to know riding a low motor vehicle. Participants with any history or presence of middle ear disorders, neurological involvement, and any history or presence of psychological problems were excluded from the study.

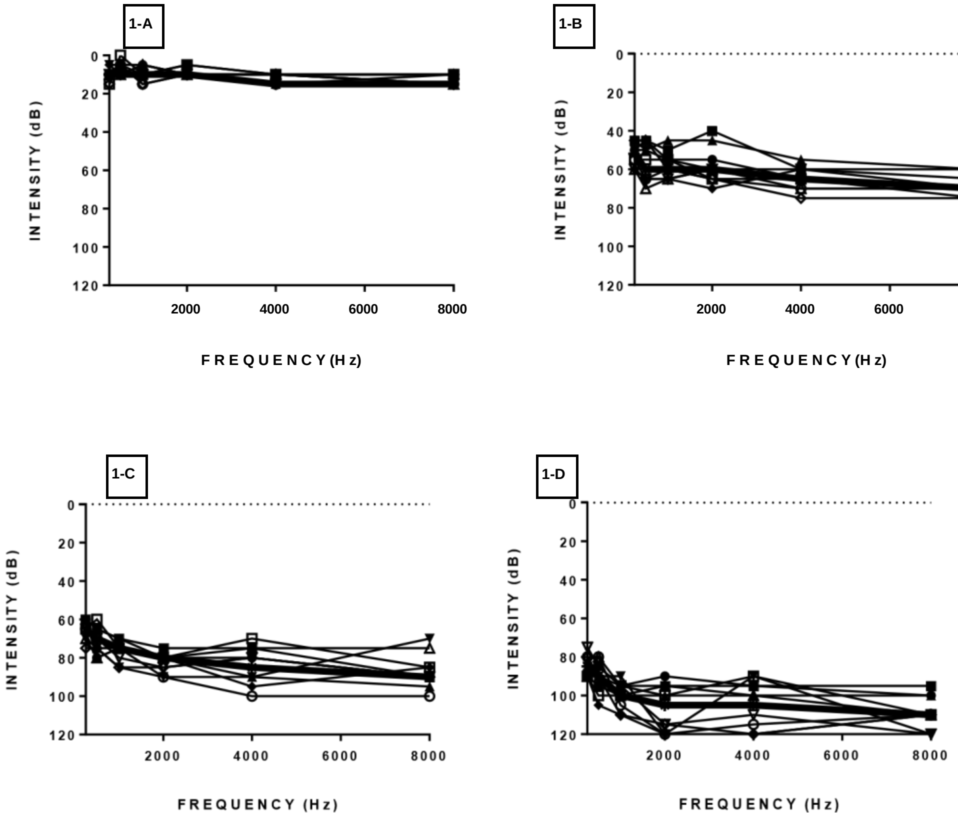


Figure 3.1. Audiogram of each participant of control and clinical groups.
A) Participants of normal hearing, B) moderate group to moderately severe, C) severe group and D) profound group. A thin line represents thresholds at each frequency. The solid thick line depicts the average threshold at each frequency.

3.2. Instruments

The following instruments were used for subject selection criteria and localization ability from the study participants.

1. A calibrated dual channel audiometer was used to assess hearing ability of the participants involved in the study.
2. Middle ear analyzer to assess middle ear status.
3. Loudspeakers to deliver sounds from different azimuth.
4. Road rash video game was used to simulate road traffic condition.
5. A standardized questionnaire on localization (Hemanth et al, ongoing) was used to assess the localization functional index from the study participants.
6. Sound level meter was used to calibrate the target test signals (Automobile horns) and a traffic noise.

3.3. Test Environment

A sound treated air conditioned double room set-up was used to administer the proposed tests. The noise level in the testing room was maintained within the permissible limits (ANSI, 1999).

3.4. Stimuli

The following stimuli were used for localization task

1. Truck horns with the center frequency of around 150 Hz at 110 dB SPL and automobile horn with the center frequency of around 350 Hz at 100 dB SPL were used as the target stimuli.

2. The recorded traffic noise at 65 dB SPL (Average traffic noise) and 75 dB SPL (peak hour traffic noise) (Sreeraj 2016, ongoing ARF project) were utilized as background noise which was used to simulate traffic condition in a more realistic situation.

3.5. Procedure

Apart from routine audiological evaluation the following test procedures were utilized to assess localization ability in both objective and subjective methods. It was carried out in two phases. In phase-1 Degree of error was objectively assessed from control and clinical groups. Further, a subjective measurement using questionnaire on localization was administered to assess the localization functional index from each group.

3.5.1. Hearing aid programming and evaluation. The participants were fitted with the digital BTE hearing aid programmed using the NAL-NL1 prescriptive formula from manufacturer specific software loaded in the personal computer. Ling's six sounds were presented at a distance of 1 meter and the participant was instructed to identify these sounds. The hearing aid gain setting was modified till the participant could identify the sounds with ease. A routine hearing aid evaluation was performed by obtaining aided thresholds for tones presented in one octave from 250 Hz to 4 kHz. Further evaluation was carried out by asking five questions and finding out speech identification score for Standardized Kannada words (Vijaylakshmi & Yathiraj, 1995) presented at 40 dB HL through loudspeaker positioned at 45^0 on right and left side of participants' ear. This measurement was performed in binaural mode.

