ASSESSMENT OF LOCALIZATION AND TRAFFIC SIGN COGNITIVE ABILITIES IN INDIVIDUALS WITH HEARING IMPAIRMENT

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CERTIFICATE

This is to certify that this dissertation entitled **'Assessment of Localization and Traffic Sign Cognitive Abilities in Individuals with Hearing Impairment'** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 16AUD023. 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 **'Assessment of Localization and Traffic Sign Cognitive Abilities in Individuals with Hearing Impairment'** is the result of my own study under the guidance of Dr. Hemanth N, Reader 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

The present study was taken up to evaluate the localization ability and traffic sign cognitive ability in a simulated traffic environment. A total of 40 participants were recruited in the study, they were divided into control group and clinical group. Clinical group was further divided into subgroups based on degree of hearing loss (Mild, Moderate to Moderately severe and Severe hearing loss). To determine the localization ability, degree of error was computed. In traffic sign cognitive ability correct scores and its average reaction time were obtained. The assessment of localization and traffic sign cognitive abilities were carried out both in unaided and aided conditions. Results revealed that clinical group committed significantly more error on localization task, a decrease in correct scores and increases in average reaction time to perform the traffic sign cognitive task when compared with control group. In addition amplification did not benefit individuals with hearing impairment as there was no significant improvement in localization ability between unaided and aided conditions. But there was a significant improvement in traffic sign cognitive abilities in aided condition. Further, there exists correlation between pure tone average and localization ability, traffic sign cognitive ability. Regression analyses predicts degree of error, traffic sign cognitive correct scores and its average reaction time from pure tone average. To conclude, localization abilities and traffic sign cognitive abilities should be included in the test protocol rather than aided audiogram to issue hearing fitness certificate to individuals with hearing impairment.

Key words: Hearing loss, Localization ability, Traffic sign cognition

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Chapter 1

INTRODUCTION

Road traffic safety is highly affected in individuals with hearing impairment. While driving, they rely more on visual modality than hearing modality (Henderson & Burg, 1973). Despite of it, there is a high chance of accidents by individuals with hearing impaired. It is inconsonance with the research study of Lundälv (2004), who reported hearing impaired is prone to get road traffic injuries. This is because of impaired function of hearing leads to lack of identification of potential hazards. In support of above statement, a study done by Ivers, Mitchell & Cumming (1999) found significant association between hearing loss and road traffic accidents. However, there are contradictory studies which conclude that individuals with hearing impairment are safe drivers (Finesilver, 1962; Norman, 1962; Grattan & Jeffcoate, 1968). Sackey (2015) reports that deaf drivers drove better than normal hearing counterparts' due to effective use of rear mirrors and their other senses well to compensate the hearing loss. Thus, providing driving license to individuals with hearing impairment holds equivocal results in literatures. In United States of America, individuals with hearing impaired are not provided with driving license, if their hearing loss is worse than 40 dB or if they unable to hear speech whisper from five feet away. Moreover, there is no appropriate test to assess hearing ability in road traffic condition. In India, there is a dearth of literature on assessing hearing status in hearing impairment especially who seeks hearing fitness certificate to apply for driving license. Till date, there is no standard protocol to assess the hearing ability in road traffic condition. In present scenario, aided audiogram obtained for warble tones (250 Hz to 4 kHz in octaves) at 0^0 azimuth in sound field condition stands as the test protocol to quantify hearing abilities in beneficiaries who seek to get the hearing status for the purpose to receive the driving license from RTO. If aided thresholds are within speech spectrum then individuals are issued the hearing fitness certificate. Unfortunately, this test protocol is not sufficient to assess the hearing ability in road traffic condition as it is far from realistic situation. Localization of sounds coming from rear side is of utmost important especially, in a road traffic noise conditions rather detection of tones in aided threshold in quite condition. Thejeswini and Hemanth (2017) developed the test protocol to assess hearing status of hearing impaired in simulated road traffic condition by incorporating localization tasks. Unfortunately, traffic sign cognitive task is not included in their protocol, which is found to be influential for safe driving. It is a well-established fact that hearing loss is strongly associated with cognition, where hearing loss might induce a cognitive decline (Lin, 2011; Lin et al., 2004; Lindenberger & Baltes, 1994; Uhlmann, Larson, Rees, Koepsell, & Duckert, 1989; Tay, Wang, & Lindley, 2006; Baltes & Lindenberger, 1997). In addition, there is a lot of listening effort exerted by individuals with hearing impaired while driving. The limited sensory acuity consumes a lot of cognitive skills leaving only small amount of cognitive workspace to process traffic signs. Thus, hearing status and cognitive abilities should be assessed before to issue the hearing fitness certificate from a qualified audiologist.

1.1. Need for the study

Delhi high court made the law to give driving license to the hearing impaired individuals, if they pass on hearing test certified by the qualified professional. In the current scenario, certificate on hearing status is provided based on aided audiogram obtained from quiet condition in which tones of different frequencies were delivered from loudspeaker located at 0^0 Azimuth. Unfortunately, the test protocol fails to quantify their hearing ability especially in the traffic environment. Localization of sound source especially from rare side in noise is the paramount factor (Thejaswini & Hemanth, 2017) needs to be considered for hearing fitness certificate. A well-known fact is that driving task involves cognition (Lyu, Xie, Wu, Fu, & Deng, 2017). Judgment based on looking into sign boards consequently taking accurate decision in handling their motor vehicle in traffic requires cognition. However, cognition is impaired in individuals with hearing impaired (Lin, 2011). Thus, there a need to include a factor of cognitive skill in the developing protocol for addressing hearing status in traffic condition.

1.2. Aim of the study

The aim of present study is to evaluate the localization and traffic sign cognitive abilities in individuals with hearing impairment in a simulated road traffic condition.

1.3. Objectives of the study

1) To determine the localization errors, traffic sign cognitive correct scores and its average reaction time between the groups in unaided and aided conditions.
2) To compare between aided and unaided condition for degree of error in localization task, traffic sign cognitive correct score and its average reaction time in each clinical group.
3) To find the relation between pure tone average and each task (localization ability and traffic sign cognitive ability) administered in unaided and aided conditions.

4) To predict degree of error in localization task; traffic sign cognitive correct score; cognitive average reaction from pure tone average in both unaided and aided condition.
5) To find the relation between existing protocol in clinic to assess hearing fitness for driving license and the adopted test utilized in the current study.

Chapter 2

REVIEW OF LITERATURE

Primary mode of travel in many countries is constituted by driving. Driving involves very complex process such as cognition, vision and auditory senses (Groeger, 2000). Individuals with normal cognition, motor control and sensory acuity (vision & audition) can perform driving task without any much difficulties. However, Individuals with hearing impairment find it difficult while driving since they have problems in hearing horns and localizing horns (Lundälv, 2004). In addition, there is an important role of cognition in processing the information about traffic signs for safe driving (Lyu, Xie, Wu, Fu, & Deng, 2017). Further, there is no globally acceptable acts concerning road safety on individuals with hearing impairment. There is no clear consensus in laws and protocols across the globe to consider hearing impaired individuals to procure driving license. A few countries act permits individuals with hearing impairment to drive and a few other countries consider them as defaulters. Further, there is no battery of test till now available to assess the hearing ability in traffic environment to localize the sound source and testing their traffic sign cognitive abilities. Thus, research conducted in these areas was thoroughly reviewed to investigate the hearing ability and cognitive abilities in traffic environment. Research regarding this topic aims in identifying the best measure to assess the hearing ability and traffic sign cognitive ability for receiving driving license.

2.1. Effect of hearing loss on traffic safety

Individual with hearing impairment were safe drivers since they are presumably cautious about road traffic accidents (MacFarland, R., Moore, R. C., & Warren, A. B. (1955). Statistics on road traffic accidents in United States reported that out of 3.9% of road traffic accidents, only 0.14% was committed by deaf drivers, which reflects that deaf individuals are not much prone to accidents (Elbel, 1960). Also the researches which were conducted in 1960's reported that there was no significant effect of hearing loss on driving (Finesilver, 1962; Norman, 1962; Grattan & Jeffcoate, 1968). However, there are studies which contradicts the above findings, one such study was by Coppin and Peck (1963) which reported that individuals with hearing impairment would be more prone to road traffic accidents. They found that individuals with hearing impairment met with road traffic accidents and found to be violating traffic rules most of the time. But one of the drawback of the study was that they did not consider the age matched control and experimental group. Henderson and Burg (1973) provided more sophisticated information about the relation between hearing ability 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 four categories of auditory stimuli which were 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 presented across three driving environments (high-noise, low-noise, and quiet), and driving behaviors that might occur in each of the scenarios. 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 less extent to guide the use of the vehicle. In a similar study by Ivers, Mitchell & Cumming (1999) investigated the relationship between hearing loss and road traffic accidents using subjective method. They used the questionnaire to document the relationship hearing loss and road traffic accidents. The results of the study revealed that individuals with moderate hearing loss had a significant association with an increased risk on road accident. Individuals with 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, Peters, Lyxell and Lidestam (2013) conducted a study to investigate driving license defaulters and no defaulters in a group of individuals with hearing impairment. 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 to three groups made based on degree of hearing loss. In their survey, they included information regarding driving license and avoidance of driving under certain conditions. In addition, audiometric data for each respondent as a measure for hearing loss was documented. 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 license when compared mild to moderate loss and severe hearing loss. Edwards et al. (2016) studied association between hearing impairment (HI) and driving safety in a longitudinal study which was 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 road traffic accidents.

Also older adults with hearing loss are at increased risk to accidents and may be more likely to have difficultly driving in challenging situations.

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) 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, interpreting 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, equivocal results were reported on hearing loss and road safety on driving. Driving defaulters are more likely in hearing impairment and its percentage increase with degree of hearing loss.

2.2. Issue of driving licenses to hearing impaired individuals

2.2.1. In abroad countries. During 1920's individuals with hearing impairment were not allowed to drive a vehicle in United States of America. However, with lot of statistical support from National Association of Deaf who protested against the rule and ban from the driving was successfully released. The procedure for licensing regulation for hearing impaired individual to drive worldwide appears to be somewhat different. After many years of prohibition, Department of Transport U.S. has agreed to 40 application filed by National association of deaf, allowing the deaf drivers to obtain commercial driving license and also reported evidence that deaf drivers are safe. According to the Department of Transport, commercial driving license applicant should pass either the whisper test or an audiological test. Hearing impaired individuals can also obtain intrastate commercial driving license from their state. However, 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's regulations and require a hearing test based on the federal requirements. 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 for procuring the driving license. 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. Also they may be required to pass a road test and 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 dB HL at 500 Hz, 1000 Hz, and 2000 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 of 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 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. Haualand and Colin (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. As stated by motor vehicle act (1989) individuals with hearing impairment are not eligible to procure driving license as they are dangerous 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, they provided the supporting documents saying that individuals with hearing impairment are a safe driver. 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 (e.g., 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 40dB in the better ear in the aided condition, measured across the frequencies of 500 Hz, 1000 Hz, 200 0Hz and 3000 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 or medicines, blood disorders and diseases of the genitourinary system and also hearing ability measured by audiological test performed by certified personnel. If the hearing impaired person has an unaided average (500 Hz, 1000 Hz, 2000 Hz and 3000 Hz) 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 eligible to take driving license test from regional transport office.

The above mentioned test assesses the audibility test in quiet condition from laboratory environment. In such condition, a stimuli were presented from 0^0 azimuth. However, in a realistic scenario, utmost important signal for road safety comes from any direction. In addition, these stimuli are certainly seldom in quiet condition. As it was mentioned earlier that driving also influenced by cognition. Thus, it is necessary to develop measure to assess hearing ability in traffic environment.

