A Study On Simulated Traffic Environment: Assessing Localization Ability From Individuals With Hearing Impairment

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Abstract

The present study was taken up to examine localization ability from subjective and objective methods in a simulated road traffic environment. The objectives were formulated as follows: a) To compare the localization errors between ages matched control group and clinical groups b) To assess the localization function index using a standardized questionnaire from control and clinical groups c) To correlate and predict degree of error and localization function index with the audiological findings of participants of the study d) To find the relation between existing protocols in clinic with the adopted test utilized in the current study. Forty participants within age range from 40 to 60 years were involved in the study. The participants were grouped into two groups namely control group and clinical group. Control group comprised of ten participants and all of them had normal hearing sensitivity. Clinical group were sub grouped into three, based on severity of hearing loss i.e. moderate to moderately severe hearing loss 40 to 70 dB HL (mean HL = 61.25 dB HL) (subgroup-1); severe hearing loss 70 to 90 dB HL (mean HL = 77.5 dB HL) (subgroup-2) and profound hearing loss > 90 dB HL (mean HL = 100 dB HL) (subgroup-3). Each subgroup comprised of ten participants. The participants were fitted binaurally with the digital BTE hearing aids. The target stimuli (Truck horn and automobile horn) were presented from five speakers and traffic noise (65 dB SPL and 75 dB SPL) was presented from four speakers as background noise to simulate traffic situation. The localization errors for each horn presented in low and high noise levels were assessed. In addition, localization functional index using the standard questionnaire was obtained from the participants of the study. Further aided SIS and aided audiogram were assessed in binaural condition. The results revealed a degree of localization error; LFI and SIS were significantly reduced with increase in degree of hearing loss. Further localization error significantly reduced with high noise level than low noise level. LFI and DOE were significantly correlated with audiological findings. To be specific, LFI decreased with increased degree of hearing loss; and hearing disability. In addition, LFI decreased with reduced SIS. Further, DOE increased with reduced localization functional index. A regression model was established through which DOE, LFI were predicted from the audiological findings. Interestingly, irrespective of degree of hearing loss, aided thresholds were within speech spectrum. The findings suggests to include localization test to identify degree of localization error instead of considering aided thresholds within speech spectrum for those individuals who seeks a hearing fitness certificate for the purpose of applying driving license. The findings of the study suggests to include localization test in a simulated road traffic condition rather aided audiogram in the present day protocol to issue hearing fitness certificate for hearing impaired individuals who seek for applying driving license. However, the eligibility criteria to issue certificate of hearing fitness for applying driving license is yet to be decided in the upcoming studies.

Key words: Hearing loss, Localization, Degree of error

Introduction

In India, a total of 18.9 % of population are hearing impaired from 2.21 % of total disabled population (NSSO-2011). Hearing impairment is found to be positioned first among other disabilities. According to Section 2(i)(iv) of the persons with Disability Act, 2016, (PWD) states that hearing disabled person is one who has the hearing loss of 60 dB or more in the better ear for conversational range of frequencies. A consequence of hearing loss can reduce traffic safety. Schmolz (1987) reported that hearing function is important while riding vehicle. It is known fact that although visual information place high demand while riding, hearing ability is partly involved in it (Henderson & Burg, 1974). A research report by Lundalv (2004) who stated that adult pedestrians and cyclists with moderate hearing loss are at a higher risk of being injured by a vehicle because they find it difficult to identify the direction of potential hazards. Thus, the majority of the states impose a few restrictions on the licensing of persons with hearing impairments for automobile driving. However, there has been a long history of concern about licensing to drive on people who cannot hear. To report a few, In United States, issuance of commercial license is prohibited if the hearing loss is worse than 40 dB or individual is unable to hear whispered speech at 5 feet. Contradictory to the previous statement a study by Sackey (2015) who had reported that deaf drivers drove better than normal hearing counterparts because they respected road safety regulations and used rear mirrors more effectively and use their other senses well to compensate the hearing loss. This is an equivocal response to issue driving license to the individual's with hearing disability and moreover there is no appropriate test to assess ability in road traffic condition. Whereas, in India, the issue on driving licensing to hearing impaired has received relatively little attention in the literature. Recently, in

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2011 Delhi high court has permitted deaf persons are entitled to receive driving license after passing a driving test. Till date, there is no standardized test to assess their hearing ability, especially in road traffic condition. In India the present scenario, aided threshold in quiet condition is obtained for the sounds presented at 0 degree azimuth. If the aided thresholds are within the speech spectrum then hearing fitness certificate has been provided to individual with hearing impairment who seek to apply for driving license. Unfortunately this test does not quantify the hearing ability in a realistic traffic noise condition because visual cues provide cue on potential hazardous source when the incidence of sound energy is from 0 degree azimuth. Localization of sounds coming from rear side is of utmost important especially in a background traffic noise conditions rather the lowest level at which a person can detect the sound. The above explained fact is in consonance with research study conducted by Yokoyama et al., (2014) who reported that hearing impaired individuals finds it difficult to locate the direction of the vehicle horn or siren of ambulance while driving vehicle. In addition, Hausler et al., (1983) reported that hearing-impaired listeners have reduced performance on binaural functioning tasks. For instance localization in everyday environment is important to make the person hear from which direction sound is coming. Localization is basically locating a sound source by utilizing interaural time difference (ITD) and interaural level difference (ILD) cues. Thus, in the present study, a standardized test protocol is adopted to assess localization ability for the horn sounds delivered from rear directions in the presence of traffic noise. Further, a localization error is computed from localization task (Ching, Incerti& Hill, 2004) on cohort of hearing impaired population who were classified based on severity of hearing loss.

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

Method

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

Phase-1. Experiment to objectively assess localization ability

Phase-2. Qualitative measures to assess the localization ability

3.1. Participants

Forty participants within age range of 40 to 60 years (mean age =50.67) were recruited in the study. The participants were grouped into two groups namely control group and clinical group. Control group comprised of ten participants and clinical group comprised of thirty participants. Further the participants in the clinical group were sub grouped into three based on severity of hearing loss i.e. moderate to moderately severe hearing loss 40 to 70 dB HL (mean HL = 61.25 dB HL) (subgroup-1); severe hearing loss 70 to 90 dB

HL (mean HL = 77.5 dB HL) (subgroup-2) and profound hearing loss > 90 dB HL (mean HL = 100 dB HL) (subgroup-3). Figure 3.1. Audiogram of each participant of control and clinical groups. A) Participants of normal hearing, B) moderate group to moderately severe, C) severe group and D) profound group. Each subgroup comprised of ten participants. Those participants in each clinical group who have been diagnosed as bilateral symmetrical sensorineural hearing loss and had either no prior experience or experienced with hearing aid usage were included in the study. As a prerequisite for the present study all the participants involved were required to know riding a low motor vehicle. Participants with any history or presence of middle ear disorders, neurological involvement, and any history or presence of psychological problems were excluded from the study.