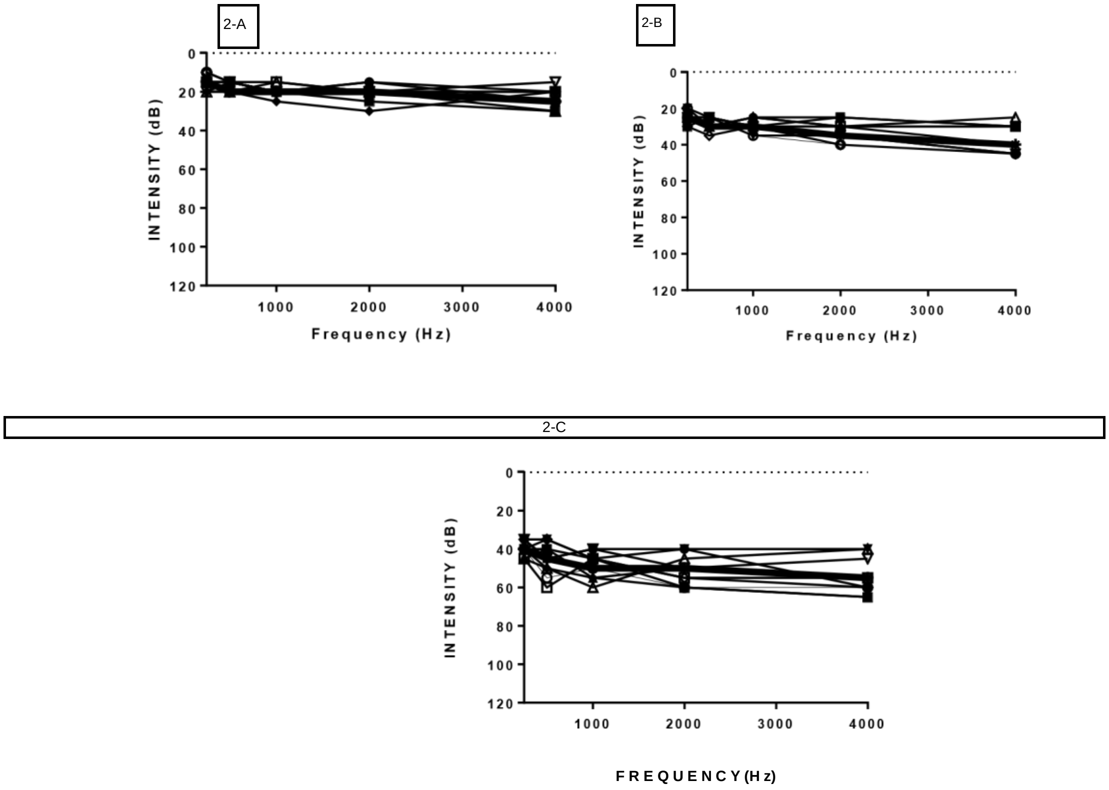


Figure 3.2. Aided Audiogram of each participant of clinical groups. 2A) Moderate group to moderately severe group 2 B) severe group and 2 C) profound group. A thin line represents aided thresholds at each frequency. The solid thick line depicts the average aided threshold at each frequency.

3.5.2. Phase 1: Experiment to objectively assess localization ability. This measure was obtained from each participant of control group and in clinical group. In clinical group, localization ability was assessed in aided conditions in a simulated traffic situation.

3.5.2.1. Calibration of the stimulus. Calibration was done in a sound treated room wherein the target stimuli (truck and the automobile horn) and noise stimuli (recorded traffic noise) from the assigned loudspeakers were calibrated using Bruel and Kjaer hand held (model no. 2270) sound level meter mounted on a Tri-Pod^{TM} (Isolation position/ or decoupler) vibration insulating table stand with a half inch free field microphone (serial no: 02616511). The microphone of the SLM was placed at the position corresponding to the center of the head at the height of one meter. A total of nine loudspeakers were used (Genelec 8020B) covering 0^0 to 360^0 azimuth which were connected to Lynux Aurora sound signal router. The stimulus and intensity level assigned to each speaker were delivered through Cubase 6 software with Lynx aurora signal router. Five loudspeakers at specified azimuth from which the target stimuli 150 Hz and 350 Hz horn sounds were calibrated to deliver 110 dB SPL and 100 dB SPL respectively. However, four loudspeakers from which traffic noise were delivered were calibrated for the two levels of intensities 65 dB SPL and 75 dB SPL. It was made sure that intensity level read on the SLM was exactly mapped to the desired intensity by varying the volume control in Cubase 6 software.

3.5.2.2. Setup: Each participant was seated in a sound-treated room. It was made sure that center of the head of each participant was equidistant from each loudspeaker (2 meters away from the center). Stimulus presentation set up is depicted in Figure-3.3. The localization task was carried out using nine loudspeakers (Genelac 8020B) arranged in a circle located at different degree of azimuth, which covers stimuli presentation from 0^0 to 360^0. The target stimuli were presented through five loudspeakers at 90^0, 140^0, 180^0, 220^0 and 270^0 azimuth. A continuous traffic noise was presented through four loudspeakers kept at 40^0, 120^0, 240^0 and 320^0 azimuth.

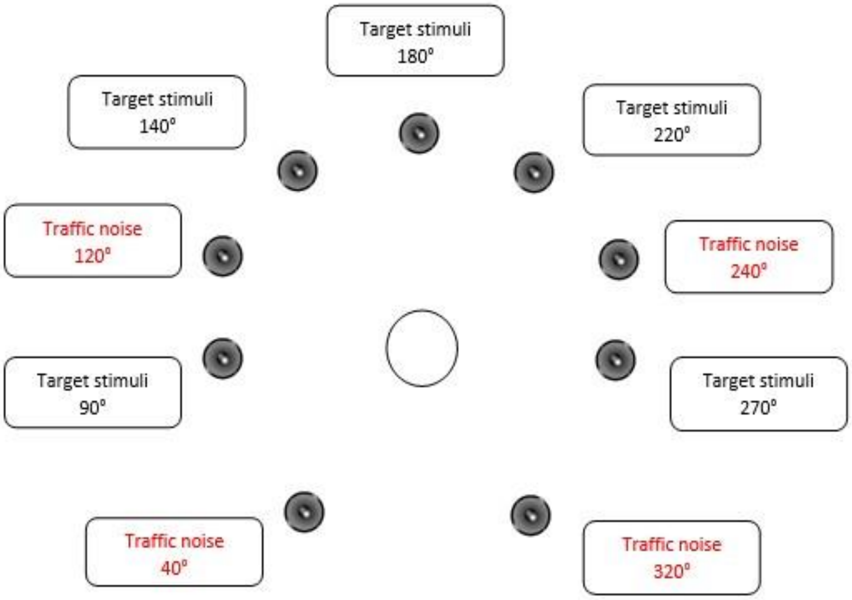


Figure 3.3. Arrangement of loudspeakers and stimuli assignment to determine localization ability from participants of the study.