2.4. Hearing Loss and Localization Abilities

Human sound localization is mediated by a wide variety of cues. The primary acoustical cues are the frequency-dependent patterns of inter-aural time (ITD) and intensity differences (ILD) that result from diffraction of incoming sound waves around the head and pinna (Middle-brooks and Green, 1990; Middlebrooks, Makous, & Green, 1989). "Duplex" theory also states that low frequencies are localized on the basis of ITDs and high frequencies on the basis of ILDs. In addition, spectral notches due to the filter action of pinna provides the additional cues for localization (Butler et.al. 1990; Musicant & Butler, 1985) According to Wightman (1992) listeners use ITD cues for frequencies up to 1000 Hz –1500 Hz, and ILD cues for frequencies above 4000 Hz (Bernstein, 1982). 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 cues 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. To be specific, the distance travelled by the low frequency sound in reaching near side takes less time than the farer ear. This timing difference in reaching two ears provides cue for locating low frequency stimulus. Thus, ITDs are directly proportional to the size of the head and it depends on frequency and intensity of the stimuli.

Obviously ITD cues are available at the ear level in individuals with hearing loss but due to attenuation and distortion induced by hearing loss makes it unable to process the information at central auditory level. Hearing loss due to sensorineural pathology is not just the attenuation of the sound but it also leads to the distortion of the signal. This distortion affects the interaction of the signal at the neural level coming from the both ears, which further affects the ability of localization. Jonkees and Veer (1957) reported hearing loss affects the localization abilities. They studied the localization abilities in individuals with conductive hearing loss and unilateral hearing loss. Results revealed that individuals with conductive pathologies had highly variable directional hearing which was not dependent degree and configuration of the hearing loss. Individuals with otosclerosis had very poor directional hearing. Surprisingly few individuals with unilateral hearing loss performed similar to normal hearing individuals. Thus, the authors concluded that directional hearing is not dependent on air conduction, bone conduction thresholds and degree of hearing loss. Similar result was found in bilateral symmetrical sensorineural hearing loss who performed poorer on localization tasks on both 500 Hz and 4000 Hz narrow band noises than normal hearing individuals (Hawkins & Wightman, 1980). To quantify the localization error in different degree of hearing loss, Häusler, Colburn, & Marr, (1983) compared the minimum audible angle (MAA) to account for vertical plane localization and just noticeable difference to account for horizontal plane in individuals with hearing impairment including conductive and sensorineural hearing loss (unilateral & bilateral) with normal hearing individuals. Stimuli used were noise bursts of flat spectrum between 250 Hz – 10000 Hz. A stimulus was presented through free field to document MAA, where the single speaker was used which was displaced angularly towards the right or left where subject has to identify location from which sound was delivered. In addition, to investigate inter-aural JND's for time and intensity, stimuli were presented through the headphones where two stimuli which were presented along with inter-aural time and intensity difference, and subject task was to identify in which ear the stimulus arrived. Individuals with conductive hearing loss performed poorer than other groups, especially individuals with unilateral conductive hearing loss performed very poor in both the task that is test of minimum audible angle and just noticeable difference (except interaural intensity difference). Individuals with sensorineural hearing loss had a better performance than individuals with conductive hearing loss. The poor performance in localization observed in conductive hearing loss is due to simultaneous stimulation of both cochlear through BC mode and delayed stimulation of cochlea through air conduction mode. This difference in mode of stimulation has lead localization error in conductive hearing loss. Whereas, in SNHL, stimulus arrive at the cochlea similar to normal hearing individuals but due to the diffuse damage in the auditory neurons lead to impaired processing of interaural cues of localization. Authors have concluded that there was no relation between degree of hearing loss and errors on MAA and JND.

2.4.1. Laterality of Hearing loss on localization. Rosenhall (1995) studied the influence the laterality of hearing loss on localization through phase audiometry.

They recruited individuals with unilateral as well as bilateral symmetrical hearing loss to assess localization ability. They used 500Hz tone which was presented at a comfortable level with the inter-aural phase differences through the head phones. Results indicated the individuals who had hearing loss < 40 dB HL at low frequencies performed similar to that of normal. Whereas, individuals whose hearing loss > 40 dB HL performed significantly poorer than normal. In addition, there was no significant difference between the performance of unilateral and bilateral hearing loss on localization abilities in vertical plane of localization. This might be due to spectral cues at the intact ear helped individuals to localize the sound source.

2.4.2. Type and Configuration of hearing loss and Localization. Noble, Byrne, Lepage and Byrne (1992) investigated the localization abilities in individuals who had different type and configuration of hearing loss. Study was done by recruiting six normal hearing individuals and 87 individuals with hearing impairment. Clinical group had wide spectrum of hearing ability with different types of hearing loss (conductive, sensorineural and mixed hearing loss) and different configuration of hearing loss. Stimuli used were short burst of pink noise (equal energy per third-octave band from 250 Hz to 8 kHz). Localization abilities of the participants was studied at different planes including front horizontal plane, medial vertical plane, lateral vertical plane & lateral horizontal plane. Authors reported that, hearing impaired individual performed significantly poorer than normal group and the results revealed that degree of hearing loss and configuration does not have any significant effect on localization. However, those individuals who had conductive loss showed a significant error on localization than sensorineural hearing loss. In individuals with conductive hearing loss, both cochleae are stimulated simultaneously by the bone conduction leading to lack of inter aural timing cues resulted in localization errors.

2.4.3. Aging and Localization. Abel and Hay (1996) aimed to evaluate the effect of aging, hearing loss & hearing protection on sound localization. The study constituted two groups consisting of control group which further divided into young normal hearing and old normal hearing. Clinical group consisting of individuals diagnosed as bilateral moderate sensorineural hearing loss. Sound localization abilities were studied in a horizontal plane using six speakers placed at 30^0, 90^0, 150^0, 210^0, 270^0 and 330^0. Pure tones of 500Hz and 4000Hz of 300ms were used as a stimulus. The results revealed that hearing loss deteriorated the localization ability significantly and it aggravates in advanced aging. Aging would result in the disruption of inter aural timing cues as the efficacy of auditory system in processing the information would be reduced.

2.4.4. Localization and Noise. Lorenzi et al. (1999) evaluated the sound source localization in individuals with hearing impairment in the presence of noise. They consider four individuals with bilateral symmetrical hearing loss with sloping configuration and four normal hearing individuals. Stimulus used was low pass filtered pulse at 1.6 kHz of 300ms duration and the overall level of the signal was fixed to 70 dB SPL ~rms. The noise used was 900ms white noise which was presented at six different levels to achieve different signal to noise ratio ranging from -9 to +18dB.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 as SNR reduced. To be specific low frequency cues were less affected by noise than high frequencies when it was presented from +/- 90 azimuth. The study participants had sloping hearing loss where presence of noise reduced the SNR leading to poorer detection of high frequency signal lead to the more errors on localization of high frequency stimuli than low frequency hearing loss. In addition, localization error was less when stimulus presented +/- 90 azimuth than 0^0 azimuth. This is because a greater inter-aural timing cues was developed at +/- 90 azimuth than 0^0 azimuth.

To summarize, individuals with advanced age who had sensorineural hearing with high frequency loss hearing impairment performs significantly poor on localization task. The localization error relatively high in the presence of noise. However, localization abilities are independent of degree and configuration of the hearing loss.

2.5. Amplification and Localization

It was noted earlier that hearing loss either a unilateral and bilateral symmetrical or asymmetrical hearing loss, individuals suffer from localization ability. This is because they unable to identify the ITD and ILD cue to hearing loss. To be specific though the head baffle effect initiates the difference in time or intensity at ear level it fails to maintain binaural hearing at the level of superior olivary complex (SOC) due to hearing loss. In providing a hearing aid with appropriate gain in both ears helps to interpret information coming from the both ears by the binaural centers (SOC). However, in individuals with hearing impairment the information from both the ears are distorted which affects the processing of the information from higher binaural centers. Hearing aids are used to restore the audibility in these individuals. Research have showed that, localization in aided condition was poorer than unaided, especially, in individuals with sensorineural hearing loss (Markides, 1977; Noble & Byrne, 1990; Byrne, Noble, & LePage,1992). It was noted there was poor performance on vertical plane localization task when individuals are fitted with hearing aids bilaterally fitted with occluding ear molds (Noble & Byrne, 1990; Byrne, Noble, & LePage,1992). According to study done by Nobel and Byrne (1990), they compared the performance of individuals with hearing impairment on localization of sound in horizontal as well as in vertical plane in both aided and unaided condition. Participants were divided into 3 groups i.e. Individuals using BTE, ITE and ITC hearing aids. Localization abilities were tested with the use of 20 speakers in both horizontal and vertical plane. Stimulus used was click train of pink noise filtered at frequencies between 250Hz to 12500Hz. They found that aided performance was poorer than unaided, especially, significant for BTE users. Poor performance might be due to alteration of spectral cues which was leading to the confusion of sound source. Dillon (2001) has supported the notion that BTE hearing aids induced more distortion to the signal than ITC/ CIC hearing aids which impairs the localization ability. In 2006, Bogaert, Klasen, Moonen, Deun and Wouters studied performance of individuals with hearing impairment performance on localization tasks in horizontal plane in both aided and unaided conditions. They consider the two groups. Control group comprised of normal hearing individuals and individuals with hearing impairment as an experimental group. They found that individuals with hearing impairment performed poorer than normal and also their aided performance was poorer than unaided condition. They speculated that 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.

Sufani et al. (2006) evaluated the effect of compression on ILD's and ITD's by measuring head related transfer function in eight individuals with hearing impairment and five normal hearing individuals. Results revealed that ILD cues were deteriorated with increased compression ratio and short attack time. In addition, there was also deteriorated ITD cues when compression in hearing aid was activated but it was not significant. The authors have speculated that the reduction of ITD and ILD scores could be due to additional time delay induced by signal processing strategies such as compression and processing delay. Francis Kuk, and Petri (2014) studied the effect of hearing aid factors on localization of sound sources. They stated that aided localization scores were poorer than unaided. The possible reason attributed for it is due to the processing delay by digital circuit in hearing aid would alter the ITD and ILD cues. Localization ability was affected depending upon hearing aid style where occluded pinna by ear mold in case of BTE hearing aids results in the loss of spectral than open fit hearing aid Alexandra et al. (2016)

In summary, use of BTE hearing aids with activation of digital signal processers such as directional microphones, compression, and noise reduction algorithms alters the localization cues leading to poor performance on localization.