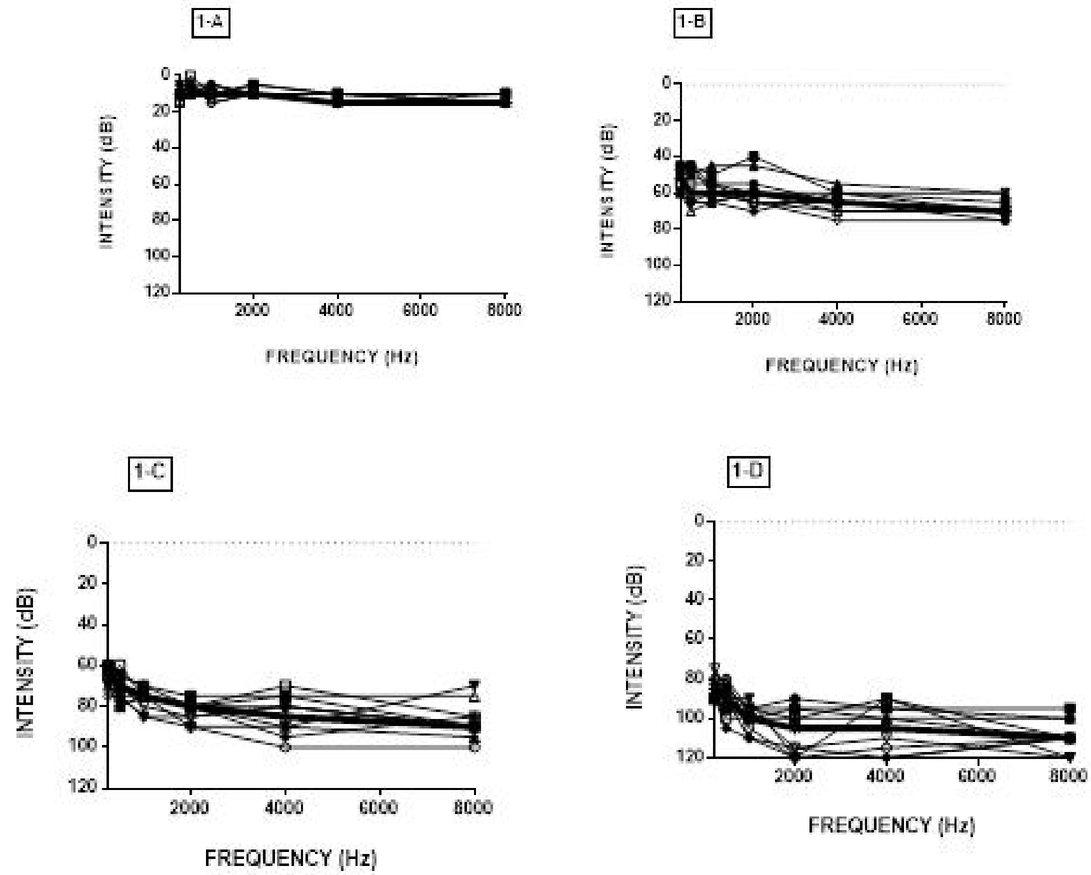


Figure 3.1. Audiogram of each participant of control and clinical groups.

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

3.2. Instruments

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

3.3. Test Environment

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

3.4. Stimuli

The following stimuli were used for localization task Truck horns having the center frequency of around 150 Hz at 110 dB SPL and automobile horn with the center frequency of around 350 Hz at 100 dB SPL were used as the target stimuli. The recorded traffic noise at 65 dB SPL (Average traffic noise) and 75 dB SPL (peak hour traffic noise) (Sreeraj 2016, ongoing ARF project) were utilized as background noise which is used to simulate traffic condition in a more realistic situation.