3.5.2.3. Stimuli: The target stimuli having center frequency 150 Hz at 110 dB SPL and 350 Hz at 100 dB SPL horn sounds were delivered randomly to the assigned loudspeakers through Cubase 6 software loaded in a personal computer to which Lynx aurora signal router was connected. A continuous traffic noise was presented through four loudspeakers kept at 40^0, 120^0, 240^0 and 320^0 azimuth. Degree of error was computed for overall loudspeakers for two stimuli presented at two levels of noise i.e., 65 dB SPL and 75 dB SPL.

3.5.2.4. Testing phase: Prior to the testing, the each participant was given a trial to get acclimatized with the test condition. During the course of testing each participant was made to sit in the reference test position and instructed to play a ROAD RASH game in the presence of noise which simulates a traffic scenario. In a continuous noise condition, each of the two stimuli (150 Hz and 350 Hz horn sounds) was delivered five times from each loudspeaker in a random order. Each participant was instructed to locate target stimulus delivered from loudspeaker by pressing the key or indicated by hand. The next target stimulus was delivered only after the participants responded to the previous one.

From each participant of control and clinical groups at each noise level Degree of Error (DOE) for overall loudspeaker was obtained. DOE was computed by the adopted procedure of Ching, Incerti & Hill (2004). DOE was calculated separately for each loudspeaker. DOE corresponds to the difference in the degree of azimuth between the loudspeakers from which the target stimulus was presented and the loudspeaker to which the participant 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 calculated for five iterations in each speaker were summated and then divided by number of stimuli were 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 horn presented at two different noise levels.

Degree of error was calculated using the following formula.

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

DOE_1: Degree of error in the speaker no. 1

DEOn: Degree of error in the nth number of speaker

RMS: Root Mean Square

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

3.5.3. Phase 2: Qualitative measures to assess on the localization ability

The Localization Handicap Index (LHI) (Hemanth et al, ongoing) consisting of 16 questions were administered on each participant of both control and clinical groups. The questionnaire majorly focused on the localization ability of the person in indoor and outdoor conditions. The participants were instructed to rate each question on a 3 point rating scale where,

1- Almost never
2- Sometimes
3- Almost always

Each rating was given a weightage to calculate the Localization Handicap Index (LHI). The weightage given was 0 for the rating of 1, 3.125 for the rating of 2 and 6.25 for the rating of 3.

3.6. Statistical analyses

The following data were subjected to statistical analyses using the SPSS (Statistical package for social science) software version 20.

1. Descriptive statistics was carried out to account mean and standard deviation of localization errors obtained from horns (Track 150 Hz and Automobile 350 Hz) presented at two different noise levels (65 dB SPL and 75 dB SPL).
2. Two way repeated measures analyses of variance (ANOVA) with between subject factor as groups (based on hearing loss) was performed to see if there was a significant main effect and an interaction effect of horn and noise levels on degree of localization error.
3. One way ANOVA and post Hoc Duncan test were performed separately in each noise level to inspect in which group have caused significance difference on degree of localization error.
4. Independent sample t-test was performed to assess localization error difference between two noise level for each group.
5. One way ANOVA and post Hoc Duncan test were performed on LHI and SIS to investigate in which group have caused significance difference.
6. Pearson Correlation was carried out to find the relation between localization functional indexes, degree of localization error and audiological findings from participants of the study.
7. Regression model was drawn in which localization functional index and degree of localization error was predicted from audiological findings.

Chapter-4

Results

The aim of the present study was to examine degree of localization error in hearing impaired population using subjective and objective methods in the simulated road traffic environment. The localization errors were obtained from age matched control group and clinical groups in the aided condition. In addition, the localization functional index using the standard questionnaire was obtained from the participants of the study. Further, the data of audiological evaluation and percentage of hearing disability calculated from pure tone average were documented from the participants of the study. These data were subjected to statistical analyses using SPSS [Statistical Package for Social Sciences] software of version 17.

4.1. Localization ability: hearing loss and noise level

Descriptive statistical analyses were performed to document the mean and standard deviation of localization errors obtained from horns (Track 150 Hz and Automobile 350 Hz) presented at two different noise levels (65 dB SPL and 75 dB SPL) on control group and clinical groups. From Table 4.1 the degree of localization error obtained from different experimental conditions on study participants was tabulated. It is observed that degree of localization error increased with degree of hearing loss. In addition, irrespective of horns, the degree of localization error increased with increased noise level and it is true in each group.

Table 4.1. Mean and standard deviation of degree of localization error obtained from two horns presented at low and high noise levels on control group and clinical groups.

Groups		**Automobile horn**		**Truck horn**	
		65 dB SPL	75 dB SPL	65 dB SPL	75 dB SPL
Control group	Mean	2.98	8.27	4.42	4.19
	SD	2.84	5.39	3.52	3.54
Mod-Mod severe	Mean	31.395	36.63	25.62	33.36
	SD	16.82	11.77	9.14	8.80
Severe	Mean	30.83	44.25	31.61	39.21
	SD	7.94	9.015	9.762	10.17
Profound	Mean	47.37	59.10	50.55	62.94
	SD	11.65	7.79	7.906	4.93

Further a two way repeated measures (noise level (2)* Horns (2)) analyses of variance (ANOVA) with between subject factor as groups (Control group and Clinical groups (Moderate to Moderately Severe, Severe and Profound)) was performed to see if there is a significant main effect and an interaction effect on degree of localization error. The result of two way repeated measures is tabulated in Table 4.2. The results revealed that degree of error was significantly increased with increasing in noise level [F (1, 36) = 31.593, $p \leq 0.001$]. Further, a main effect of between subject factor as group was found significant [F (3, 36) = 155.312, $p \leq 0.001$] such that localization error was significantly increased with degree of hearing loss. In addition, a two way interaction noise level * group was found significant [F (3, 36) = 2.321, $p \leq 0.050$] on degree of localization error such that in each group degree of error increased with increased noise level. It is observed that main effect of horn; and interaction effects of horn* group; horn* noise level and horn* noise level * group have no significant effect on degree of localization error. Thus, the data of localization error obtained from two horns at each noise level were combined. This was done for each group.

Table 4.2. The results of main and interaction effects [df (1, 36)] of two way repeated measures ANOVA with within subject factors as groups.