2.6. Hearing loss and Cognition

It is being since thirty years, Audiologists suspected the significant correlation between hearing loss and cognition. Loss of audibility would lead to less cognitive input and social isolation (Banks, 2016). However, it is noticed that hearing loss has been associated with greater declines in cognitive function in older adults than in their counterparts without hearing loss (Lin, 2011; Lindenberger & Baltes, 1994; Ulhmann et al., 1989; Tay, Wang, & Lindley, 2006; Baltes & Lindenberger, 1997). Lin (2011) studied the relationship between hearing loss and cognitive functioning especially on memory and executive function. For memory, free recall test and for executive function, Stroop Mixed and Trail Making tests were used. A total of 347 participants above 55 years with mild to moderate hearing loss were recruited for the study. Results revealed that greater hearing loss was significantly associated with lower scores on measures of memory and executive function. This is because cognitive load induced by hearing loss result in a smaller pool of resources being available for other cognitive tasks under a resource according to capacity model proposed by Kahneman (1973). A review article by Wie et al, 2017 where, they did a meta-analysis of ten published cohort studies which related the association between hearing loss and cognition. It was noticed that hearing loss and cognitive decline were associated despite variations in hearing test protocols, assessment methods, and outcome measures and their pooled analysis confirms a strong association between hearing impairment and adverse cognitive status. Two main explanatory hypotheses have been proposed to explain the mechanisms underlying the association between hearing loss and cognitive decline. The first hypothesis also known as ‘Common Cause Model’ suggests that hearing loss and cognitive decline share a common neuropathologic origin, such as age-related neurodegenerative changes caused by microvascular diseases and inflammation (Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1994). In other words, this model proposes that hearing loss and cognitive impairment in older adults may share the same underlying pathology. The second hypothesis, known as the “cascade” hypothesis, argues for a causal relationship between hearing loss and cognitive decline, and suggests that hearing loss exists in conjunction with or interacts with other risk factors to accelerate cognitive loss (Lin, 2011). According to this hypothesis, hearing loss may impact cognition in three main ways:

1. Long-term auditory deprivation may result in reduced cognitive function (Birren, 1964; Wahl & Heyl, 2003).
2. One possibility is that the link between hearing loss and cognitive decline is mediated by lifestyle factors. Hearing loss may result in reduced participation in social leisure activities and in withdrawal from social interactions. In fact, hearing loss is independently associated with social isolation and depression (Gates & Mills, 2005). There is also a connection between social isolation and depression and cognitive decline (Steffens et al., 2006; Plassman et al., 2007). The cascade hypothesis suggests that social isolation can lead to depression and other psychological consequences that may affect cognitive function.
3. Hearing loss may result in increased compensatory cognitive effort exerted to fill in the gaps caused by missing speech.

To conclude, hearing loss is a risk factor to develop cognitive impairment.

2.8. Cognition and Traffic safety

Cognition plays a major role in traffic safety as driving involves processing of multiple information. During complex traffic situations and high traffic work load requires huge cognitive load, otherwise it may lead road crashes. Study done by Lyu, Xie, Wu, Fu, & Deng (2017) aimed at studying the cognitive workload while driving and reaction time for the processing of the traffic sign information. Before the test, subjects were asked to complete a questionnaire providing their basic information: age, gender, driving experience, whether myopic or not, whether the subject had undergone a brain operation, whether the subject had a cold, and whether the subject drank coffee or other stimulating drinks and drugs that would affect brain function before the test. Study recruited a total of 22 participants who were professional drivers and 22 non-professional drivers. The experiment was conducted using an E430 Lenovo computer in the Driving Behaviors Lab at Wuhan University of Technology. Authors have used different volumes of traffic sign stimulus in terms of bit information. The 4 (information level) × 2 (driving experience) × 2 (gender) repeated measures mixed design presented four traffic sign information levels: level 1 (total information volume below 40 bits), level 2 (total information volume between 41 and 80 bits), level 3 (total information volume between 81 and 120 bits), and level 4 (total information volume above 121 bits) .Stimulus presentation involved presentation of + sign to grab the attention of the participant followed by the target name and interval of 1000ms was given before the subsequent stimulus. Finally target name was displayed along with distracters. Here subjects were encouraged to identify the target stimulus on traffic sign board by pressing right/ left arrow keys. Results showed that cognitive work load and reaction time increased significantly as the volume information of the stimulus increased. Thus, there is a role of cognition in information processing while driving. Cognition plays an important role in information processing of the traffic sign stimuli which is necessary in safe driving.

Chapter 3

METHOD

A standard group and comparative research design were utilized to assess the localization ability and traffic sign cognitive ability in a simulated traffic environment.

3.1. Selection of participants

A total of 40 participants in the age range of 40 to 60 years were recruited in the study. Among those, 10 participants constituted the control group who had normal hearing with no otological and/or neurological conditions. The clinical group consisted of 30 participants who had bilateral symmetrical sensorineural hearing loss. The clinical group was further divided into three subgroups based on their severity of hearing loss that is Mild hearing loss (PTA: 26-40 dB HL), Moderate to Moderately severe hearing loss group (PTA: 41-70 dB HL) and Severe hearing loss group (PTA: 70-90 dB HL). Each clinical sub-group comprised of 10 participants, who had no prior experience with hearing aid. All participants of study had normal middle ear status and no other otological complaints.

3.2. Instrumentation

The following instruments were used for subject selection criteria and assessment of localization ability and traffic sign cognition ability.

1. A calibrated dual channel audiometer "Gradsen Stadler Model GSI 61" was used to assess hearing sensitivity.
2. Middle ear analyzer "Gradsen Stadler Model GSI Tympstar v-2" was used to assess middle ear status.

3. Loud speakers connected to personal computer controlled by Cubase software (Version 2.0.2.) to deliver sounds from different azimuths to investigate localization ability.
4. Cognition test software (Version-1) developed using visual studio software was used to assess the traffic sign cognitive ability.
5. A Bruel and Kjaer hand held sound level meter (SLM) was used to calibrate the target test signal (Truck horn) and a traffic noise.

3.3. Test Environment

A sound treated air-conditioned double room set-up was used to administer all the tests. The noise level in the testing room was maintained within the permissible limits as per the ANSI S3.1-1999-R2013 (American National Standard Institute, 1999).

3.4. Stimuli

The following stimuli were used for assessment of localization ability and traffic sign cognitive ability.

1. For localization test, a truck horn having a center frequency of around 272 Hz at 100 dB SPL was used as target stimulus.
2. Traffic noise at 65 dB SPL was used as background noise (Konadath & Jain, under review).
3. Traffic signs were used as a stimuli in cognition test software (Version-1) to assess traffic sign cognitive ability.

3.5. Hearing aid programming and aided thresholds

Each participant was bilaterally fitted with the digital hearing aids. These hearing aids were connected to NOHA link, which in turn connected to a personal computer loaded with hearing aid specific software. The connected hearing aids were programmed using NAL- NL1 fitting formula for providing appropriate gain with respect to participant's hearing loss. It was ensured that directional microphone and noise reduction circuit were deactivated. From each participant of clinical group, aided thresholds were obtained from 500 Hz to 4 kHz (in octave frequencies) for warble tones delivered only at 0^0 azimuth (Figure 3.1). It was observed in each group, aided thresholds were within the speech spectrum

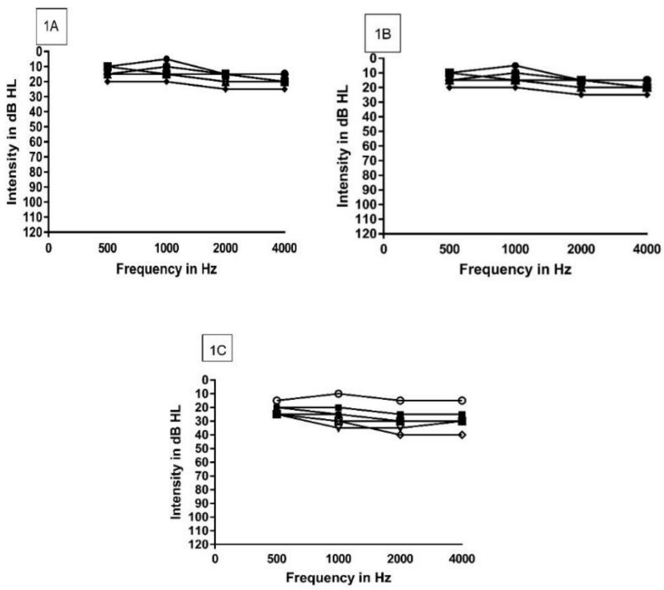

Figure 3.1. Aided audiogram of each participant in the clinical groups: 1A. Mild hearing loss group 1B. Moderate to Moderately severe hearing loss group and 1C. Severe hearing loss group.

3.6. Procedure

3.6.1. Localization ability. Localization ability was assessed in each of the participant of both control group and clinical group. In clinical group, localization ability was assessed in both unaided and aided conditions.

3.6.1.1. Localization setup. The target stimulus (Truck horn) was presented through five speakers located at 90^0, 140^0, 180^0, 220^0 and 270^0 azimuth. A traffic noise was continuously presented through four speakers positioned at 40^0, 120^0, 240^0 and 320^0 azimuths. It was ensured that center of the head of each participant was equidistant from each loudspeaker which was 2 meters away from the center. Stimulus presentation set up is depicted in Figure 3.2.

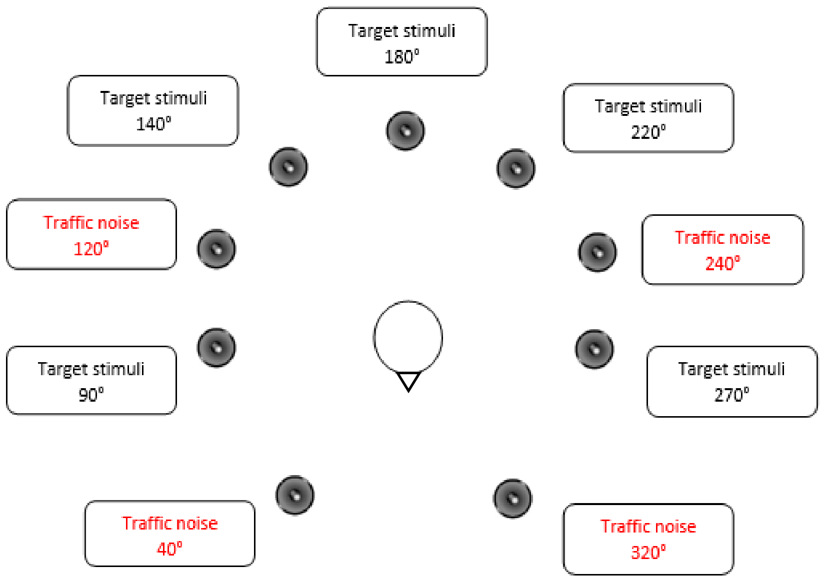

Figure 3.2. Localization test set-up: Location of the loudspeakers and stimuli assignment.

3.6.1.2. Stimuli. A total of nine stimuli tracks were created in the Cubase software (Version 2.0.2.). Number corresponded to each speaker was assigned to each track. Tracks containing the 272 Hz horn was assigned to speakers placed at 90^0, 140^0, 180^0, 220^0 and 270^0 azimuths. Further, tracks containing the traffic noise was assigned to speakers positioned at 40^0, 120^0, 240^0 and 320^0 azimuths.

3.6.1.3. Calibration. To calibrate the target test stimulus (Truck horn) and traffic noise, a Bruel and Kjaer hand held sound level meter (Model no. 2270) mounted on a tripod stand with a half inch free field microphone (serial no: 02616511) was used. Sound level meter (SLM) was located at 2-meter equidistance from each of the speakers assigned to deliver target test stimulus and noise. In SLM, the A weighting network, automatic gain control and fast time network were opted to calibrate the target stimulus. The target stimulus 272 Hz horn was delivered through Cubase software (Version 2.0.2) routed through Lynx aurora sound card to the assigned speakers. Test signal was calibrated at 100 dB SPL. Calibration of the horn stimulus was performed in each of the speaker by adjusting the volume control in Lynx mixer of Cubase software (Version 2.0.2), to ensure that desired intensity has read in SLM. However, traffic noise was calibrated by presenting continuously through speakers assigned to it and calibrated at 65 dB SPL using a similar procedure. Unlike SLM setting for target signal, a slow weighting network was used in SLM to calibrate traffic noise.

3.6.1.4. Instruction and Task. Each participant was seated in the sound-treated room. Prior to the testing, a trial was given to familiarize with the test procedure. Each participant was instructed as follows: You will be presented the horn sound which may come from either of the five speakers positioned at rear side. You have to locate the speaker in which the horn sound was delivered either through pointing or tell the number assigned to the speakers. Horn sound in the presence of traffic noise were delivered four times from each of the loudspeaker in a random order.