3.5. Procedure

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

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

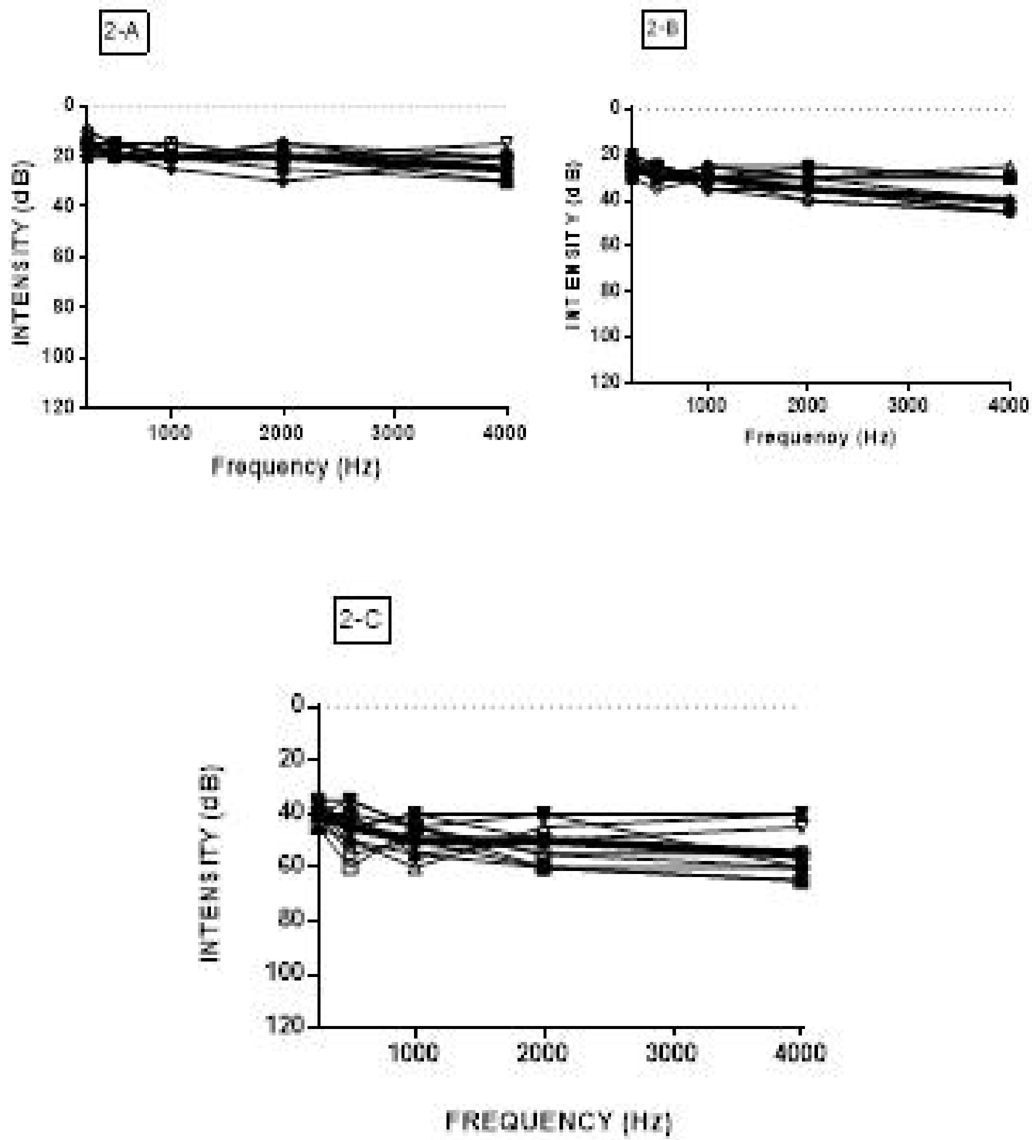


Figure 3.2. Aided Audiogram of each participant of clinical groups. 2A) Moderate group to moderately severe group 2 B) severe group and 2 C) profound group. A thin line represents aided thresholds at each frequency. The solid thick line depicts the average aided threshold at each frequency.

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

3.5.2.1. Calibration of the stimulus. Calibration was done in a sound treated room wherein the target stimuli (truck and the automobile horn) and noise stimuli (recorded traffic noise) from the assigned loudspeakers were calibrated using Bruel and Kjaer hand held (model no. 2270) sound level meter mounted on a Tri-PodTM (Isolation position/ or decoupler) vibration insulating table stand with a half inch free field microphone (serial no: 02616511). The microphone of the SLM was placed at the position corresponding to the center of the head at the height of one meter. A total of nine loudspeakers were used (Genelec 8020B) covering 00 to 3600 azimuth which were connected to Lynux Aurora sound signal router. The stimulus and intensity level assigned to each speaker were delivered through Cubase 6 software with Lynx aurora signal router. Five loudspeakers at specified azimuth from which the target stimuli 150 Hz and 350 Hz horn sounds were calibrated to deliver 110 dB SPL and 100 dB SPL respectively. However, four loudspeakers from which traffic noise were delivered were calibrated for the two levels of intensities 65 dB SPL and 75 dB SPL. It was made sure that intensity level read on the SLM was exactly mapped to the desired intensity by varying the volume control in Cubase 6 software.

3.5.2.2. Setup: Each participant was seated in a sound-treated room. It was made sure that center of the head of each participant was equidistant from each loudspeaker (2 meters away from the center). Stimulus presentation set up is depicted in Figure-3. The localization task was carried out using nine loudspeakers (Genelac 8020B) arranged in a circle located at different degree of azimuth, which covers stimuli presentation from 00 to 3600. The target stimuli were presented through five loudspeakers at 900, 1400, 1800, 2200 and 2700 azimuth. A continuous traffic noise was presented through four loudspeakers kept at 400, 1200, 2400 and 3200 azimuth.

3.5.2.3. Stimuli:

The target stimuli having center frequency 150 Hz at 110 dB SPL and 350 Hz at 100 dB SPL horn sounds were delivered randomly to the assigned loudspeakers through Cubase 6 software loaded in a personal computer to which Lynx aurora signal router was connected. A continuous traffic noise was presented through four loudspeakers kept at 400, 1200, 2400 and 3200 azimuth. Degree of error was computed for each loudspeaker and overall loudspeakers for two stimuli at two different SNRs i.e., 65 dB SPL and 75 dB SPL.

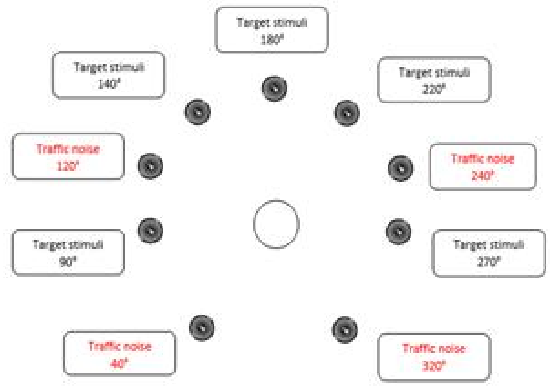


Figure 3.3. Arrangement of loudspeakers and stimuli assignment to determine localization ability from participants of the study.

3.5.2.4. Testing phase:

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

From each participant of control and clinical groups at each SNR DOE for each loudspeaker and overall loudspeaker were obtained. Degree of Error was computed by the adopted procedure of Ching, Incerti & Hill (2004). Degree of Error (DOE) was calculated separately for each loudspeaker. DOE corresponds to the difference in the degree of azimuth between the loudspeaker from which the target stimuli was presented and the loudspeaker to which the participants points to. For example, if the target stimulus was presented through second loudspeaker (450) and participant points it to 5th loudspeaker (1800) then the degree of error is 1350 (180 0- 450). The calculated degree of error was squared. DOE2 calculated for five iterations in each speaker were summated and then divided by number of stimulus presented. The average DOE2 computed for five speakers were summated and divided by number of speakers used to present the stimuli. The resultant value was square rooted to obtain the degree of localization error. Similar procedure was used to identify DOE for each horn presented at two different SNRs.

Degree of error was calculated using the following formula.

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

DOE1: Degree of error in the speaker no. 1

DEOn: Degree of error in the nth number of speaker

RMS: Root Mean Square

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

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

The Localization Handicap Index (LHI) (Hemanth et al, still ongoing) consisting of 16 questions were administered on each participant of both control and clinical groups. The questionnaire majorly focused on the localization ability of the person in indoor and outdoor conditions. The participants were instructed to rate each question on a 3 point rating scale where, Almost never, Sometimes, Almost always.

