PROJECT REPORT

EFFECT OF AUDITORY DEPRIVATION ON SOME ASPECTS OF TEMPORAL PROCESSING AND SPEECH PERCEPTION ABILITIES

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EFFECT OF AUDITORY DEPRIVATION ON SOME ASPECTS OF TEMPORAL PROCESSING AND SPEECH PERCEPTION ABILITIES

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Contents

Abstract

Objectives. The current study aimed to systematically document the effect of auditory deprivation on temporal processing and speech perception abilities. **Design.** A total of 220 individuals in the age range of 16 to 60 years participated in the study. They were divided into two groups; 30 participants with normal hearing sensitivity in the control group and 190 participants in clinical group with mild to moderately severe hearing loss. Participants in clinical group were further divided based on duration of hearing loss which was the independent variable. Their auditory processing and perceptual abilities were tested using word recognition scores, nonsensesyllable identification in quiet and noise, gap detection test, difference limen for frequency modulation, acceptable noise levels and SNR-50 measures. **Results.** In the current study effect of auditory deprivation was manifested as a decline in word recognition scores, nonsensesyllable identification in quiet and noise and poorer performance in gap detection test, difference limen for frequency modulation, acceptable noise levels and SNR-50 measures. The results suggest that temporal processing and speech perception in noise are most susceptible to the effect of auditory deprivation. Further, the effects of auditory deprivation are more pronounced if untreated, with the increase in the duration of hearing loss and is more widespread. It also suggested that over the years the auditory deprivation affects the peripheral functioning to the functioning of higher centers in the auditory pathway. **Conclusions.** The findings show that auditory deprivation effects start by the second year of hearing loss and the negative effects on temporal processing and speech perception become more serious if left untreated. The findings can be used to justify early rehabilitation of adventitious hearing loss and in counseling the patients.

Chapter 1

Introduction

Hearing loss leads to decline in the auditory perceptual abilities in terms of peripheral hearing sensitivity as well as decline in higher auditory processing. This is due to the fact that hearing loss leads to reduced frequency selectivity and compressive non-linearity leading to impairment in fine and gross temporal processing leading to impaired speech perception (Moore, 2008). Further, if the hearing loss is left untreated it would lead to deterioration in the auditory processing. Studies on long standing hearing loss have shown that the hearing sensitivity alone cannot account for the perceptual deficits, rather other consequent factors lead to deterioration in auditory perception (Boothroyd, 1993). Such deterioration is known to be because of the auditory deprivation. Arlinger et al. (1996) defined the effect of auditory deprivation as the "systematic decrease over time in auditory performance associated with the reduced availability of acoustic information".

1.1. Conductive Hearing Loss and Auditory Deprivation

Studies have been done to observe the effect of auditory deprivation due to conductive hearing loss on perceptual abilities during the later stages of school and adulthood (Gravel, Wallace, & Ruben, 1995, 1996; Maruthy & Mannarukrishnaiah, 2008; Moore, 2008). These studies have shown that auditory deprivation caused by episodes of otitis media leads to affected neural processing leading to longer conduction times and consequent speech perception. These studies have also shown that even short episodes of otitis media impairs auditory processing of spectrally degraded speech and also the auditory brainstem responses.

Dieroff (1993) compared the speech recognition scores in the aided and unaided ears of 46 participants with the symmetrical conductive hearing loss after 10-12 years of monaural hearing aid fit. They reported a poorer speech recognition scores in the unaided ear when compared to the aided ear even though the hearing threshold of both the ears were similar. Gravel et al. (1995) carried out a longitudinal study to assess the effect of mild conductive hearing loss, acquired due to early otitis media, on the higher auditory processing abilities. A study was done on 74 infants, who were assessed for their middle ear functioning and auditory thresholds during the first year of life and a total of 7 follow up sessions was done during the first year of life. The infants were divided into 2 groups: otitis media positive (OM+) (30% or more of their first-year visits showed otitis media bilaterally) and otitis media negative (OM-) (80% or more of their first-year visits showed normal middle ear function bilaterally). Later the auditory processing abilities were assessed at 4, 6 and 9 years of life. The results revealed a significantly poorer performance of the OM+ group on speech in competing noise test, auditory memory task and masking level difference task compared to the OM- group. It was concluded that the poorer performance in auditory processing abilities could be due to the mild recurrent conductive hearing loss in the critical developmental age that was associated with otitis media with effusion (OME).