3.6.1.5. Analysis. The number assigned to each loudspeaker form which the stimulus was presented and the response from the client to each corresponding trial is tabulated and the same is depicted in Table 3.1. Data on number assigned to each speaker and the response given by a participant entered in excel work sheet was fed to confusion matrix software (Version -1) to generate a stimulus response matrix (Table-3.2). The degree of error was computed using an excel based ready reckoned degree of error application, represented in Table 3.3. To compute average degree of error, the method of Ching, Van Wanrooy, Hill, & Dillon (2005) was adopted. The equation to calculate the average degree of error is given below.

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

DOE_1: Degree of error in the speaker no. 1

DOEn: Degree of error in the n^{th} number of speaker

RMS: Root Mean Square

N= Number of stimuli presented from each loudspeaker/ overall loudspeaker.

Table 3.1

Stimulus & Response column

Stimulus	Response
1	1
1	1
1	1
1	1
2	2
2	2
2	2
2	2
3	3
3	3

Stimulus	Response
3	3
3	3
4	4
4	4
4	4
4	4
5	5
5	5
5	5
5	5

Table 3.2

Stimulus and response matrix generated from confusion matrix software for each participant

	Response				
Stimulus	**1**	**2**	**3**	**4**	**5**
1	4	0	0	0	0
2	0	4	0	0	0
3	0	0	4	0	0
4	0	0	0	4	0
5	0	0	0	0	4

Table 3.3

Ready reckoned degree of error

	Response				
Speaker number	**1**	**2**	**3**	**4**	**5**
1	0	45	90	135	180
2	-45	0	45	90	135
3	-90	-45	0	45	90
4	-135	-90	-45	0	45
5	-180	-135	-90	-45	0

3.6.2. Traffic sign cognitive abilities

3.6.2.1. Stimuli. Four different sets of stimuli were used to evaluate the traffic sign cognitive ability. The cognition test software (Version-1) loaded in a personal computer was utilized to present these stimuli. Each set of stimulus was presented five times in a random order. The four sets of stimuli were given below.

1) Target stimulus with distractor stimulus
2) Target stimulus with direction congruency
3) Target stimulus with color congruency
4) Target stimulus with appropriate algebraic equation of the distance.

3.6.2.2. Task and instructions. Each participant was seated in localization set up where traffic signs were displayed in a personal computer. In beginning of the experiment, fixation point was displayed for about 1000ms to seek the attention of the participants followed by presentation of target stimulus with a rendering time of 2000 ms. This was done to prompt the subject to identify the target stimulus in a subsequent display. Traffic signs were displayed along with distractions (other than target stimulus) for about 6000 ms. Participants were instructed to press either right or left arrow key to the side where target name was displayed. An inter stimulus interval of 7000 ms was assigned before the arrival of next of stimulus on the screen. It was ensured an intra-stimulus interval of 1000 ms was given between fixation point and target stimulus; and target stimulus and distracting stimulus.

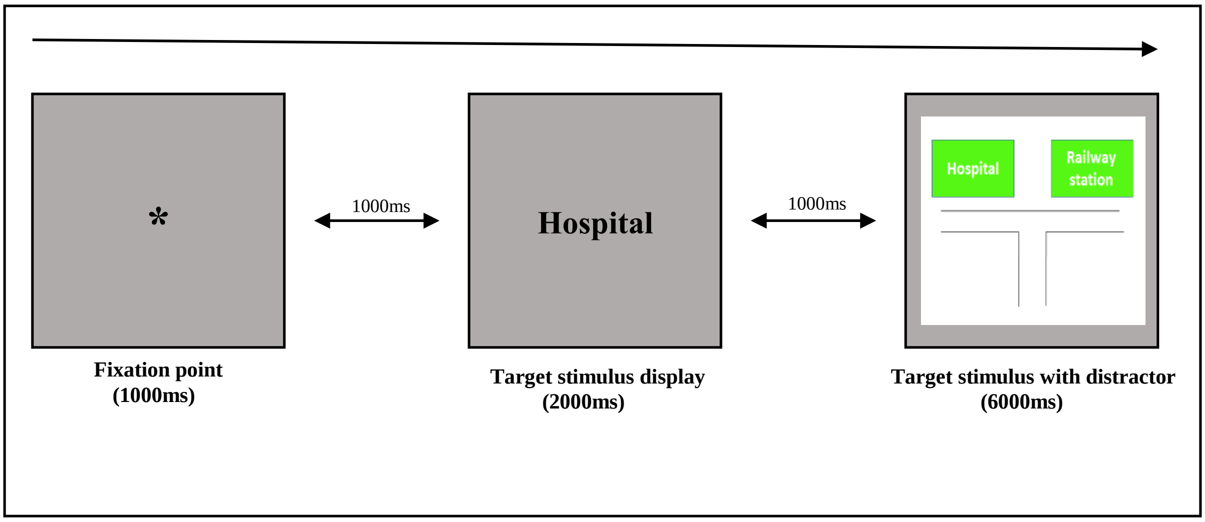

Figure-3.3. Type-1 traffic sign cognitive stimulus - Target stimulus with distractor stimulus.

Similar procedure was utilized to deliver second set of stimulus. Target stimulus on either sides were displayed with direction shown in sign board being congruent to direction of road on one side and incongruent on the other side. Here, each participant was instructed to identify the target with direction congruency.

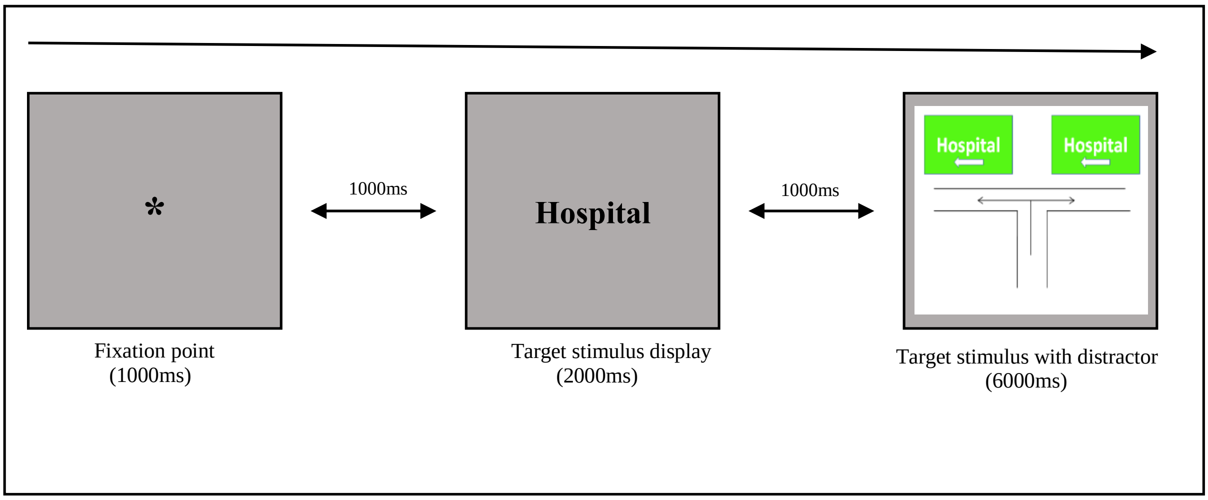

Figure-3.4. Type-2 traffic sign cognitive stimulus - Target stimulus with direction

In third set of stimulus, target name along with direction was displayed on either sides. However, the color being same or incongruent between direction and target name. In this, participant was encouraged to identify the side where both direction and target name are congruent in color.

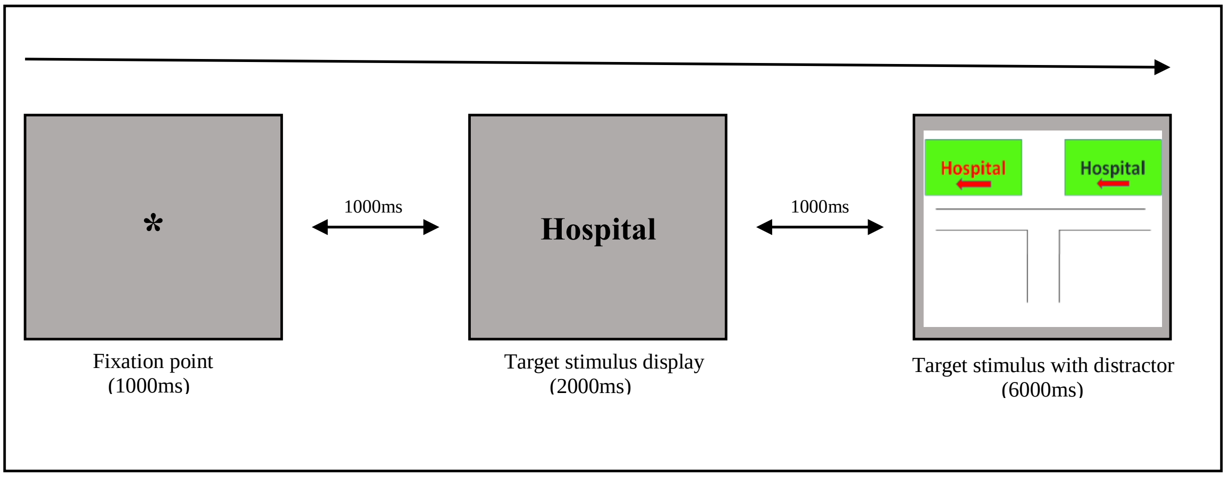

Figure-3.5. Type-3 traffic sign cognitive stimulus - Target stimulus with color congruency

In the fourth set of stimulus, mathematical operation with respect to distance of the target place was displayed. Each participant was instructed to select the sign board where mathematical equation is appropriate.

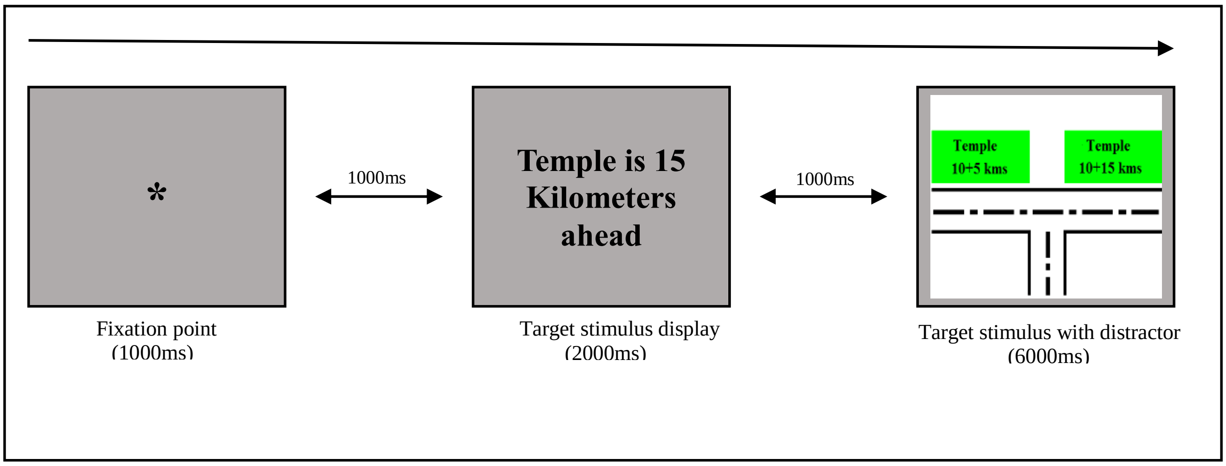

Figure-*3.6.* Type-4 traffic sign cognitive stimulus - Target stimulus with appropriate algebraic equation of the distance.

3.6.2.3. Analyses. Correct response and its reaction time (four sets - presented five times) were considered to assess traffic sign cognitive ability. Each correct response was awarded with a score of one and incorrect was assigned a score of zero. Cognition test software (Version-1) computes the correct response from the scores obtained from four sets of traffic signs. A maximum score of 20 was assigned for traffic sign cognitive task. In addition, cognition test software (Version-1) software automatically computes the average reaction time from the correct response.