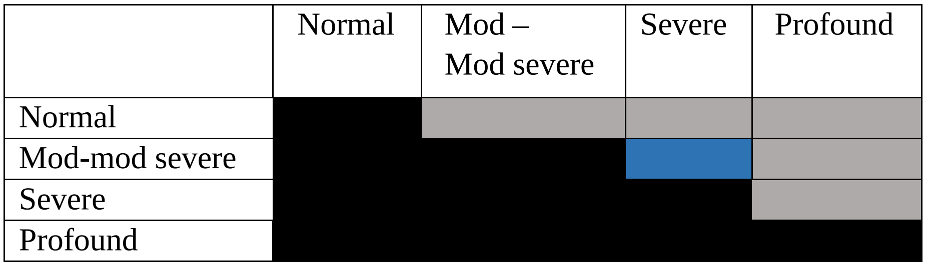
Conditions	***F value***	***P value***
Noise level	31.593	0.001***
*Noise level * group*	2.321	0.05*
Horns	0.643	0.428
Horn group*	1.471	0.239
*Noise level * Horns*	0.805	0.376
*Noise level * Horns* Group*	0.874	0.464

*Note- df: degree of freedom; p≤0.001***; p≤0.010 = **; p≤0.05=**

Further, a one way ANOVA was performed separately in each noise level to inspect group having caused significant differences on degree of localization error. This was done as there was a significant main effect of noise level and group on two way repeated measures. The result of one way ANOVA showed that with increase in degree of hearing loss a significant increase in localization error was found in both 65 dB SPL [F (3, 79) = 76.088, p ≤0.001] and 75 dB SPL [F (3, 79) = 154.007, p

≤0.001]. Further, a post Hoc Duncan test was performed separately for each noise level on the data of degree of localization obtained from four groups.

From Figure 4.1 the results of the Duncan post hoc test for 65 dB SPL showed a significant difference between control group and each clinical group (<0.05) on degree of localization error. There was also significant difference noted between moderate to moderately severe group and profound group indicating that degree of localization error increased with increase in hearing loss (<0.05). In addition, there was a significant difference noted between severe group and profound group on degree of localization error. Though the degree of localization error increased with degree of hearing loss, its mean difference did not reach significant between Moderate to Moderately severe and severe groups.



	Normal	Mod – Mod severe	Severe	Profound
Normal	■	▨	▨	▨
Mod-mod severe	■	■	🟦	▨
Severe	■	■	■	▨
Profound	■	■	■	■

Note: Grey area= significant difference; Blue area=no significant difference

Figure 4.1. Duncan test results showing significant difference between each group for 65 dB SPL

In addition, the Duncan test was performed for 75 dB SPL, the results revealed significant difference between each group (Figure 4.2.). It indicates that degree of localization error significantly increased with respect to degree of hearing loss.

	Normal	Mod – Mod severe	Severe	Profound
Normal	■	▒	▒	▒
Mod-mod severe	■	■	▒	▒
Severe	■	■	■	▒
Profound	■	■	■	■

Note: Grey area= significant difference

Figure 4.2. Duncan test results showing significant difference between each group for 75 dB SPL

In addition, a significant difference was observed in the interaction effect of noise level *group on localization error. Hence, an independent sample t-test was performed to assess localization error difference between noise levels for each group. The mean and standard deviation of degree of error for two different noise levels in each group is shown in the Figure 4.3.

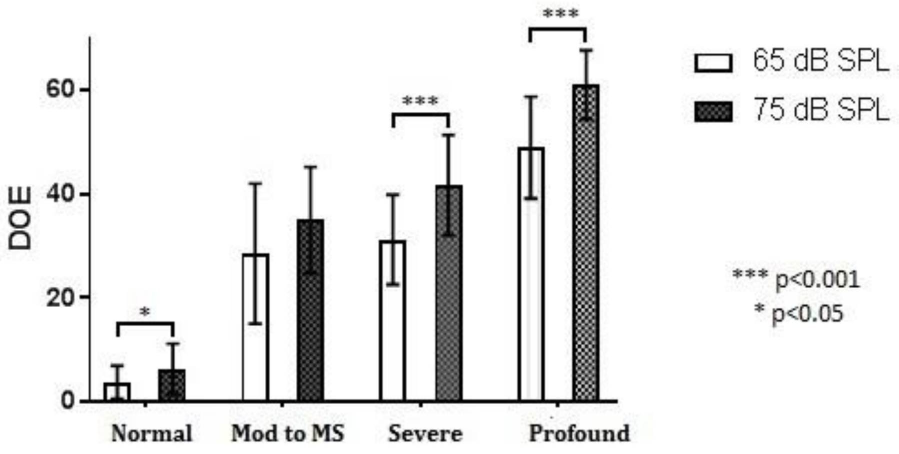


Figure 4.3. Mean and standard deviation of degree of error in different noise levels obtained from clinical and control group.

The results showed that degree of error increased with increased noise level and this difference reached significance in control group (t (19) = -2.142, p= 0.045), severe (t (19) = -4.360, p=0.000) and profound (t (19) = -6.585, p=0.000). Although, degree of localization error increased with increase noise levels, the mean difference did not reach significance in moderate to moderately severe group (t (19) = -1.667, p = 0.112).

4.2. Localization functional index and aided speech identification score.

Descriptive statistical analyses were performed to document the mean and standard deviation of localization functional index scores (LFI) and aided speech identification scores (SIS) from control group and clinical groups. One way ANOVA was carried out separately for the data of LFI and SIS obtained from control group and clinical groups. It was found that localization function index reduced with degree of hearing loss and its mean difference reached statistical significance between groups [F (3, 39) = 25.318, p ≤0.001]. In addition, as expected the SIS scores reduced with degree of hearing loss and its mean difference reached significance between groups [F (3, 39) = 69.937, p ≤0.001]. Since there was a significant difference observed between groups on LFI and SIS, a post Hoc Duncan test was carried out. This was done to check in which groups have caused significant difference on LFI and SIS.

From Figure 4.4., a Duncan test results for LFI revealed that except moderate to moderately severe group, there was a significant difference in LFI score between control group and severe and profound groups, such that localization functional index decreased with increase in degree of hearing loss. The data of LFI obtained for moderate to moderately severe showed a significant difference with severe group and profound group. In addition, a significant difference was noted between severe group and profound group on LFI. The results obtained indicated that there is decrease in LFI scores with increase in degree of hearing loss.