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

3.6. Statistical analyses

The following data were subjected to statistical analysis using the SPSS (Statistical package for social science) software version 20.Descriptive statistics was carried out to account mean and standard deviation of localization errors obtained from horns (Track 150 Hz and Automobile 350 Hz) presented at two different SNRs (65 dB SNR and 75 dB SNR).Two way repeated measures analyses of variance (ANOVA) with between subject factor as groups (based on hearing loss) was performed to see if there is a significant main effect and an interaction effect of horn and SNR on degree of localization error.One way ANOVA and Post Hoc Duncan test were performed separately in each SNR to inspect in which group have caused significance difference on degree of localization error. Independent samples t-test was performed to assess localization error difference between SNRs for each group.One way ANOVA and Post Hoc Duncan test were performed on LHI and SIS to investigate in which group have caused significance difference. Pearson Correlation was carried out to find the relation between localization functional indexes, degree of localization error and audiological findings from participants of the study.

Regression model was drawn in which localization functional index and degree of localization error was predicted from audiological findings.

Results

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

4.1. Localization ability across hearing loss and SNR

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

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

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

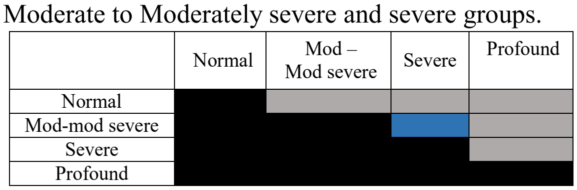
Further a two way repeated measures (SNR (2)* Horns (2)) analyses of variance (ANOVA) with between subject factor as groups (Control group and Clinical groups (Moderate to Moderately Severe, Severe and Profound)) was performed to see if there is a significant main effect and an interaction effect on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

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

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

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

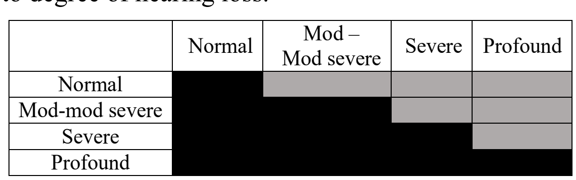
Further, a one way ANOVA was performed separately in each SNR to inspect group having caused significant differences on degree of localization error. This was done as there was a significant main effect of SNR and group on two way repeated measures. The result of one way ANOVA showed that with increase in degree of hearing loss a significant increase in localization error was found in both 65 dB SNR [F (3, 79) = 76.088, p ?0.001] and 75 dB SNR [F (3, 79) = 154.007, p ?0.001]. Further, a Post Hoc Duncan test was performed separately for each SNR on the data of degree of localization obtained from four groups. From Figure 4.1. the results of the Duncan post hoc test for 65 dB SNR showed a significant difference between control group and each clinical group (<0.05) on degree of localization error. There was also significant difference noted between moderate to moderately severe group and profound group indicating that degree of localization error increased with increase in hearing loss (<0.05). In addition, there was a significant difference noted between severe group and profound group on degree of localization error. Though the degree of localization error increased with degree of hearing loss, its mean difference did not reach significant between Moderate to Moderately severe and severe groups.



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

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

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



Note: Grey area= significant difference

Figure 4.2. Duncan test results showing significant difference between each group for 75 dB SNR In addition, a significant difference was observed in the

interaction effect of SNR*group on localization error. Hence, an independent sample t-test was performed to assess localization error difference between SNRs for each group. The mean and standard deviation of degree of error for two different SNRs in each group is shown in the Figure 4.3.

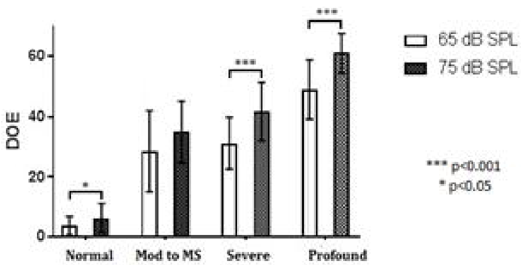


Figure 4.3. Mean and standard deviation of degree of error for different SNRs in each group

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

4.2. Localization functional index and aided speech identification score.

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

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

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

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

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

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

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

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

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

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

4.3.1. Relation between LFI and DOE. The results of Pearson correlation showed there was a significant negative correlation between LFI and DOE for each SNR and type of horn. It indicates that, in each condition, as the degree of error increased there was a significant decrease in localization functional index. Further, a linear regression was drawn to predict the LFI from degree of error for each SNR and type of horn. The best regression line was fitted in scatter plot for each condition as shown in Figure 4.6. The correlation values between LFI and DOE and regression values in predicting the LFI from DOE for each condition is shown in Table 4.3. and Table 4.4.

Table 4.3. The correlation values between LFI and DOE

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

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

Table 4.4. Regression values in predicting the LFI from DOE for each condition

DOE in each condition (N=40)	R^2	a	b
Automobile 65 dB SNR	0.333	-0.601	78.48
Truck 65 dB SNR	0.454	-0.741	82.356
Automobile 75 dB SNR	0.434	-0.647	85.542
Truck 75 dB SNR	0.500	-0.639	83.876