In an another study, Sandeep and Jayaram (2008) assessed the speech perception ability on 21 children who had hearing loss due to OM in the first year of life. The children in the age range of 5.1 to 6.6 years had one or more episodes of OM between the ages of 6 months to 12 months. Speech identification was assessed for time compressed words, spectrally distorted words and natural words. The results indicated that the children with a history of OM during their early life had significantly poorer speech identification scores on time compressed and spectrally distorted words compared to the age matched normal children while the identification scores for natural word stimulus was similar to the normal children. It was hypothesized that reduced auditory experience during the first year of life would have a deleterious effect on speech perception, especially in unfavorable listening conditions as the auditory neural pathway develops maximally (maturation) during this period.

Following this report Maruthy and Mannarukrishnaiah (2008) conducted a study to document the effect of hearing loss due to early otitis media on auditory brainstem and cortical physiology/ processing. Click evoked Auditory Brainstem Responses (ABRs) and Late Latency responses (LLRs) were recorded from thirty children in the age range of 3.1 to 5.6 years who had a history of an episode of OM between the age of 6 and 12 months. They reported a significant decrease in the wave I and III amplitude and an increase in the inter peak latencies of ABR. This would reflect an abnormal neural firing and slower central conduction time in the lower brain stem. Further, the OM group had poorer LLR waveform morphology, which could be due to the dys-synchronous neural activity at the level of brainstem which would result in an inaccurate encoding of auditory signal especially the temporal features at the auditory cortex. It was also reported that this effect was seen only in children in the age range of 3.1 to 3.6 years age group and children above the age of 4.1 years did not show any difference in response when compared to the age matched controls.

Thus, it can be concluded from the above studies that auditory deprivation due to conductive hearing loss have a negative impact on speech perception abilities and it also leads to the abnormal neural firing and slower conduction time in lower brain stem. Further, the encoding of auditory signal at the auditory cortex is also inaccurate in them.

1.2. Sensorineural Hearing Loss and Auditory Deprivation

Auditory deprivation due to sensorineural hearing loss can also have similar deleterious effects on auditory perception. Studies on the effect of auditory deprivation consequent to sensorineural hearing loss are very scarce. Studies in the literature have reported a decline in speech perception score over time in the unaided ear, in individuals with bilateral hearing loss with monaural hearing aid fitting (Hurley, 1999; Silman, Gelfand, & Silverman, 1984; Silman, Silverman, Emmer, & Gelfand, 1992; Silverman & Emmer, 1993; Silverman & Silman, 1990). Silman et al. (1984) reported a progressive decline in the auditory perception abilities in the unaided ear in 39% of patients with bilateral symmetrical sensorineural hearing loss. The decline in the auditory perception was defined as the progressive reduction in the word recognition scores (WRS) over time in the unaided ear, even when there was no change in the hearing sensitivity. This effect was termed as the unaided ear effect and was hypothesized to be a consequence of auditory deprivation. Further Silverman and Silman (1990) and Silman et al. (1992) in their study reported that the auditory deprivation effect in the unaided ear begins as early as 2 years post the monaural hearing aid fit. Gelfand (1995) provided follow up data on the 17% of the 48 monaurally fitted participants who experienced an unaided ear effect showing that the effect may occur in either the right or the left ear.

Hurley (1999) examined the WRS on 77 monaurally fitted and 65 binaurally fitted patients in the age range of 26 to 76 years with symmetric bilateral sensorineural hearing loss in the intervals of 1, 3, and 5 years after hearing aid fit. A significant reduction in the WRS in the unaided ear was seen in 25 percent of the participants fitted with monaural hearing aids at 5 years post hearing aid fit. Whereas, only 6 percent of the participants who were fitted with binaural hearing aid had a significant change in the WRS in both ears. Further they suggested that the deterioration of scores can occur as early as 1 year with in the monaural hearing aid fit, but with a smaller prevalence. This decline in the auditory functioning continued over five years time span even when there was no significant change in the hearing sensitivity over time. They concluded that the degree of hearing loss plays an important role in determining the onset of unaided ear effect caused due to auditory deprivation.