	Normal	Mod – Mod severe	Severe	Profound
Normal	■	🟦	▨	▨
Mod-mod severe	■	■	▨	▨
Severe	■	■	■	▨
Profound	■	■	■	■

Note: Grey = significant difference; Blue=no significant difference

Figure 4.4. Duncan test results showing significant difference between each group on LFI in (%) as a function of hearing loss

The SIS score was compared between seven pairs of groups using Duncan test. The results revealed a significant difference between each pair such that SIS score significantly reduced with increased degree of hearing loss based on which groups were made (Figure 4.5.).

	Normal	Mod – Mod severe	Severe	Profound
Normal	■	▨	▨	▨
Mod-mod severe	■	■	▨	▨
Severe	■	■	■	▨
Profound	■	■	■	■

Note: Grey = significant difference; Blue=no significant difference

Figure 4.5. Duncan test results showing significant difference between each group on SIS in (%) as a function of hearing loss.

4.3. Relation between localization functional index, degree of localization error and audiological findings from participants of the study

4.3.1. Relation between LFI and Audiological findings. The pure tone average, speech identification score and computed hearing disability from participants' hearing loss obtained from four groups (n=40) were correlated with the localization function index using Pearson correlation. Further, LFI was predicted from the each audiological finding using linear regression.

4.3.1.1. Relation between localization functional index and pure tone average. The results of Pearson correlation showed there was a significant negative correlation between LFI and PTA. It indicates that localization functional index reduced as the hearing loss increased (N=40, r = -0.710, p =0.000). Further, a linear regression was drawn to predict the LFI from PTA as shown in Figure 4.6. Equation y = a (x) +b (r^2 =0.504; a = -0.417; b = 87.31) was obtained to predict LFI from PTA. It indicates that with a 0 dB HL the localization functional index predicted to be 87. 31 %. Further, a 1 dB increase in threshold leads to reduction in localization function index by 0.41 (in %).

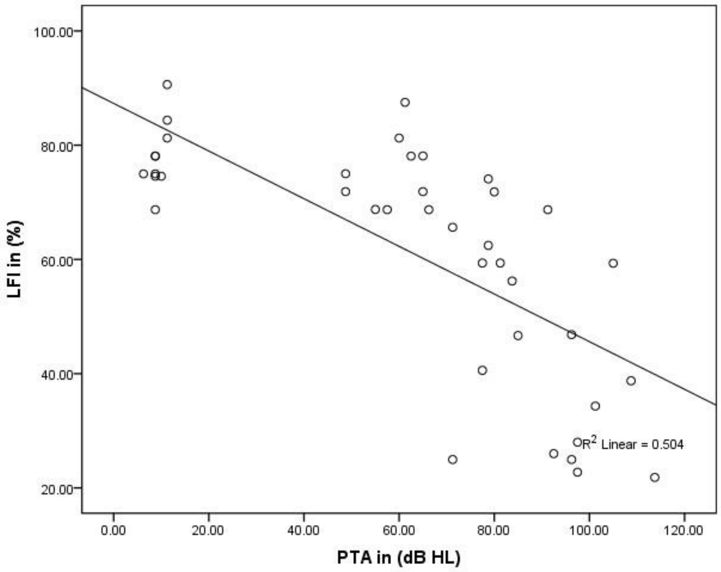


Figure 4.6. Linear regression drawn with measured data and mean of the predicted data for LFI and PTA on a scatter plot. The predicted data shows that with increase in pure tone average (dB) there is a decrease in localization functional index linearly.

4.3.1.2. Localization functional index and aided speech identification scores The results of Pearson correlation showed there was a significant positive correlation between LFI and SIS, indicating that LFI scores are better with increase in the SIS scores (N= 40, r= 0.842, p=0.000). A linear regression was drawn to predict the LFI from SIS as shown in Figure 4.7. Equation y = a (x) +b (r^2 =0.710; a = 1.006; b = -17.54) was obtained to predict LFI from SIS scores. It indicates localization function index increased by 1% with a 1 % increase in SIS score.

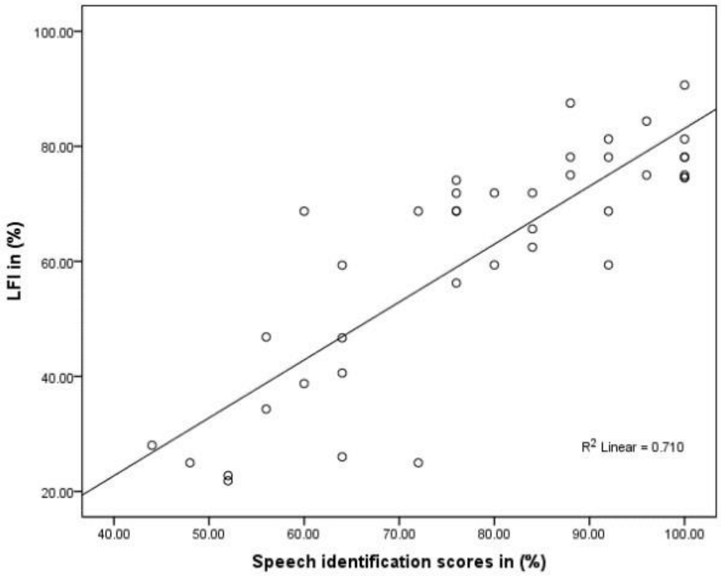


Figure 4.7. Linear regression drawn with measured data and mean of the predicted data for LFI and SIS on a scatter plot. The predicted data shows that with increase in SIS there is a increase in localization functional index linearly.

4.3.1.3. Localization functional index and hearing disability. The results of Pearson correlation showed there was a significant negative correlation between LFI and hearing disability (N=30, r= -0.731, p≤0.001). It indicates, LFI reduces with increase in hearing disability. Further a linear regression was drawn to predict the LFI from hearing disability as shown in Figure 4.8. Equation y=a (x) +b (r^2 =0.535; a = -0.514; b = 100.618) was obtained to predict LFI from hearing disability. It indicates that with a 0 dB disability the localization functional index predicted to be 100 %. Further, a 1 % increase in hearing disability leads to reduction in localization function index by 0.51 %.