Note; a= Intersection; b = slope

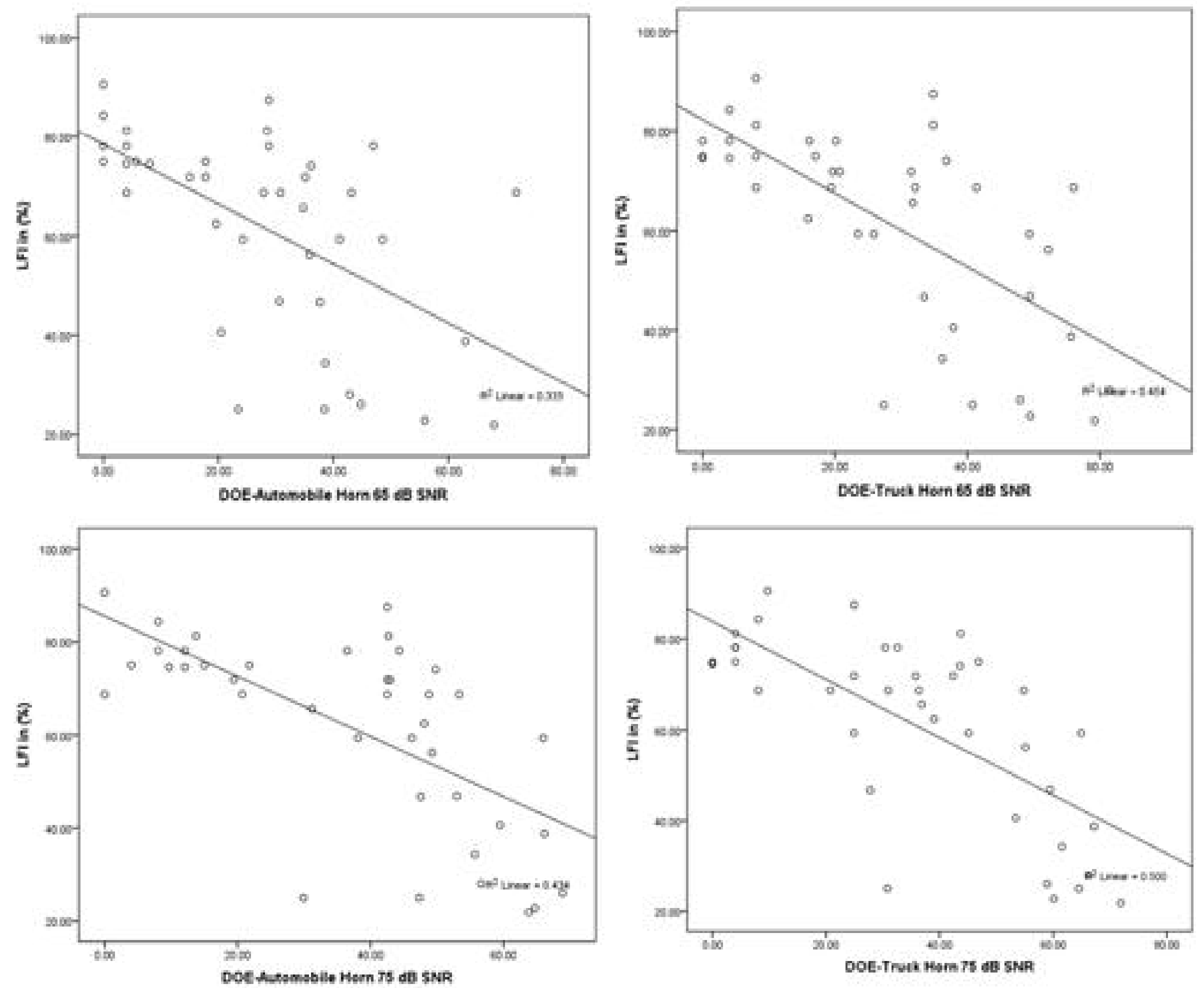


Figure 4.6. A linear regression drawn with measured data and mean of the predicted data for LFI and DOE on a scatter plot for each condition. The predicted data shows that with increase in degree of error there is decrease in localization functional index linearly.

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

4.3.2. 1. Relation between localization functional index and pure tone average. The results of Pearson correlation showed there was a significant negative correlation between LFI and PTA. It indicates that localization functional index reduced as the hearing loss increased (N=40, r = -0.710, p =0.000). Further, a linear regression was drawn to predict the LFI from PTA as shown in Figure 4.7. Equation y = a (x) +b (r2 =0.504; a = -0.417; b = 87.31) was obtained to predict LFI from PTA. It indicates that with a 0 dB HL the localization functional index predicted to be 87. 31 %. Further, a 1 dB increase in threshold leads to reduction in localization function index by 0.41 (in %).

4.3.2.2. Localization functional index and aided speech identification scores The results of Pearson correlation showed there was a significant positive correlation between LFI and SIS, indicating that LFI scores are

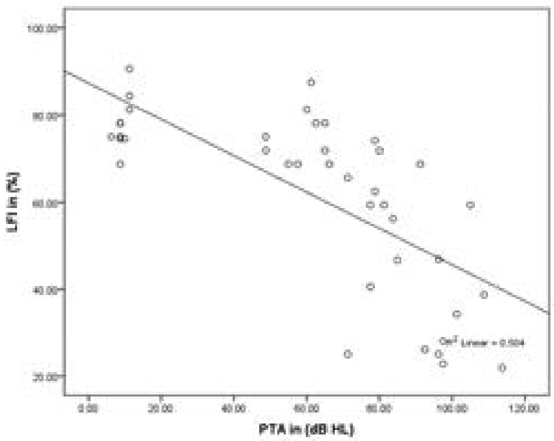


Figure 4.7. Linear regression drawn with measured data and mean of the predicted data for LFI and PTA on a scatter plot. The predicted data shows that with increase in pure tone average (dB) there is a decrease in localization functional index linearly.

better with increase in the SIS scores (N= 40, r= 0.842, p=0.000). A linear regression was drawn to predict the LFI from SIS as shown in Figure 4.8. Equation y = a (x) +b (r2 =0.710; a = 1.006; b = -17.54) was obtained to predict LFI from SIS scores. It indicates localization function index increased by 1% with a 1 % increase in SIS score.

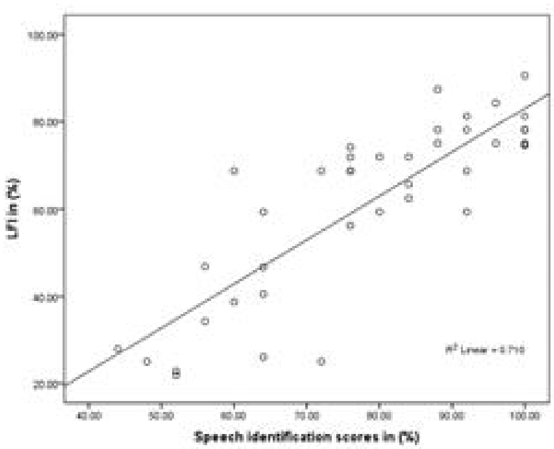


Figure 4.8. Linear regression drawn with measured data and mean of the predicted data for LFI and SIS on a scatter plot. The predicted data shows that with increase in SIS there is a increase in localization functional index linearly.

4.3.2.3. Localization functional index and hearing disability. The results of Pearson correlation showed there was a significant negative correlation between LFI and hearing disability (N=30, r= -0.731, p?0.001). It indicates, LFI reduces with increase in hearing disability. Further a linear regression was drawn to predict the LFI from hearing disability as shown in Figure 4.9. Equation y=a (x) +b (r2 =0.535; a = -0.514; b = 100.618) was obtained to predict LFI from hearing disability. It indicates that with a 0 dB disability the localization functional index predicted to be 100 %. Further, a 1 % increase in hearing disability leads to reduction in localization function index by 0.51 %.

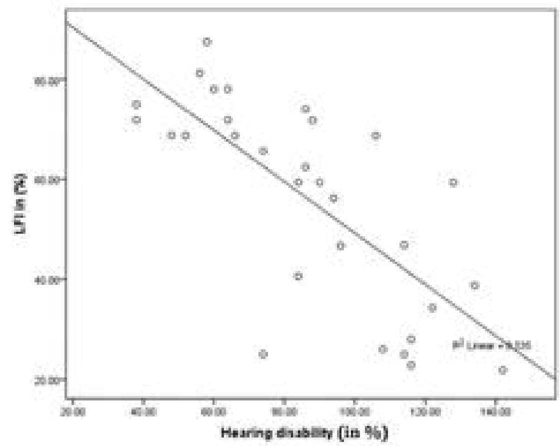


Figure 4.9. Linear regression drawn with measured data and mean of the predicted data for LFI and hearing disability on a scatter plot. The predicted data shows that with increase in hearing disability there is decrease in localization functional index linearly.