Both the tasks i.e., localization task and traffic sign cognition task were presented in a pseudo randomized order. The presentation of stimuli were organized in such a way that traffic horn of precedes the every presentation of stimuli corresponding to traffic sign cognitive task.

3.7. Statistical analyses

The data obtained were subjected to statistical analyses using the SPSS (Statistical package for social science) software version 21.

1. Descriptive statistics was carried out to account mean and standard deviation of degree of error, traffic signs cognitive score and its average reaction time in unaided and aided conditions.
2. Multiple analyses of variance (MANOVA) with between subject factor as groups (based on hearing loss) was performed to see if there was a significant main effect of group on degree of error, traffic signs cognitive score and its average reaction time in unaided condition. Similarly, MANOVA was used to document main effect of group in aided condition.
3. To document significant difference between groups on each task in unaided condition a Post Hoc Duncan test was performed. Similar test was administered in aided condition to determine the significant difference between each group on each task.
4. Paired sample t-test was performed to see if there was a significant difference between unaided and aided performance on degree of error, traffic sign cognitive scores and its average reaction time.
5. Karl Pearson correlation was carried out to find the relation between pure tone average and degree of error, traffic sign cognitive score as well as its average reaction time from participants of the study.
6. Regression model was drawn to estimate degree of error, traffic sign cognitive correct score and its average reaction time by the predictor pure tone average of the participants.

Chapter 4

RESULTS

The aim of the present study was to investigate localization and cognition abilities in hearing impaired individuals in a simulated traffic condition. The degree of errors in localization task, correct scores and its average reaction time on traffic sign cognitive task were obtained from the age matched control group and clinical groups in unaided and aided conditions. These data were subjected to statistical analyses using SPSS [Statistical Package for Social Sciences] software of Version 21.0.

4.1. Localization and traffic sign cognitive abilities in unaided condition

Descriptive statistical analysis were performed to document mean and standard deviation of degree of errors, traffic sign cognitive correct scores and its average reaction time obtained from control group and clinical group in unaided (Table 4.1.) It is observed that, as the degree of hearing loss increased, the degree of error in localization task and cognitive average reaction time increased and correct scores decreased in traffic sign cognitive task. In addition, the degree of error was more in hearing impaired individuals than normal hearing individuals. Further, reduced traffic sign cognitive scores and increased reaction time were noticed in hearing impaired group than normal hearing individuals. A similar result on degree of error in localization task, traffic signs cognitive correct scores and its average reaction time were observed when each group of hearing impaired was compared with normal hearing individuals.

Table 4.1

Mean and Standard deviation of degree of error in localization task, traffic sign cognitive correct scores and its average reaction time obtained from both control and clinical group in the unaided condition.

Groups	***Degree of error***		***Correct scores***		***Average reaction time (ms)***	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Normal	7.92	4.36	17.5	1.27	2287.35	498.70
Mild	24.48	9.72	14.70	2.71	2986.30	751.65
Moderate to Moderately severe	27.35	10.51	12.50	2.91	3626.00	566.16
Severe	42.42	6.08	11.00	1.49	3967.00	449.63

Further, Multivariate analysis of variance (MANOVA) with between the subject factors as a group (Control group & Clinical group) was performed to see, if there was a significant main effect on degree of errors in localization task, traffic signs cognitive correct scores and its average reaction time in the unaided condition. Significant effect between the groups [F (3, 36) = 30.606, p<0.001] for degree of error in localization task was observed, such that degree of error increased as degree of hearing loss increased. In addition, a traffic sign cognitive score was reduced with increase with degree of hearing loss and this difference was found significant [F (3, 36) =16.240, p<0.001]. Further, traffic sign cognitive average reaction time was significantly longer with increase in degree of hearing loss [F (3, 36) =16.441, p<0.001].

A post hoc analysis was performed to account for significant difference between study groups in unaided condition using the Duncan test. From the Figure 4.1., it is noticed that there was a significant difference between control group and each clinical group ($p<0.05$) on degree of error. In addition, there was a significant difference between mild and severe hearing loss group ($p< 0.05$) on degree of error and there was a significant difference between moderate to moderately severe hearing loss and severe hearing loss group ($p< 0.05$) on degree of error. However, there was no significant difference between mild and moderate to moderately severe hearing loss groups.

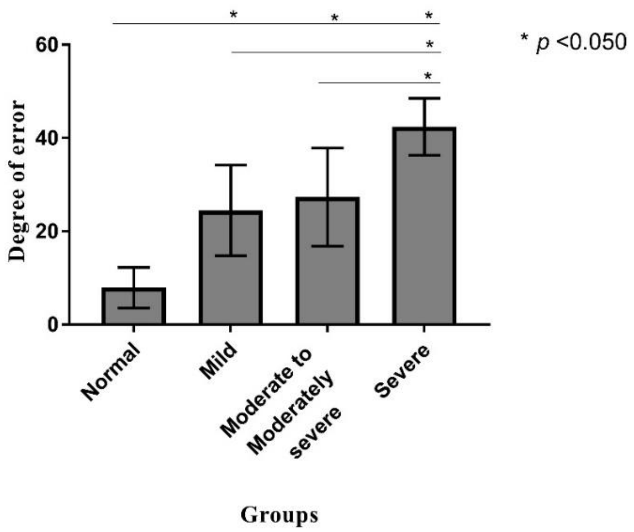

Figure 4.1. Mean and standard deviation of degree of error for each group in unaided condition.

A Duncan test on traffic sign cognitive correct scores revealed a significant ($p<0.05$) difference between normal and each group of hearing impaired group (Figure 4.2). Individuals with mild hearing loss was performed significantly ($p<0.05$) better on traffic sign cognitive correct scores than individuals with moderate to moderately severe hearing loss and severe degree of hearing loss. Though correct scores on cognitive traffic signs decreased with increase with the degree of hearing loss, there was no significant difference between moderate to moderately severe and severe hearing loss groups.

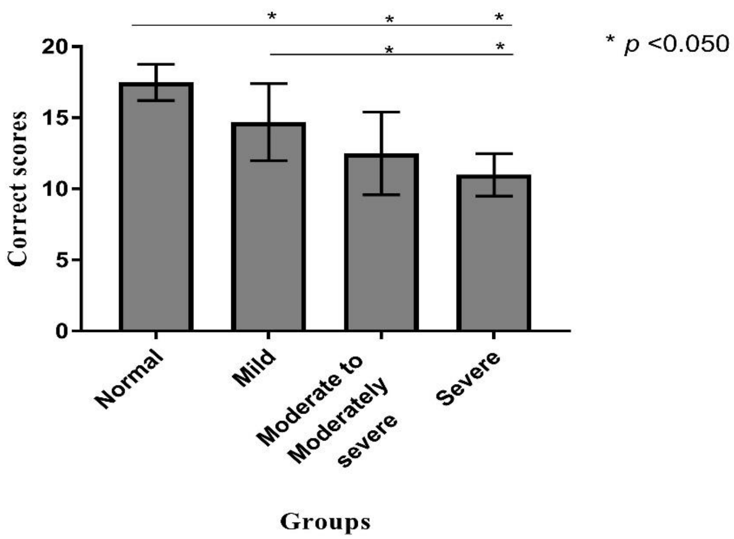

Figure 4.2. Mean and standard deviation of traffic sign cognitive correct score for each group in unaided condition.

In addition, the results of Duncan test revealed that significant ($p<0.05$) difference between control and each clinical group on average reaction time (Figure 4.3). Within clinical group, individuals with mild hearing loss took significantly lesser time ($p<0.05$) to perform traffic signs cognitive task than individuals with moderate to moderately severe and severe hearing loss. However, there was no significant difference between moderate to moderately severe and severe hearing loss group.

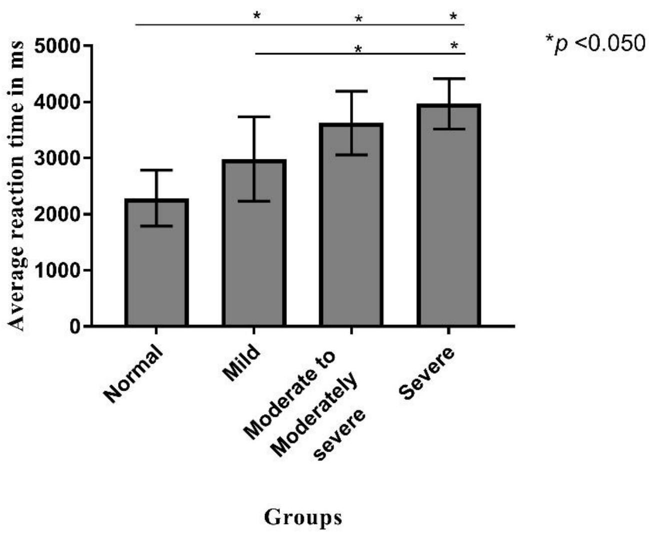

Figure 4.3. Mean and standard deviation of average reaction time for each group in unaided condition.

4.2. Localization abilities and traffic sign cognitive abilities in aided condition

Descriptive statistical analysis was performed to document mean and standard deviation of degree of errors in localization task, traffic signs cognitive correct scores and its average reaction time obtained from clinical group in aided conditions. Table 4.2 represents degree of error, correct scores and average reaction time in aided condition. It is observed that as the degree of hearing loss increased, degree of error in localization task and traffic sign cognitive average reaction time increased. However, traffic sign cognitive correct scores decreased with increased in degree of hearing loss.

Table 4.2

Mean and Standard deviation of degree of error, correct scores and average reaction time obtained from clinical group in the aided condition.

Groups	***Degree of error***		***Correct scores***		***Average reaction time (ms)***	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Mild	23.30	8.80	16.50	2.71	2381.57	1119.28
Moderate to Moderately severe	28.68	11.45	13.40	2.63	3005.45	782.58
Severe	40.90	9.17	11.80	1.32	3703.90	611.09

Further, Multivariate analyses of variance was performed with between the subjects factors as a group to see, if there was a significant main effect on degree of error, traffic sign cognitive correct scores and its average reaction time in aided condition. Main effect with between subjects factor as a group was found significant [F (2, 27) = 8.324, $p \leq 0.05$] for degree of error, such that degree of error increased with the increase in the degree of hearing loss. Further, traffic sign cognitive correct scores decreased as degree of hearing loss increased significantly [F (2, 27) =10.669, $p<0.05$]. In addition, average reaction time found to be significantly longer as degree of hearing loss increased [F (2, 27) =6.430, $p<0.05$].

Post hoc Duncan test analysis was performed to see, in which groups have accounted for significant difference on degree of localization error in aided condition.

From Figure 4.4, it is noticed that there was a significant difference between mild and severe hearing loss group ($p < 0.05$) on degree of error. In addition, there was a significant difference between moderate to moderately severe and severe hearing loss group ($p<0.05$) on degree of error. Further, it was noted that increase in the degree of hearing loss increases as the degree of error increased and this difference failed to reach significant difference between mild and moderate to moderately severe hearing loss on degree of error.