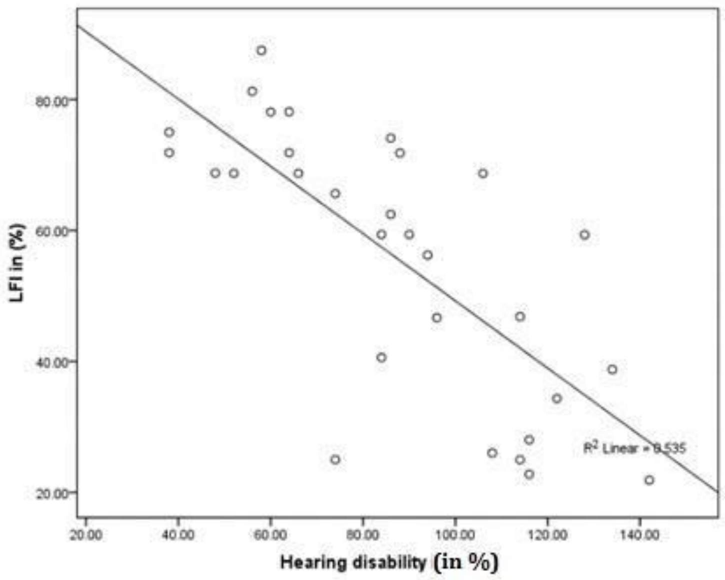


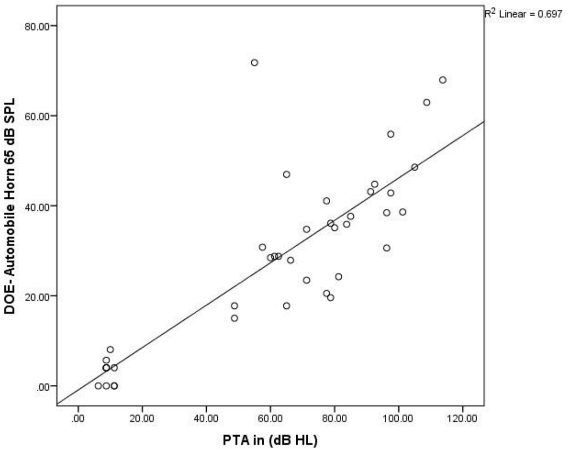
Figure 4.8. Linear regression drawn with measured data and mean of the predicted data for LFI and hearing disability on a scatter plot. The predicted data shows that with increase in hearing disability there is decrease in localization functional index linearly.

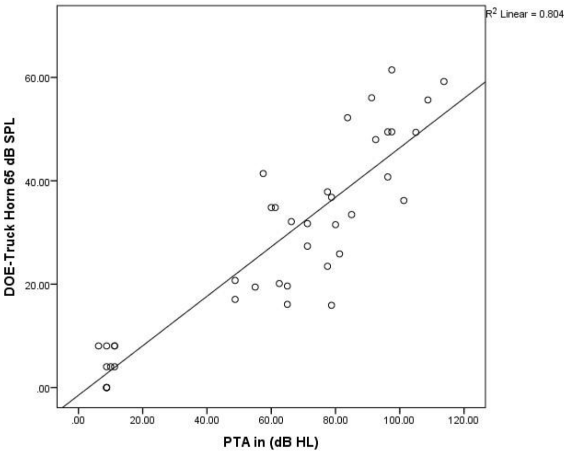
4.3.2. Relation between pure tone average and degree of error. The results of Pearson correlation showed there was a significant positive correlation between PTA and DOE for each type of horn and noise level (Table4.5.). The results show that with increase hearing loss the DOE in the localization task also increases. Further a linear regression was drawn to predict the DOE from pure tone average as shown in Figure 4.10. A linear equation y=a (x) +b was obtained to predict the DOE from pure tone average. Where y is the degree of error, x is the pure tone average, ‘a’ is the intersection and ‘b’ is the slope of regression line. The best regression line was fitted in scatter plot for each condition as shown in Figure 4.9. The correlation values between PTA and DOE and its regression values in predicting the DOE from PTA for each condition is shown in Table 4.3.

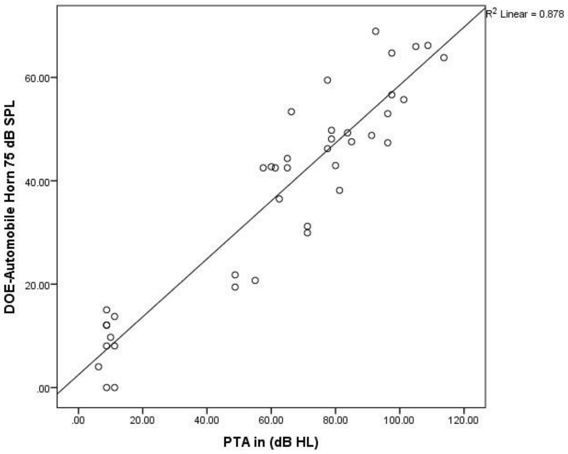
Table 4.3. Regression values in predicting the DOE in PTA in each condition

Horn	r	p	R_2	a	b
Automobile 65 dB SPL	0.835	0.000	0.697	0.471	-0.907
Truck 65 dB SPL	0.896	0.000	0.804	0.479	-1.491
Automobile 75 dB SPL	0.937	0.000	0.878	0.561	-2.470
Truck 75 dB SPL	0.937	0.000	0.878	0.618	-2.693

Note; a= Intersection; b = slope







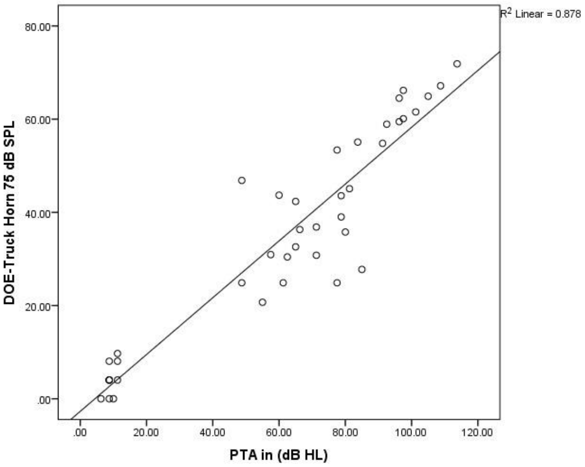


Figure 4.9. Linear regression drawn with measured data and mean of the predicted data for PTA and DOE on a scatter plot for each condition. The predicted data shows that with increase in pure tone average there is increase in degree of error linearly.