Silverman, Silman, Emmer, Schoepflin and Lutolf (2006) assessed the effect of auditory deprivation in participants with asymmetrical SNHL. The air-conduction pure-tone threshold, speech-recognition threshold, and supra-threshold word-recognition scores was examined on 28 participants having a mean age of 54.4 years (control group) and 21 monaurally aided participants with mean age of 55.7 years (experimental group) in unaided condition. A significant reduction over time in the supra-threshold WRSs at 1 and 2 years post-baseline for the worse ears of the control participants was reported. Moreover, no decline was observed in the WRSs in the aided ears of the experimental group or the better ears of either of the groups. The results of most of the above studies are based on the WRSs in quiet. Gatehouse (1992) suggested that nonsensesyllabic word recognition scores in quiet is a relatively insensitive measure for assessing subtle changes in the auditory function. The speech recognition in noise test in individuals with bilateral hearing loss with monaural hearing aid was examined. The results showed a decline in the auditory functioning of the unaided ear as early as 3 months post monaural hearing aid fit. It was suggested that using a more sensitive test paradigm would help in early detection of the auditory deprivation effect in the unaided ear.

These studies show a definite effect of hearing loss on the auditory processing ability. Also, the onset of auditory deprivation in the unaided ear varies depending on the sensitivity of test materials used which ranges from as early as 3 months (Gatehouse, 1992) to 10 years post hearing aid fit (Dieroff, 1993). Further, Gatehouse (1992) suggested that the better performance of the aided ear for the supra-threshold speech perception tests could be due to acclimatization effect. He hypothesized that the aided ear would be acclimatized to listening at the supra-threshold levels and thus performs better when test materials are presented at this acclimatized listening range, unlike the unaided ear. Therefore, the decrease in the performance of the unaided ear can be due to the asymmetry in the stimulation of the auditory system rather than only the effect of auditory deprivation. Researchers have only sparsely ventured to study the effect of auditory deprivation on temporal processing and other higher order auditory processes.

1.3. Auditory Deprivation in Animals

Experimental studies have also been carried out on animals in order to account for the effect of the brief duration of inadequate sensory experience during the developmental period on the structure and function of central nervous system in animals. Caras and Sanes (2015) conducted a study to determine the effect of transient auditory deprivation on sound perception in 93 gerbils. Brief duration of hearing loss was induced in the animals by rearing them with ear plugs bilaterally for 12 days, either from postnatal age of 11 days (P11) to 23 days (P23) or from 23 days (P23) to 35 days (P35). The threshold shift due to the ear plugging was measured using ABR and it ranged from 15 dB at 1000 Hz to 49 dB at 6000 Hz (greater effect was seen at high frequency). AM detection ability was tested in these animals 15 days after the removal of the earplugs, with the threshold being restored. Elevated AM detection threshold were reported in animals with ear plugs during their critical developmental period, that is, from P11-P23 when compared with the controls. Whereas the animals who were reared with ear plugs from P23-P35 had normal AM detection thresholds. Although, the induced perceptual deficit was resolved by adulthood in most of the animals, the impairment still persisted in a subset of these animals.

They, suggested that sensory deprivation,even for a brief duration, during the critical period is deleterious to the central auditory processing and can persist through adulthood, even when the auditory periphery is intact.

Mowery, Kotak and Sanes (2015) studied the changes in the synaptic property and cell physiology of the auditory cortical neurons following a brief duration of auditory deprivation. Malleable ear plugs were inserted into the ears of 132 gerbils bilaterally, which induced a mild degree of hearing loss. The insertion of the ear plugs varied from post-natal day 11 (P11) to day 23 (P23). The ear plugs were removed either before P17 [Before the closure of critical period (CP)] or after P23. The whole cell recordings were obtained from the pyramidal neurons of the auditory cortex for 6 consecutive days after the removal of the ear plugs, to check for the changes in the cortical membrane properties. They reported a significant deficit in the membrane and synaptic properties induced due to the hearing loss. More specifically, they reported a diminished Action potential (AP) amplitude, increased AP width, changes in resting membrane potential (RMP) and decreased firing rate. When the hearing loss was reverted within the CPs of the animals, the membrane and synaptic properties recovered to normal values. However, when ear plugs were removed after the CPs, the changes in the cellular properties persisted even through adulthood.