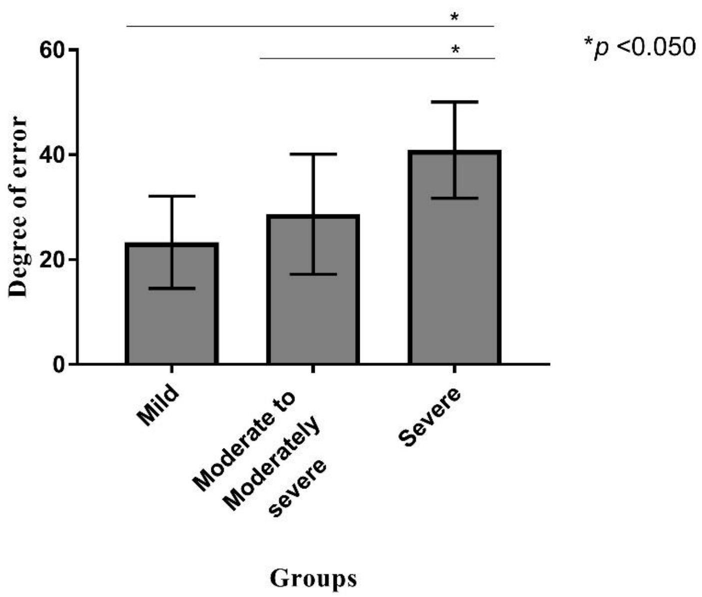

Figure 4.4. Mean and standard deviation of degree of error for each group in aided condition.

The Duncan test on traffic sign cognitive scores revealed that traffic sign cognitive correct scores were significantly higher ($p<0.05$) in mild group than moderate and severe hearing loss groups, respectively (Figure 4.5). Though the correct scores decreased with increase in the degree of hearing loss, there was no significant difference between moderate to moderately severe and severe hearing loss groups.

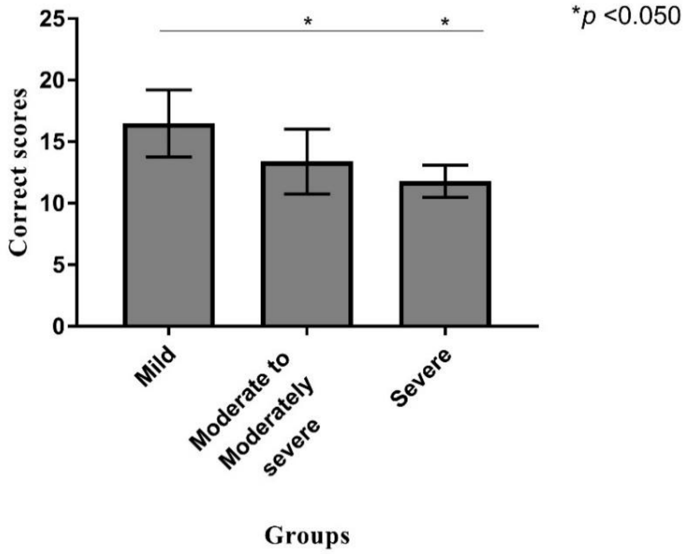

Figure 4.5. Mean and standard deviation of correct score for each group in aided condition.

In addition, the results of Duncan test revealed that reaction time required to perform cognitive task was significantly lesser in mild group (p<0.05) than moderate to moderately severe group and severe group (Figure 4.6). Though the average reaction time to perform cognitive task was lesser in moderate to moderately severe hearing loss group than severe hearing loss group, this difference failed to reach significant.

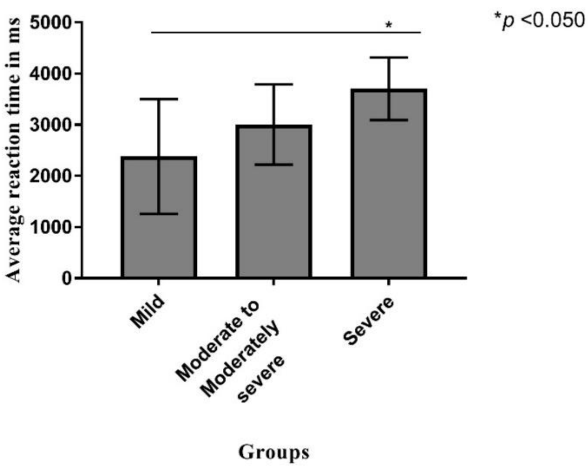

Figure 4.6. Mean and standard deviation of average reaction time for each group in aided condition.

4.3. Comparison between aided and unaided condition for degree of error in localization task, traffic sign cognitive correct score and its average reaction time in each group.

A paired sample t-test was performed to check whether there was a significant difference between unaided and aided conditions for each of the task in each clinical group.

4.3.1. Degree of error in aided and unaided condition. The mean and standard deviation of degree of error in both aided and unaided conditions for each clinical group is represented in Figure 4.7. Though the degree of error was higher in unaided condition than aided condition, the mean difference did not reach significance for mild hearing loss group [t (9) =0.276, p=0.789], moderate to moderately severe hearing loss group [t (9) = -0.473, p=0.648] and severe hearing loss group [t (9) = 0.740, p=0.478].

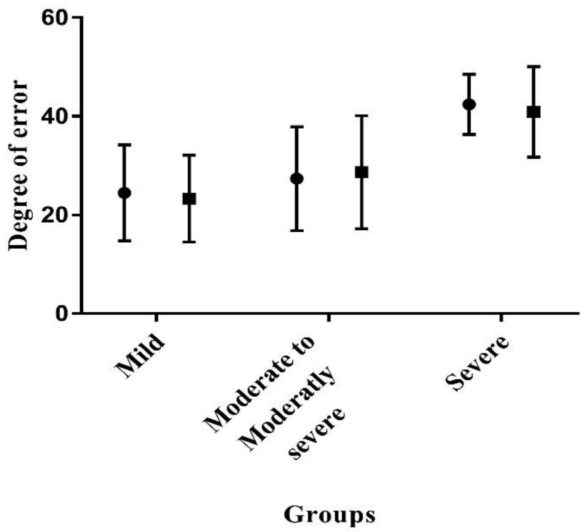

Figure 4.7. Mean and standard deviation of degree of error for both aided and unaided conditions in each clinical group.

4.3.2. Traffic sign cognitive correct scores in aided and unaided condition. The mean and standard deviation of traffic sign cognitive correct scores in both aided and unaided conditions for each clinical group is represented in Figure 4.8. The mean traffic sign cognition score was higher in aided condition than unaided condition. This difference reached significant and it was observed in mild hearing loss group [t (9) =-3.674, p=0.005], moderate to moderately severe hearing loss group [t (9) = -2.586, p=0.029] and severe hearing loss group [t (9) = -2.753, p=0.022].

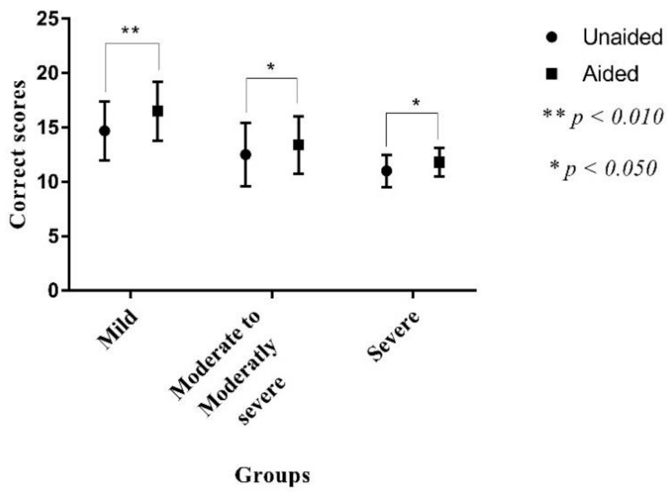

Figure 4.8. Mean and standard deviation of correct scores for both aided and unaided conditions in each clinical group.

4.3.2. Average reaction time in aided and unaided condition. The mean and standard deviation of average reaction time both aided and unaided conditions for each clinical group is represented in Figure 4.9.

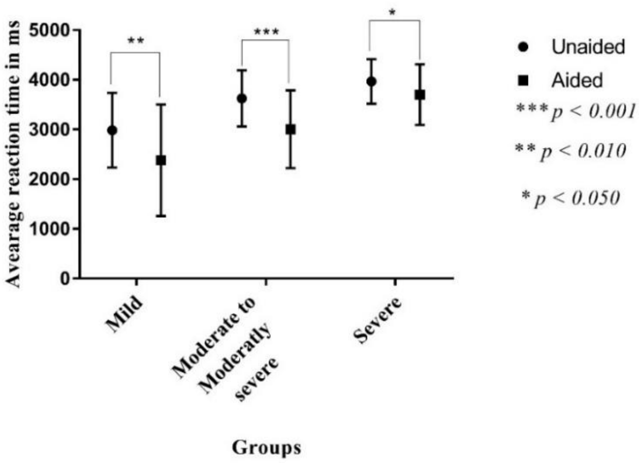

Figure 4.9. Mean and standard deviation of average reaction time for both aided and unaided condition in each clinical group.

The mean traffic sign cognitive reaction time was taken more in unaided condition than aided condition. This difference reached significant and it was observed in mild hearing loss group [t (9) =2.541, p=0.0320], moderate to moderately severe hearing loss group [t (9) = 4.863, p=0.001] and severe hearing loss group [t (9) =3.362, p=0.008], respectively.

4.4. Relation between pure tone average and each task in unaided condition.

Pure tone average obtained from the participants of four groups (N=40) was correlated with degree of error in localization task; traffic signs cognitive correct scores and average reaction time using Karl Pearson's correlation. Further, degree of error, traffic sign cognitive correct response and its average reaction time was predicted from pure tone by using linear regression.

4.4.1. Relation between pure tone average and degree of error in unaided condition. The results of Karl Pearson correlation showed there was a strong positive correlation between pure tone average and degree of error. It indicates that degree of error increased with increase in degree of hearing impairment (*N*=40, *r* = 0.816, *p*=0.000). Further, a linear regression was performed to predict the degree of error from PTA as shown in Figure 4.10. A model of regression was found significant [R^2=0.666, F (1, 38) =75.70, p=0.000]. Equation $y = a + b(x)$ (a = 5.995; b =0.465) was obtained to predict degree of error from PTA, where y is dependent variable, x is independent variable, a is the intersection point of the curve and b is the slope of the curve. It infers degree of error was found to be 5.995, if the individuals having their pure tone average of 0 dB HL. Further, a 1 dB increase in pure tone average would result in 6.46 degree of error.

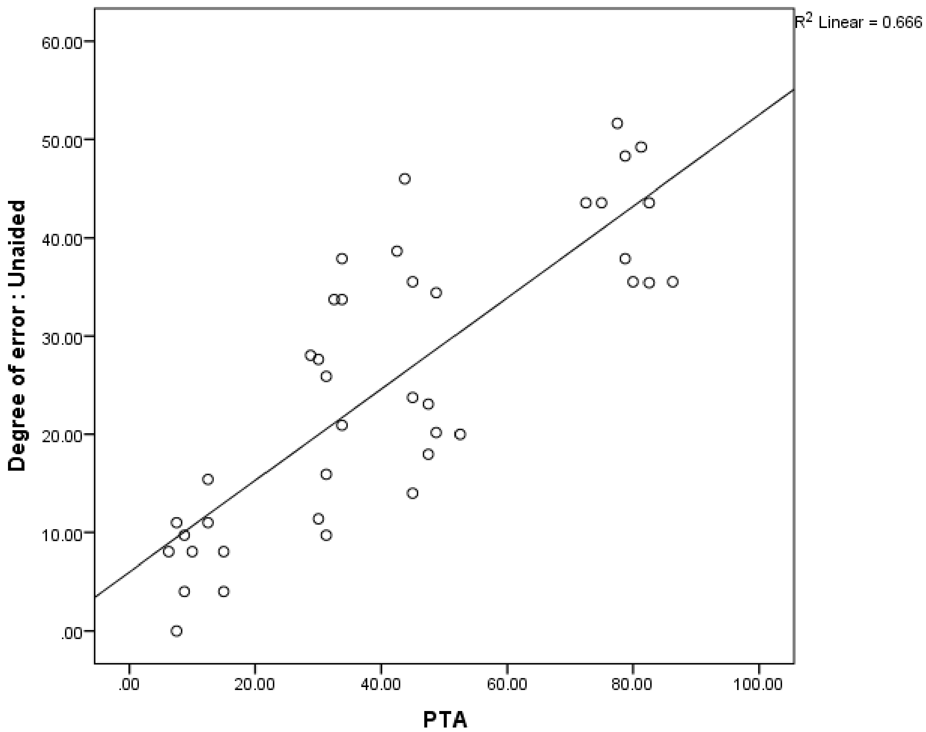

Figure 4.10. Linear regression drawn with measured data and mean of the predicted data for degree of error and PTA on a scatter plot.