4.3.3. Relation between LFI and DOE. The results of Pearson correlation showed there was a significant negative correlation between LFI and DOE for each noise level and type of horn. It indicates that, in each condition, as the degree of error increased there was a significant decrease in localization functional index. Further, a linear regression was drawn to predict the LFI from degree of error for each noise level and type of horn. The best regression line was fitted in scatter plot for each condition as shown in Figure 4.10. The correlation values between LFI and DOE and regression values in predicting the LFI from DOE for each condition is shown in Table 4.4. and Table 4.5.

Table 4.4. The correlation values between LFI and DOE

DOE in each condition (N=40)	**r**	**p**
Automobile 65 dB SPL	-0.577	0.000***
Truck 65 dB SPL	-0.674	0.000***
Automobile 75 dB SPL	-0.658	0.000***
Truck 75 dB SPL	-0.707	0.000***

*Note: - r= regression coefficient; p≤0.001 ***; p≤0.010 **; p≤0.05 *;*

Table 4.5. Regression values in predicting the LFI from DOE in each condition

DOE in each condition (N=40)	R_2	a	b
Automobile 65 dB SPL	0.333	-0.601	78.48
Truck 65 dB SPL	0.454	-0.741	82.356
Automobile 75 dB SPL	0.434	-0.647	85.542
Truck 75 dB SPL	0.500	-0.639	83.876

Note; a= Intersection; b = slope

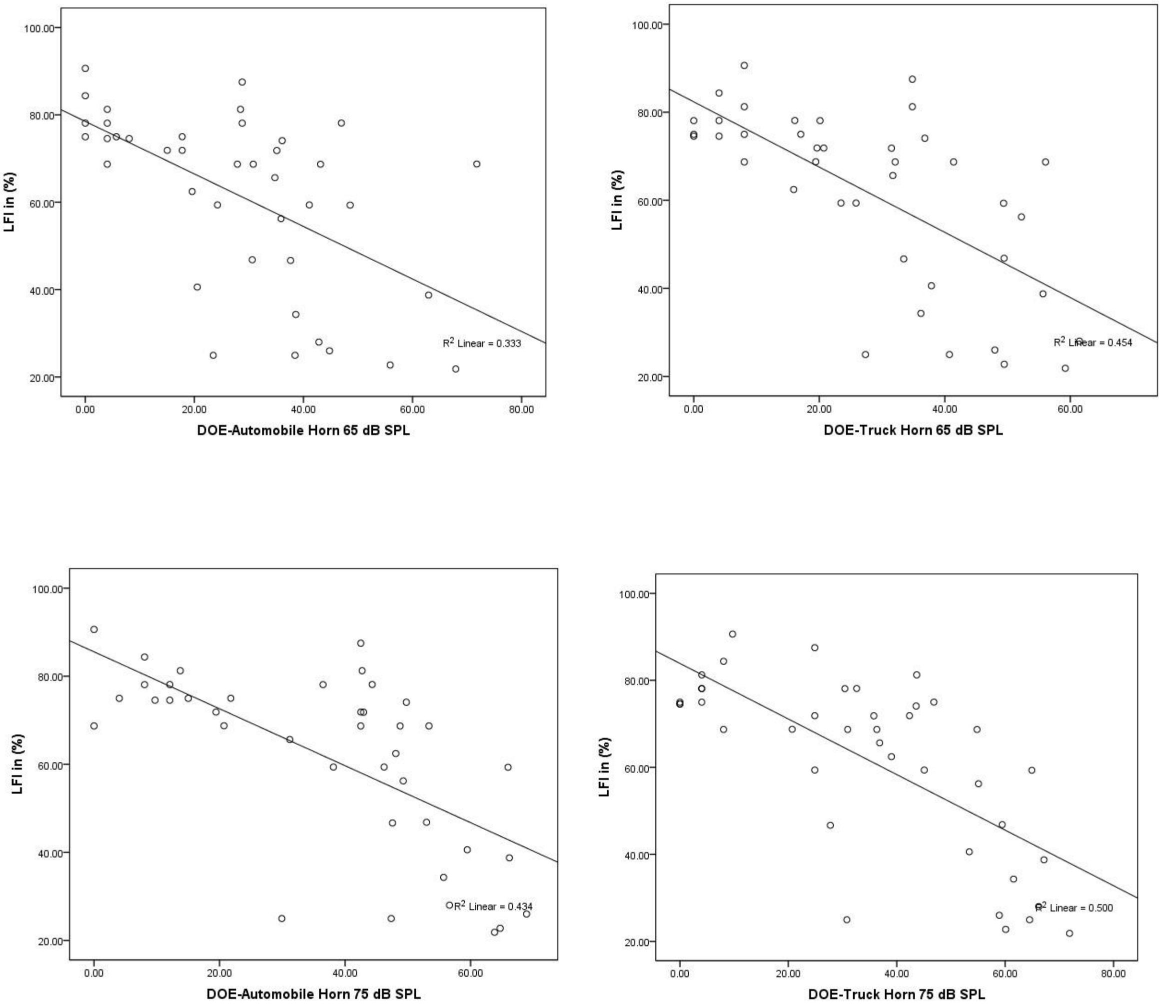


Figure 4.10. A linear regression drawn with measured data and mean of the predicted data for LFI and DOE on a scatter plot for each condition. The predicted data shows that with increase in degree of error there is decrease in localization functional index linearly.

To summarize, a significant increase in degree of error was observed with the degree of hearing loss. In addition, the degree of error increased with increased noise level. The localization functional index and SIS were decreased with increased in degree of hearing loss. Further, there was a significant correlation between localization functional index, degree of localization error and audiological findings**.** Regression model was drawn through which LFI; and degree of error was predicted from each audiological finding.