4.3.3. Relation between pure tone average and degree of error. The results of Pearson correlation showed there was a significant positive correlation between PTA and DOE for each type of horn and SNR (Table4.5.). The results show that with increase hearing loss the DOE in the localization task also increases. Further a linear regression was drawn to predict the DOE from pure tone average as shown in Figure 4.10. A linear equation y=a (x) +b was obtained to predict the DOE from pure tone average. Where y is the degree of error, x is the pure tone average, 'a' is the intersection and 'b' is the slope of regression line. The best regression line was fitted in scatter plot for each condition as shown in Figure-12. The correlation values between PTA and DOE and its regression values in predicting the DOE from PTA for each condition is shown in Table 4.5.

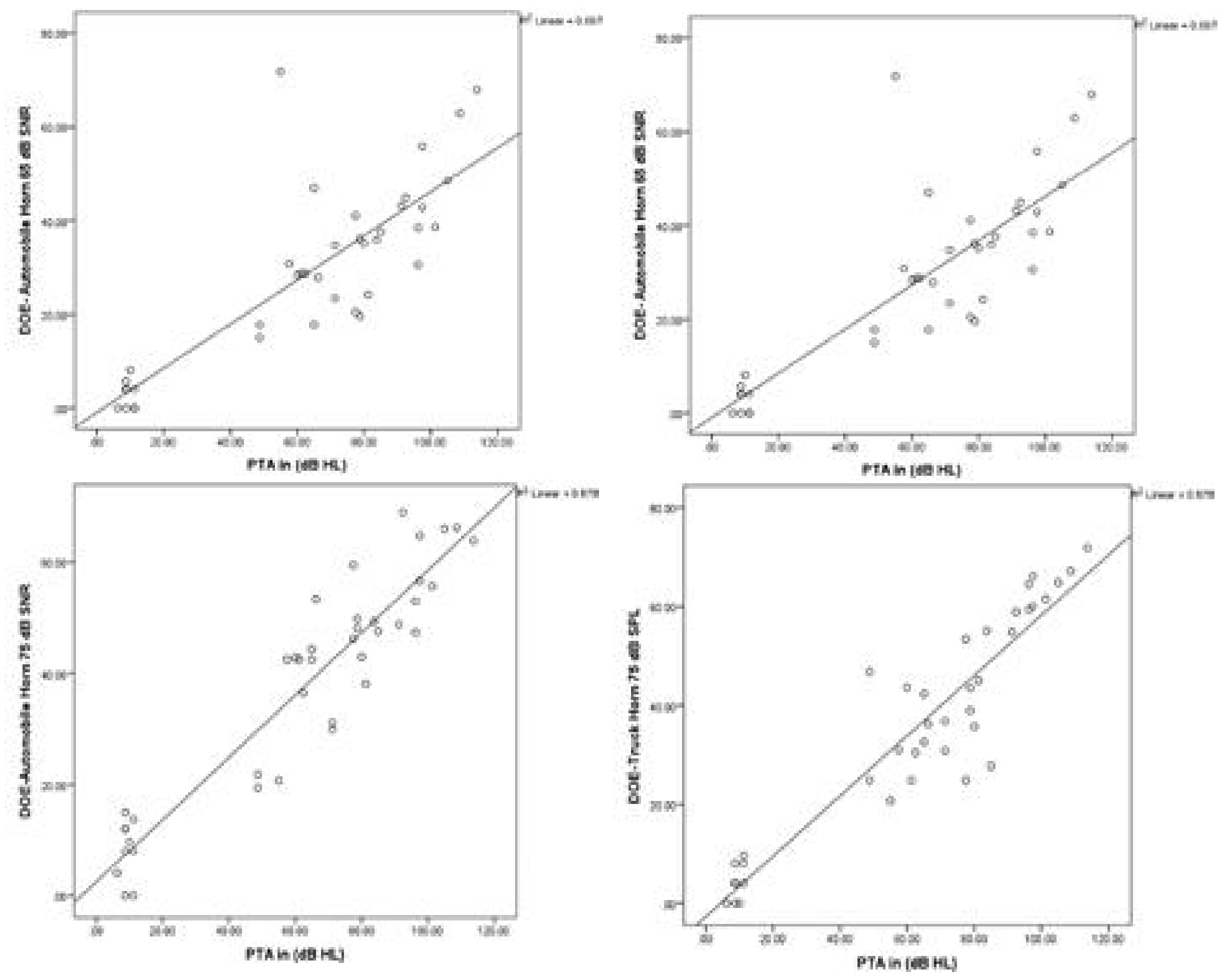
Figure 4.10. Linear regression drawn with measured data and mean of the predicted data for PTA and DOE on a scatter plot for each condition. The predicted data shows that with increase in pure tone average there is increase in degree of error linearly.

To summarize, a significant increase in degree of error was observed with the degree of hearing loss. In addition, the degree of error increased with reduced

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

Horn	r	p	R^2	a	b
Automobile 65 dB SNR	0.835	0.000	0.697	0.471	-0.907
Truck 65 dB SNR	0.896	0.000	0.804	0.479	-1.491
Automobile 75 dB SNR	0.937	0.000	0.878	0.561	-2.470
Truck 75 dB SNR	0.937	0.000	0.878	0.618	-2.693

Note; a= Intersection; b = slope



SNR. The localization functional index and SIS were decreased with increased in degree of hearing loss. Further, there was a significant correlation between localization functional index, degree of localization error and audiological findings. Regression model was drawn through which LFI; and degree of error was predicted from each audiological finding.