4.4.2. Relation between pure tone average and traffic sign cognitive correct scores in unaided condition. The results of Karl Pearson's correlation revealed that there was a strong negative correlation between pure tone average and traffic signs cognitive correct scores. It indicates that traffic sign cognitive correct scores decreased as the hearing loss increased (*N*=40, *r* =0.714, *p*=0.000). Further, a linear regression was administered to predict the correct score from PTA as shown in Figure 4.11. A model of regression was found significant [R^2=0.510, *F* (1, 38) =39.516, *p*=0.000]. Equation *y* = *a* +*b(x)* (*a*=17.741; *b* =-0.091) was obtained to predict traffic sign cognitive correct scores from PTA. It infers that traffic sign cognitive correct score was found to be 17.74, if their pure tone average is equal to 0 dB HL. Further, a 1 dB HL increase in pure tone average would result in a reduction of traffic sign cognitive score by 0.091.

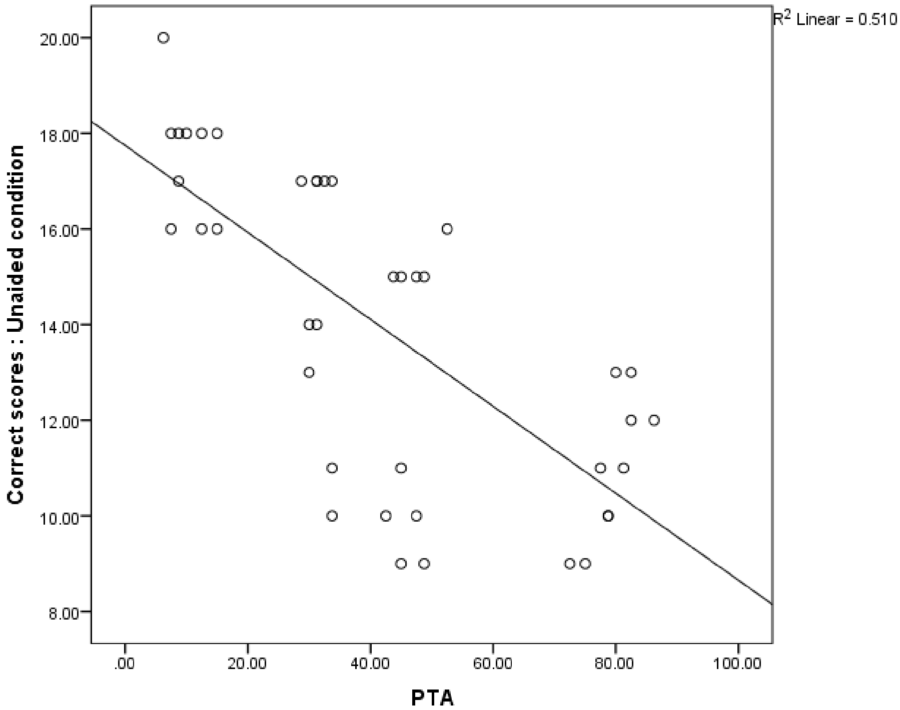

Figure 4.11. Linear regression drawn with measured data and mean of the predicted data for correct scores and PTA on a scatter plot.

4.4.3. Relation between pure tone average and average reaction time in unaided condition. Further, the results of Karl Pearson's correlation revealed that there was a strong positive correlation between average reaction time and pure tone average.

It indicates that average reaction time increased as the hearing loss increased (N=40, r =0.710, p =0.000). Further, a linear regression was drawn to predict the average reaction time from PTA as shown in Figure 4.12. A model of regression was developed found significant [R^2=0.505, F (1, 38) =38.734, p=0.000]. Equation $y = a + b(x)$ (a =2222.071; b =23.66) was obtained to predict average reaction time from PTA. It infers that average reaction time was found to be 2222.07 ms, if their pure tone average is 0 dB HL. Further, a 1 dB HL increase in pure tone average would result in an average reaction time of 2244.73 ms.

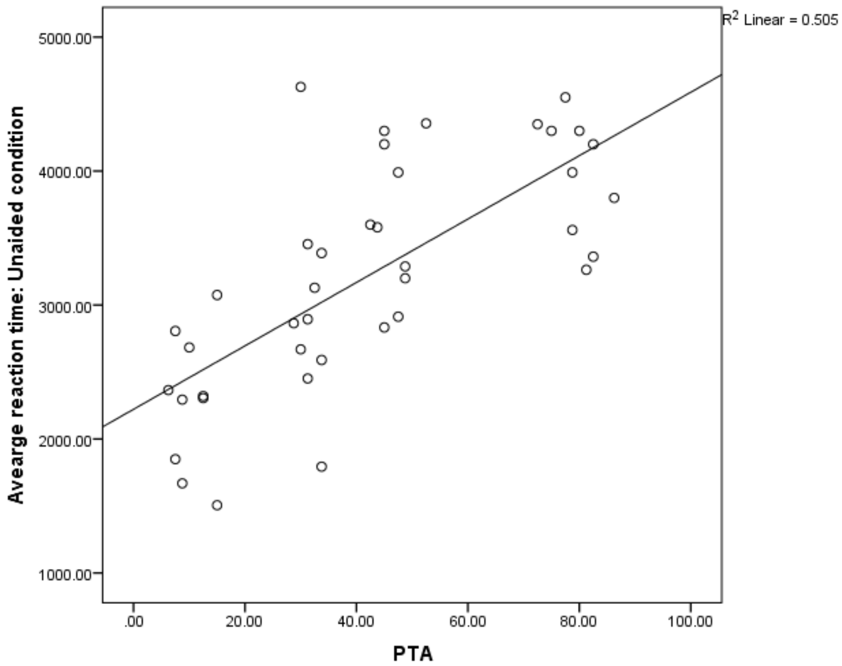

*Figure 4.12.*Linear regression drawn with measured data and mean of the predicted data for average reaction time and PTA on a scatter plot.

4.5. Relation between pure tone average and each task in aided condition.

Pure tone average obtained from the participants of three groups (N=30) was correlated with localization task and cognitive task in aided condition using Pearson's correlation. Further, degree of error, correct response and average reaction time was predicted from pure tone average by using liner regression.

4.5.1. Relation between pure tone average and degree of error in aided condition. The results of Karl Pearson's correlation showed there was a significant moderate positive correlation between pure tone average and degree of error. It indicates that degree of error increased as the hearing loss increased (N=30, r = 0.589, p =0.001). Further, a linear regression was drawn to predict the degree of error in aided condition from PTA as shown in Figure 4.13. A model of regression was developed found significant [R^2=0.347, F (1, 28) =14.908, p=0.001]. An equation $y = a + b(x)$ (a =12.671; b =0.348) was obtained to predict degree of error from PTA. It infers degree of error was found to be 12.67, if the individuals have their pure tone average of 0 dB HL. Further, a 1 dB change in pure tone average would result in 13.01 degree of error.

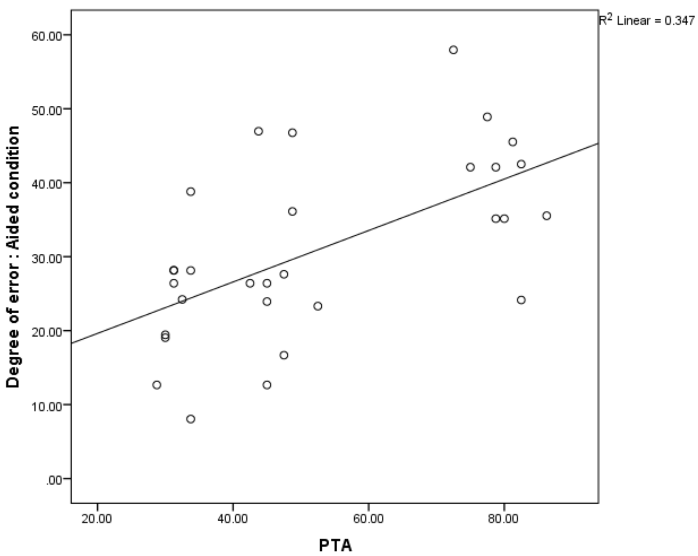

Figure 4.13. Linear regression drawn with measured data and mean of the predicted data for degree of error and PTA on a scatter plot.

4.5.2. Relation between pure tone average and traffic sign correct cognitive scores in aided condition. The results of Karl Pearson's correlation revealed that there was a moderate negative correlation between traffic sign cognitive correct scores and pure tone average. It indicates that traffic sign cognitive score decreased as the hearing loss increased (*N*=30, *r* =-0.591, *p*=0.001). Further, a linear regression was drawn to predict the traffic sign cognitive correct score from PTA as shown in Figure 4.14. A model of regression was developed which was significant [R^2=0.349, F (1, 28) =38.734, p=0.001]. An equation y = a +b(x) (a=18.415; b =-0.086) was obtained to predict traffic sign cognitive correct from PTA. It infers that traffic sign cognitive score was found to be 18.41, if their pure tone average is 0 dB HL. Further, a 1 dB HL increase in pure tone average would result in a traffic sign cognitive score of 18.32.

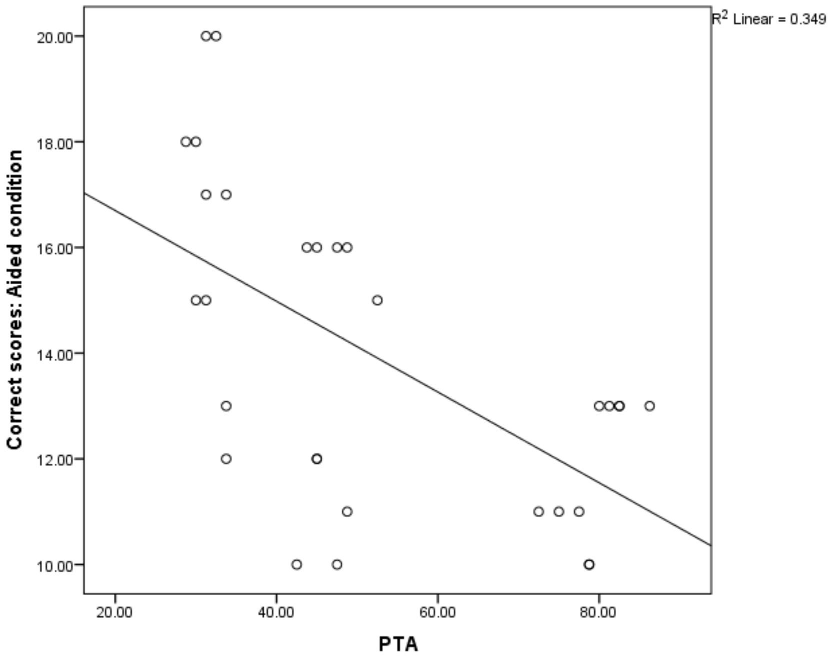

Figure 4.14. Linear regression drawn with measured data and mean of the predicted data for correct scores and PTA on a scatter plot.