Chapter 5

Discussion

The study aimed to investigate localization ability in hearing impaired individuals from subjective and objective methods in a simulated road traffic environment. The localization errors and localization functional index using the standard questionnaire were obtained from the age matched control group and clinical groups. Though the audibility was corrected by providing appropriate gain from hearing aid the findings of DOE, LFI and SIS from each of the clinical group was significantly reduced than control group. The reason could be that output from hearing aids delivered to both ears were almost same, there by reduced a level difference between ears. Moreover, ITD is a cue for localizing a low frequency sound which gets annulled when presented at 40 dB SL (David and Stephens, 1974), as in the present study low frequency horn sounds were presented at the 110 and 110 dB SPL. In addition, there could be a mixture of unamplified sound and amplified sound leading to confusion in localization as the study participants had a good reasonable low frequency hearing(except profound group). This confusion results in distortion of interaural time difference as the small delay induced, when the sound is processed through the hearing aid may have resulted in different phase between unaided and aided sounds.Thus, neurons at auditory brainstem would have failed to effectively interact an aided signal leading to suboptimal representation of available cues. Further, it was noted that DOE and LFI were significantly reduced with increase in degree of hearing loss based on which clinical groups were made. This is because hearing loss produces a neural distortion in interaction of two sounds between ears, which is directly proportional to the increased degree of hearing loss. This infers that amplification may not restore localization to the normal level. Further, as expected the DOE found to be significantly reduced in low level of noise than high level of noise and this was true in each control and clinical groups. This could be because binaurally making noise might have released from short burst of signal presented at different azimuth. This phenomenon is relatively less with increased noise level.

It was found that in United States, passing in the standardized whisper test administered at 5 feet or average hearing loss in the better ear greater than 40 decibels (500 Hz, 1,000 Hz, and 2,000 Hz) with or without a hearing aid are the criteria to receive certificate of hearing status for those applicants who seek to apply for driving license. However, in India, aided thresholds within speech audiogram are found to be a pass criterion to certify hearing status for driving license. It is known fact that hearing is of utmost importance for driving other than visual information. Moreover rather than hearing a sound merely does not result in sound localization which is most important for safe driving. The test administered and the criteria utilized in the current scenario are in contrast to the subjective and objective findings of the present study. It was found that localization functional index was reduced with increased degree of hearing loss; reduced speech identification score; and increased hearing disability respectively. This indicates that the hearing loss is specifically linked to localization disability. However, there is a high chance that individuals with hearing impairment might deny to have localization disability when questionnaire is administered. Thus, a regression model was established, wherein localization functional index can be predicted from any audiological findings by a linear formula $y = ax + b$ ($r^2 = 0.504$; $a = -0.417$; $b = 87.31$). To illustrate, if the hearing loss is 60 dB then localization function index predicted to be 62.29 %. Likewise, we can predict the LFI from hearing disability and speech identification scores. Further, to substantiate the above finings an objective degree of localization error test was administered and correlated with pure tone average. It was found that degree of error was significantly increased with increased degree of hearing loss and this finding was true in each horn presented at 65 dB SPL and 75 dB SPL. In addition, degree of error was successfully predicted from pure tone average (Table 4.5.). Further, it was observed that a strong negative correlation between DOE and LFI. Localization function index reduced with increase in degree of hearing loss and it is successfully predicted using linear regression model. It suggests that both subjective and objective tests used in the present study compliments to each other to identify localization difficulty. Interesting part is irrespective of degree of hearing loss the aided thresholds were within speech spectrum (Figure 3.2). Thus, this study recommends localization test to be included rather than aided audiogram to issue the certificate of hearing status.

Chapter 6

Summary and conclusion

Aided audiogram was used in the present day test protocol to certify hearing status required for driving license. Hearing a sound with amplification does not merely help in localization. Locating a sound source is found to be important skill while driving. Considering the safety regards of hearing impaired individuals the present study was undertaken with the aim of investigating localization ability in hearing impaired individuals from subjective and objective methods in a simulated road traffic environment.

Forty participants within age range from 40 to 60 years were recruited in the study. The participants were grouped into two groups namely control group and clinical group. Control group comprised of ten participants and clinical group comprised of thirty participants. Further the participants in the clinical group were sub grouped into three based on severity of hearing loss i.e. moderate to moderately severe hearing loss 40 to 70 dB HL (subgroup-1); severe hearing loss 70 to 90 dB HL (subgroup-2) and profound hearing loss > 90 dB HL (subgroup-3). Each subgroup comprised of ten participants. The participants were fitted with the digital BTE hearing aid. The target stimuli (Truck horn and automobile horn) were presented from five speakers and the recorded traffic noise (65 dB SPL and 75 dB SPL) were presented at four speakers as background noise to simulate traffic situation. The degree of localization error was assessed from two horns presented at 65 dB SPL and 75 dB SPL. In addition, localization functional index was obtained the study participants. Further, aided pure tone thresholds and aided speech identification scores were obtained apart from audiological evaluation.

The findings of the present study revealed that degree of error and SIS were significantly increased with degree of hearing loss. In addition LFI reduced with degree of hearing loss. The reason could be neural distortion at the lower auditory brainstem has failed to integrate the inputs from two ears. At high input intensity the ITD cues gets nullified. Further, mixture of unaided and aided sounds led to distortion of the interaural time difference as the study participants had a good low frequency hearing. In addition, degree of error dramatically reduced with increase in noise level. In correlation and regression analyses it was found that LFI was strong negatively correlated and predicted with the pure tone thresholds; speech identification; and hearing disability. Further, DOE was positively correlated and predicted with degree of hearing loss and it was true in each horn presented at 65 dB SPL and 75 dB SPL. Interestingly, irrespective of degree of hearing loss the aided threshold was within speech spectrum.

To summarize, localization error increased with increase in degree of hearing loss; reduced localization function index. Unfortunately, irrespective of hearing loss, the aided thresholds were within speech spectrum. The findings suggest audiologists to assess degree of localization error rather than aided audiogram to certify the hearing status for the purpose of obtaining driving license.

Implication of the study

The findings of the study suggest investigating degree of localization error rather than aided audiogram in the test protocol when applicant seeks the certificate of hearing status for the purpose of obtaining driving license.

Limitations

Wearing helmet has been a mandatory rule to drive two wheelers in metropolitan cities. Feedback is the most common issue when a hearing aid user wears a helmet. In addition, localization difficulty will be more as it attenuates the sounds coming different direction. Thus, these variables pose a challenge for health profession to consider it in research design to assess localization ability. In addition, rear mirrors are maximally utilized when driving. Further, driving requires cognitive skills for safety. However, in the present study these variables are not considered to investigate the localization error in the simulated traffic environment. Incorporating these variables in the upcoming study design ensures to have realistic approach to assess localization ability which is utmost important skill for driving.

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