DISCUSSION

The study aimed to investigate localization ability in hearing impaired individuals from subjective and objective methods in a simulated road traffic environment. The localization errors and localization functional index using the standard questionnaire were obtained from the age matched control group and clinical groups. Though the audibility was corrected by providing appropriate gain from hearing aid the findings of DOE, LFI and SIS from each of the clinical group was significantly reduced than control group. The reason could be that output from hearing aids delivered to both ears were almost same, there by reduced a level difference between ears. Moreover, ITD is a cue for localizing a sound which gets annulled when presented at 40 dB SL (David and Stephens, 1974), as in the presented study low frequency horn sounds are presented at the 110 and 110 dB SPL. However, there could be a mixture of unamplified sound and amplified sound leading to a confusion in localization as the study participants had a good reasonable low frequency hearing. This confusion results in distortion of interaural time difference as the small delay induced, when the sound is processed through the hearing aid may result in different phase between unaided and aided sounds.Thus, neurons at auditory brainstem would have failed to effectively interact an aided signal leading to suboptimal representation of available cues. In addition, it was noted that DOE and LFI were significantly reduced with increase in degree of hearing loss based on which clinical groups were made. This is because hearing loss produces a neural distortion in interaction of two sounds between ears, which is directly proportional to the increased degree of hearing loss. This infers that amplification may not restore localization to the normal level. Further, as expected the DOE found to be significantly reduced in low level of noise than high level of noise and this was true in each control and clinical groups. This could be because binaurally making noise might have released from short of signal presented at different azimuth. This phenomenon is relatively less with increased noise level. It was found that in United States, passing in the standardized whisper test administered at 5 feet or average hearing loss in the better ear greater than 40 decibels (500 Hz, 1,000 Hz, and 2,000 Hz) with or without a hearing aid are the criteria for those applicant seek to certificate of hearing status for driving license. However, in India, aided thresholds within speech audiogram is found to be a pass criterion to certify hearing status for driving license. It is known fact that hearing is of utmost importance for driving other than visual information. Moreover rather than hearing a sound merely does not result in sound localization which is most important for safe driving. The test administered and the criteria utilized in the current scenario are in contrast to the subjective and objective findings of the present study. It was found that localization handicap index was reduced with increased degree of hearing loss; reduced speech identification score; and increased hearing disability respectively. This indicates that the hearing loss is specifically linked to localization disability. However, there is a high chance that individuals with hearing impairment might deny to have localization disability when questionnaire is administered. Thus, a regression model was established, wherein using localization functional index can be predicted from any audiological findings by a linear formula $y = ax + b$ ($r2 = 0.504$; $a = -0.417$; $b = 87.31$). To illustrate, if the hearing loss is 60 dB then localization function index predicted to be 62.29 %. Likewise, we can predict the LFI from hearing disability and speech identification scores. Further, to substantiate the above finings an objective degree of localization error test was administered and correlated with pure tone average. It was found that degree of error was significantly reduced with increased degree of hearing loss and this finding was true in each horn presented at 65 dB SPL and 75 dB SPL. In addition, degree of error was successfully predicted from pure tone average (Table 4.5.). Further, it was observed that a strong negative correlation between DOE and LHI. Localization function index reduced with increase in degree of hearing loss and it is successfully predicted using linear regression model. It suggests that both subjective and objective tests used in the present study compliments to each other to identify localization difficulty. Interesting part is irrespective of degree of hearing loss the aided thresholds were with in speech spectrum (Figure 3.2). Thus, this study recommends localization test to be included rather than aided audiogram to issue the certificate of hearing status.

Implication of the study

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

Limitation

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

SUMMARY AND CONCLUSION

Aided audiogram was used in the present day test protocol to certify hearing status required for driving license. Hearing a sound with amplification does not merely help in localization. Locating a sound source is found to be important skill while driving. Considering the safety regards of hearing impaired individuals the present study was undertaken with the aim of investigating localization ability in hearing impaired individuals from subjective and objective methods in a simulated road traffic environment. Forty participants within age range from 40 to 60 years were recruited in the study. The participants were grouped into two groups namely control group and clinical group. Control group comprised of ten participants and clinical group comprised of thirty participants. Further the participants in the clinical group were sub grouped into three based on severity of hearing loss i.e. moderate to moderately severe hearing loss 40 to 70 dB HL (subgroup-1); severe hearing loss 70 to 90 dB HL (subgroup-2) and profound hearing loss > 90 dB HL (subgroup-3). Each subgroup comprised of ten participants. The participants were fitted with the digital BTE hearing aid. The target stimuli (Truck horn and automobile horn) were presented from five speakers and the recorded traffic noise (65 dB SPL and 75 dB SPL) were presented at four speakers as background noise to simulate traffic situation. The degree of localization error was assessed from two horns presented at 65 dB SPL and 75 dB SPL. In addition, localization functional index was obtained the study participants. Further, aided pure tone thresholds and aided speech identification scores were obtained apart from audiological evaluation. The findings of the present study revealed that degree of error; LFI and SIS were significantly increased with degree of hearing loss. The reason could be neural distortion at the lower auditory brainstem has failed to integrate the inputs from two ears. It happened as the ITD was nullified due to high input intensity. Further, mixture of unaided and aided sounds led to distortion of the interaural time difference as the study participants had a good low frequency hearing. In addition, degree of error dramatically reduced with increase in noise level. In correlation and regression analyses it was found that LFI was strong negatively correlated and predicted with the pure tone thresholds; speech identification; and hearing disability. Further, DOE was positively correlated and predicted with degree of hearing loss and it was true in each horn presented at 65 dB SPL and 75 dB SPL. Interestingly, the aided threshold was within speech spectrum. It infers that localization error increased with increase in degree of hearing loss; reduced localization function index. Unfortunately, irrespective of hearing loss, the aided thresholds were with in speech spectrum. The findings suggest audiologists to assess degree of localization error rather than aided audiogram to certify the hearing status for the purpose of obtaining driving license.

REFERENCES

Appollonio, I., Carabellese, C., Frattola, L., & Trabucchi, M. (1996). Effects of sensory aids on the quality of life and mortality of elderly people: a multivariate analysis. Age and ageing, 25(2), 89-96.

Austroads and the National Transport Commission Australia (2014). Assessing Fitness to Drive for Commercial and Private Vehicle Drivers. Online.

Burch, S. (2004). Signs of resistance: American deaf cultural history, 1900 to World War II. NYU Press.

Bernstein, L. R., & Trahiotis, C. (1982). Detection of interaural delay in high?frequency noise. The Journal of the Acoustical Society of America, 71(1), 147-152.

Blauert, J. (1969). Sound localization in the median plane. Acta Acustica united with Acustica, 22(4), 205-213.

Brungart, D. S., Durlach, N. I., & Rabinowitz, W. M. (1999). Auditory localization of nearby sources. II. Localization of a broadband source. The Journal of the Acoustical Society of America, 106(4), 1956-1968.

Cacciatore, F., Napoli, C., Abete, P., Marciano, E., Triassi, M., & Rengo, F. (1999). Quality of life determinants and hearing function in an elderly population: Osservatorio Geriatrico Campano Study Group. Gerontology, 45(6), 323-328.