4.5.3. Relation between pure tone average and average reaction time in aided condition. Further, the results of Pearson's correlation revealed that there was a moderate positive correlation between average reaction time and pure tone average. It indicates that average reaction time increased as the hearing loss increased (*N*=30, r =0.543, *p* =0.002). Further, a linear regression was drawn to predict the average reaction time from PTA as shown in Figure 4.15. A model of regression was developed found significant [R^2=0.295, F (1, 28) =11.715, p=0.001]. Equation $y = b + a (x)$ (a = 1601.924; b =26.765) was obtained to predict average reaction time from PTA. It infers that average reaction time was found to be 1601.924 ms, if their pure tone average is 0 dB HL. Further, a 1 dB HL increase in pure tone average would result in average reaction time of 1628.69 ms.

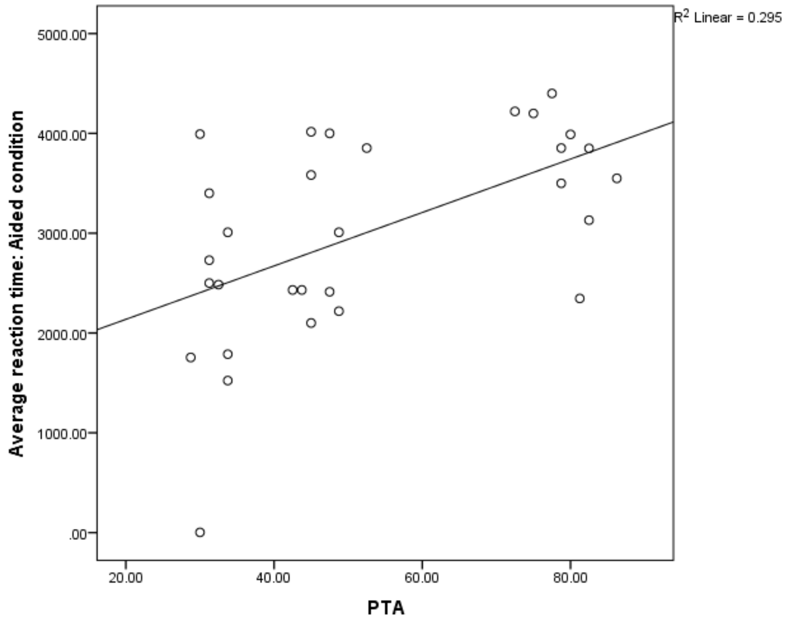

Figure 4.15. Linear regression drawn with measured data and mean of the predicted data average reaction time and PTA on a scatter plot.

In summary, there was a significant increase in degree of error and average reaction time as well as decrease in the traffic sign cognitive correct scores as the hearing loss increases. In addition, there was a significant correlation between degree of error, correct scores and average reaction time with hearing loss. Further, each of the task such as degree of error, cognitive correct responses and average reaction time of both unaided and aided conditions was predicted from pure tone average using linear regression model.

Chapter 5

DISCUSSION

Participants attended to the stimuli of localization and cognitive tasks which were presented sequentially in a pseudo-randomized just to simulate the road traffic environment. Degree of error in localization, traffic sign cognitive correct score and its average reaction time were significantly affected in clinical subgroups than control group. Further, it was noticed that with increase in the degree of impairment increased as the degree of localization error increased. Cognitive correct score reduced and its average reaction time increased as the degree of hearing impairment increased.

In localization task, the low frequency horn was utilized. To detect the source of incident sound energy requires detection of inter aural time difference which could be affected in individuals with hearing loss. To be specific individuals with moderate to moderately severe and severe hearing loss committed significantly more errors than mild hearing loss group. This can be explained with the help of travelling wave propagation mechanism. The basilar membrane is stiffer at base and relatively flaccid at apical end, travelling wave usually propagates from base to apex. It takes at least 5 to 9 ms for the travelling wave to reach point of maximum amplitude along the basilar membrane in response to low frequency stimuli. Normal travelling wave propagation mechanism is majorly depends on the nonlinear mechanics of the cochlea, where sharp frequency tuning was mediated by healthy functioning outer hair cells. Damage to outer hair cell causes disturbance in the nonlinear mechanics of cochlea which in turn affects travelling wave propagation mechanism. When the traveling wave propagation is affected, ITD cues are not efficiently coded, leading to errors in locating the low frequency sounds. Extent of damage to cochlea increases as degree of hearing loss and causes a failure in retrieving the ITD cues (Ruggero, 1994) which was reflected in positive correlation between degree of error and hearing loss. Further, precision in phase locking is affected in individuals with cochlear hearing loss also leads to the impaired ITD discrimination (Hawkins & Wightman, 1980; Noble, Byrne, Lepage, & Byrne, 1994). In addition, the dual task paradigm taxes both auditory and cognitive systems. The effort invested by auditory system to perform localization task is relatively more with increased degree of hearing loss and left with small resource available to do the cognitive task. Thus, in the present study the cognitive correct scores was reduced and its reaction increased with degree of hearing loss. The result of the study is in consonance with the reports of Lin et al., 2013; Lin et al., 2004; Lindenberger and Baltes, 1994; Ulhmann et al., 1989; Tay et al., 2006; Baltes and Lindenberger, (1997), who have reported hearing loss and cognition are associated, with increase in hearing impairment more effort required to perform the task and eventually leads to error.

It was observed that there was no significant change in the degree of error between unaided and aided conditions. Hearing aids restores audibility but unable to overcome effects of the distorted physiological mechanism observed in SNHL. Restoring the audibility might not necessarily improve the localization ability as distortion in the auditory system still persists. Thus, one may not expect restoration of localization abilities to the normal extent with the usage of hearing aid. Further, additional delay induced by the hearing aid by its signal processing strategies might distort the original ITD cues of the incoming signal. (Kuk & Korhonen, 2014). In addition, deprivation of auditory stimulation in individuals with hearing impairment would have developed some alternative compensatory strategies (e.g. head and body movements, visual searching) to locate the sound source. In addition, brain should undergo malleability to interpret the newly amplified signal till it retrain and put it in auditory memory. Whereas, in the present study the naïve hearing aid users are involved who were, exposed to the novel sound in which they failed to improve their localization ability in aided condition over unaided condition. Further, the microphone location effect might be a contributing factor for poor performance in localization. In the present study aided performance on localization was evaluated using behind the ear (BTE) hearing aid. Usually microphones are kept away from the eardrum in BTE hearing aids which influences the original ITD cues. The front microphone placement results in a distortion of ITD information at −90°and +90°, which could have affected localization performance (Bogaert et al., 2008). In addition, performance of participants of the clinical group on traffic sign cognitive abilities were significantly better in aided condition when compared to unaided condition. Individuals took relatively lesser time to perform the cognitive task and scored better than unaided condition which was found to be significant. The reason could be, wearing a hearing aid offers improved signal to noise ratio led to reduced listening effort (Downs, 1982 & Dillon, 2008). The available cognitive resource was effectively used in dual task when signal was amplified and lessen the effort driven to both tasks.

In India aided thresholds within the speech spectrum is considered as eligible criteria to provide hearing fitness certificate for those who seek to apply for driving license. However, the present study results showed that though the aided threshold was with in speech spectrum, localization ability did not improve and cognitive abilities did not match the control group. It questions the eligibility criteria of those individuals with hearing impaired who were tested with aided audiogram. This is because locating the sound source is the utmost important factor while driving which is significant for safe driving. Moreover, merely hearing to sound does not result in localization. In addition to localization, traffic sign cognitive abilities are also influential for safe driving. Individuals with hearing impairment would not process the traffic signs as efficiently as normal hearing individuals which might lead to complications while driving. Thus, the findings of the present study insist to add the localization and cognitive tasks in the test battery to decide the eligibility criteria for hearing impairment individuals who seeks hearing fitness certificate for applying driving license. A regression model was established where the degree of error, traffic sign cognitive scores and its average reaction time were predicted from pure tone average by the equation $y=a + bx$. For example, if individual has a hearing loss of 50dBHL, then the predicted degree of error, traffic sign cognitive score and its average time would be 29.245 (R^2=0.666; a=5.995; b=0.465), 13.197(R^2=0.510; a=17.747; b=-0.091) and 3372.071ms (R^2=.0505;a=2222.071;b=23) respectively. Thus, with this equation one can predict localization error and cognitive scores from their hearing ability rather just rely on aided audiogram to provide hearing fitness certificate.

Chapter 6

SUMMARY AND CONCLUSION

In the present day clinical scenario aided audiogram in quite condition is used as the standard protocol to assess hearing status for those individuals with hearing impairment who seeks for hearing fitness certificate to apply for driving license. Locating sound source and processing the traffic sign informations are the vital factors for safe driving. Hearing sound just through hearing aid does not merely help to localize the sound source. In this view assessing localization and cognitive tasks in simulated traffic environment closely matches realistic environment. Thus, the present study investigated localization and traffic sign cognitive abilities in individuals with hearing impairment in a simulated road traffic environment.

Fourty participants with age ranging from 40-60 years were recruited in the study where they were divided into control group and clinical group. Control group consisted of ten individuals whose hearing sensitivity was within normal limits and clinical group was comprised of thirty individuals with hearing impairment. Further, clinical group was divide into three groups based on degree of hearing loss i.e. mild hearing loss, moderate hearing to moderately severe loss and severe hearing loss. Each subgroup was consisted of ten participants. Assessment of localization and traffic sign cognitive ability were assessed in individuals with hearing impairment in. unaided and aided conditions. In localization task, each participant was instructed to locate the low frequency horn which was presented at 100dB SPL from the rare side in the presence of traffic noise at 65 dB SPL. A degree of localization error was computed. In addition, randomly cognitive road traffic sign stimuli were presented in pseudo random order. The correct score and its reaction time were documented. Results revealed that, in the unaided condition, the degree of error was significantly increased in the clinical group. In cochlear pathology, frequency tuning properties of basilar membrane is affected due to the loss of outer hair cells. Since the physiology of basilar membrane is altered, it will affect the traveling wave propagation. Alteration in travelling wave propagation affects the efficient coding of ITD cues. There might be also alteration in the coding of neural impulses for ITD cues leading to more error when localizing the sound source. In addition, degree of error increased as degree of hearing loss increased where, Moderate to moderately severe and severe hearing loss group committed more errors than mild hearing loss group. On the other hand, there was a significant decrease in the traffic sign cognitive correct scores in clinical group than control group Participants of clinical group took relatively longer time to perform traffic sign cognitive task. This could be because of limited cognitive resource available to perform traffic sign cognition task as additional listening effort exerted on individuals with hearing impairment while performing localization task

In spite of providing the appropriate gain to the individuals with hearing impairment, the localization ability did not improve significantly. Distortion caused by the sensorineural hearing loss still persist even after restoring audibility. Microphone placement effect, additional delay induced by hearing aid signal processing might hinder improvement in localization ability even after aiding. However, traffic sign cognitive scores and its average reaction time improved in the aided condition, this might be due to reduced the listening effort. Further, pure tone average was correlated with degree of error, traffic sign cognitive score and its average reaction time. As the degree of hearing loss increased, degree of error and average reaction time to perform the cognitive task also increased. Whereas traffic sign cognitive correct scores decreased as the hearing loss increased. Similar results were also replicated in the aided condition

Though the aided audiogram was observed within speech spectrum, the degree of localization error increased with degree of hearing impairment. Further, a significant reduced cognitive score and its increased reaction time were observed with degree of hearing loss. Thus, the results suggests to incorporate the assessment of localization abilities and traffic sign cognitive ability rather than aided audiogram to certify the hearing status for the purpose of applying driving license.

Implications of the study

In addition to aided audiogram, the findings of the study suggests to include the localization and cognitive tasks in the test battery when applicant seeks the certificate of hearing status for the purpose of obtaining driving license.

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