Overall, these studies suggest that even a mild degree of hearing loss can induce significant changes in the auditory nervous system physiology and cellular properties. If these cellular deficits are long lasting and occur during developmental age, it may lead to delay in the acquisition of auditory skills that may persist even during adulthood.

1.4. Need for the study

Clinically, it is often taken for granted that the longer the duration of hearing loss, greater is the effect on auditory perception. However, there is no systematic and empirical evidence as to if this is really true, and if the duration effects are also influenced by other factors like type and degree of hearing loss and other concomitant medical conditions.

Studies on long standing hearing loss have shown that the hearing sensitivity alone cannot account for the perceptual deficits, rather other consequent factors lead to deterioration in auditory perception (Boothroyd, 1993). However, most of these studies are mainly focused on the effect of hearing loss and auditory deprivation in the developing auditory systems. The matured auditory system may not necessarily respond in the similar way to hearing loss and auditory deprivation. Therefore, the findings obtained from a developing auditory system cannot be blindly generalized to adults.The matured auditory system does not necessarily respond in the same way as the developing auditory system to the hearing loss. Also, the decrease in the performance of the unaided ear can be due to the asymmetry in the stimulation of the auditory system rather than only the effect of auditory deprivation.

Considering the move towards evidence based clinical practice and patient care and counselling, it is important that stakeholders be given a realistic picture about their prognosis based on empirical evidence. Hence, the present study stems from the need to generate empirical evidence regarding the influence of auditory deprivation on perceptual outcomes, which would enable us in providing evidence based rehabilitation options and counselling in individuals with hearing loss.

1.5. Aim of the Study

The aim of the present study was to document the effect of duration of hearing loss on speech perception measures, temporal perception and accepted noise levels.

1.6. Objectives of the study

1. To document the effect of duration of hearing loss on speech perception measures through word identification scores, nonsensesyllable identification scores in quiet and noise, sentence identification in noise.
2. To document the effect of duration of hearing loss on temporal processing abilities through gap detection test and frequency modulation difference limen.
3. To document the effect of duration of hearing loss on acceptable noise levels.
4. To document the role of degree of hearing loss on auditory deprivation.

Chapter 2

Methods

In order to verify the objectives of the study, individuals with different duration of hearing loss and various degrees of hearing loss were studied for their temporal processing and speech perception abilities. The details of the participants and the procedures used are discussed in this chapter.

2.1. Research Design

Post Ex Facto experimental research design was used to assess the effect of the duration of hearing loss on temporal processing and the speech perception skills. An informed written consent was taken from all the participants according to the AIISH ethics committee guidelines.

2.2. Participant selection criteria

A total of 220 participants in the age range of 16-60 years participated in the study. They were divided into two groups; 30 participants (52 ears) with normal hearing sensitivity in the control group and 190 participants (305 ears) with mild to moderately severe hearing loss in the clinical group. All the participants in the clinical group met the following criteria:

- Mild to moderately severe hearing loss with conductive, mixed or sensorineural (cochlear origin) type of hearing loss.
- Participants with neural hearing loss were excluded from the study.
- The participants having any neurological or psychological disturbances were excluded from the study.

Out of 190 participants in the clinical group, 133 had sensorineural, 28 had conductive and 29 had a mixed hearing loss. The duration of the hearing loss ranged between 3 months to 10 years and none of them were previously rehabilitated for the hearing loss. To study the effect of duration of hearing loss, the participants were divided into 4 groups; those with duration less than 1 year (1 year group), between 1 and 2 years (2 years group), between 2 and 3 years (3 years group), and more than 4 years (4 years group).