Coppin, R. S., & Peck, R. C. (1963). The Totally Deaf Driver in California. Part I: The Driving Performance and Descriptive Characteristics of a Large Sample of Deaf Drivers.

Coppin, R. S., & Peck, R. C. (1965). The totally deaf driver in California. Highway Research Record, (79).

Ching, T. Y. C., Incerti, P., & Hill, M. (2004). Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. Ear and Hearing, 25(1), 9-21.

Dash, D. (2016, march 18). Hearing impaired may soon get driving licenses. The Times of India.

Davis, R. J., & Stephens, S. D. G. (1974). The effect of intensity on the localization of different acoustical stimuli in the vertical plane. Journal of Sound and Vibration, 35(2), 223-229.

Edwards, J. D., Lister, J. J., Lin, F. R., Andel, R., Brown, L., & Wood, J. M. (2016). Association of hearing impairment and subsequent driving mobility in older adults. The Gerontologist. 1-9.

Finesilver, S. G. (1962). They Can't Hear, but They Get the Message. California News, 77(8):1-5.

Good, M. D., & Gilkey, R. H. (1996). Sound localization in noise: The effect of signal?to?noise ratio. The Journal of the Acoustical Society of America, 99(2), 1108-1117.

Grattan, E., & Jeffcoate, G. O. (1968). Medical factors and road accidents. British Medical Journal, 1(5584), 75.

Groeger, J. A. (2000). Understanding driving: Applying cognitive psychology to a complex everyday task. Psychology Press. 15-200.

Haeusler, R., Colburn, S., and Marr, E. (1983). Spatial localizationi n subjectsw ith impairedh earing. Acta Oto-laryngol.S uppl. 400, 1-61.

Haualand, H., & Allen, C. (2009). Deaf people and human rights. World Federation of the Deaf and Swedish National Association of the Deaf.

Henderson, R. L., & Burg, A. (1973). The role of vision and audition in truck and bus driving.

Ivers, R. Q., Mitchell, P., & Cumming, R. G. (1999). Sensory impairment and driving: the Blue Mountains Eye Study. American Journal of Public Health, 89(1), 85-87.

Kait, S. (2008, October). Judgement of the High Court. New Delhi. (592), 2-5.

Keidser, G., Convery, E., & Hamacher, V. (2011). The effect of gain mismatch on horizontal localization performance. The Hearing Journal, 64(2), 26-30.

Keidser, G., Rohrseitz, K., Dillon, H., Hamacher, V., Carter, L., Rass, U., & Convery, E. (2006). The effect of multi-channel wide dynamic range compression, noise reduction, and the directional microphone on horizontal localization performance in hearing aid wearers. International Journal of Audiology, 45(10), 563-579.

Kramer, S. E., Kapteyn, T. S., Festen, J. M., & Tobi, H. (1995). Factors in subjective hearing disability. Audiology, 34(6), 311-320.

Lorenzi, C., Gatehouse, S., & Lever, C. (1999). Sound localization in noise in normal-hearing listeners. The Journal of the Acoustical Society of America, 105(3), 1810-1820.

Lorenzi, Christian, Stuart Gatehouse, and Catherine Lever. "Sound localization in noise in normal-hearing listeners." The Journal of the Acoustical Society of America 105.3 (1999): 1810-1820.

Lundälv, J. (2004). Self-reported experiences of incidents and injury events in traffic among hearing impaired people as pedestrians and cyclists. A follow-up study of mobility and use of hearing equipment. International Journal of Rehabilitation Research, 27(1), 79-80.

Lutman, M. E., Brown, E. J., & Coles, R. R. A. (1987). Self-reported disability and handicap in the population in relation to pure-tone threshold, age, sex and type of hearing loss. British journal of audiology, 21(1), 45-58.

Macpherson, E. A., & Middlebrooks, J. C. (2002). Listener weighting of cues for lateral angle: the duplex theory of sound localization revisited. The Journal of the Acoustical Society of America, 111(5), 2219-2236.

Mayer, C. (2007). What really matters in the early literacy development of deaf children. Journal of Deaf Studies and Deaf Education. 12 (4): 411-431.

Motor vehicle Act, India (1988). National police, Road transport and safety commity, 1998, 1-233.

Noble, W. G., & Atherley, G. R. (1970). The Hearing Measurement Scale: A questionnaire for the assessment of auditory disability. Journal of Auditory Research.10(3): 229-250.

Noble, W., & Byrne, D. (1990). A comparison of different binaural hearing aid systems for sound localization in the horizontal and vertical planes. British Journal of Audiology, 24(5), 335-346.

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

Noble, W., Sinclair, S., & Byrne, D. (1998). Improvement in aided sound localization with open earmolds: observations in people with high-frequency hearing loss. Journal of American Academy of Audiology, 9, 25-34.

Noble, W., Sinclair, S., & Byrne, D. (1998). Improvement in aided sound localization with open earmolds: observations in people with high-frequency hearing loss. Journal of American Academy of Audiology, 9, 25-34.

Noble, W., Ter-Horst, K., & Byrne, D. (1995). Disabilities and handicaps associated with impaired auditory localization. Journal of American Academy of Audiology, 6, 129-129.

Norman, L. G. (1962). Driving and medical fitness. The Journal of the Royal Institute of Public Health and Hygiene, 25, 288.

Owsley, C., & McGwin, G. (1999). Vision impairment and driving. Survey of ophthalmology, 43(6), 535-550.

Rapin, I. (1993). Hearing Disorders. Pediateics in Review, 14(2), 45-49.

Schmolz, W. (1987).The importance of hearing in traffic. Police Traffic Engineering.32 (11):379-380.

Singh,V.(2015). Hearing in India: All aspects. Otolaryngology Online journal, 5(1), 1-31.

Stevens, S. S., & Newman, E. B. (1936). The localization of actual sources of sound. The American Journal of Psychology, 48(2), 297-306.

Tobergte,D., Curtis,S. (2013). Accidents Among Hearing-Impaired Drivers. Journal of Chemical Information and Modeling, 53(9), 1689-1699.

Thorslund, B., Peters, B., Lyxell, B., & Lidestam, B. (2013). The influence of hearing loss on transport safety and mobility. European transport research review, 5(3), 117-127.

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

Wightman, F. L., & Kistler, D. J. (1992). The dominant role of low?frequency interaural time differences in sound localization. The Journal of the Acoustical Society of America, 91(3), 1648-1661.

Wood, K. C., & Bizley, J. K. (2015). Relative sound localisation abilities in human listeners. The Journal of the Acoustical Society of America, 138(2), 674-686.