All the participants in the control group met the following criteria:

- All of them had hearing thresholds of less than15 dBHL at all octave frequencies from 250 Hz to 8000 Hz. Speech recognition thresholds (SRT) within ±12 dB of pure tone average (average threshold of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz) and speech identification scores greater than 90% at 40 dB SL (ref SRT).
- Normal middle ear functioning with A type tympanogram and reflexes present within the normal intensity range.
- No significant history of any otological and neurological symptoms.

All the participants were proficient speakers of Kannada language.

2.3. Test Environment

All the tests were carried out in a sound treated room with the noise levels being within the permissible ambient noise level as per the American National Standard Institution (ANSI, 1999) specifications. All the participants were seated comfortably on a chair with appropriate back and neck support throughout the testing.

2.4. Instrumentation

The following instruments were used in the study:

- A two channel Piano Inventis audiometer, coupled with a calibrated TDH-39 supra-aural headphones and Radioear B-71 was used to obtain air-conduction and bone-conduction thresholds, SRT, SIS and UCL.
- A calibrated clinical Immittance instrument, GSI-tympstar middle ear analyser version 2.0 was used to carryout tympanometry and reflex audiometry.
- ILO 292 DP Echo port system was used to record transient evoked otoacoustic emissions and distortion product otoacoustic emission.
- Biologic navigator pro version 7.0.0 coupled with impedance matched Etymotic ER-3A insert earphones was used to record click-evoked auditory brainstem responses.
- Lenovo G585 laptop computer coupled with Sennheiser HDA 200 supra aural headphones was used to present the stimulus. The stimulus output through the headphones was calibrated.

2.5. Test Materials

- A standardised Kannada word list for adults developed by Yathiraj and Vijayalakshmi (2005) was used for testing the word recognition scores.
- Apex 3.0 software was used for assessing nonsensesyllable identification score in quiet and noise.
- MATLAB version 7.9 (The Math Works, Inc., MA, USA, 2009) was used for testing Acceptable Noise Levels (ANL).

- MLP toolbox, implemented in MATLAB by Grassi and Soranzo (2009) was used for testing frequency modulation detection and gap detection.

2.6. Stimulus and Procedure

2.6.1. Preliminary Audiological evaluation

Case history. A detailed structured case history was obtained to include the details regarding, the duration of hearing loss (actual), type of hearing loss, nature of progression of hearing difficulty, presence of tinnitus, speech perception difficulties, and presence and duration of other medical conditions like diabetes and hypertension.

Otoscopy. Otoscopic examination was done to rule out the presence of impacted wax, any external ear anomalies or ear discharge.

Pure-tone evaluation. Pure-tone thresholds for air- and bone-conduction were obtained at octave frequencies from 250 Hz to 8000 Hz and 250 Hz to 4000 Hz, respectively, using the modified Hughson Westlake method. Speech audiometry included determination of, SRT, SIS and UCL for each ear.

Immittance evaluation. This was done to rule out middle ear pathology. Tympanometry was carried out with a probe-tone frequency of 226 Hz at 85 dB SPL by varying air pressure in the external ear canal from +200 daPa to -400 daPa at a pump speed of 50 dapa/s. The same probe-tone frequency, along with reflex eliciting signal at octave frequencies from 500 Hz to 2000 Hz, was used to measure ipsilateral as well as contralateral acoustic reflex thresholds.

Auditory Brainstem Response (ABR). Two channel ABR was recorded to rule out the presence of any retro cochlear pathology using click stimulus with rarefaction polarity at a repetition rate of 11.1/s and 90.1/s. The inverting electrode was placed on the mastoid of both the ears, the non-inverting electrode was placed on the vertex and the ground on the forehead. The ipsilateral and contralateral brainstem responses were recorded. The difference in absolute latency of wave V between repetition rates of 11.1/s and 90.1/s was noted. The peaks were also analyzed for absolute latency, interpeak latency and inter aural wave V latency difference. The participants with normal results in each of the mentioned parameters were further considered for the study.

2.6.2. Speech perception, temporal processing and acceptable noise level assessment

Speech perception, temporal processing and acceptable noise level were measured using the following tests:

1. Word recognition scores
2. Nonsense syllable identification in quiet and noise
3. Speech perception in noise
4. Gap detection threshold
5. Frequency modulation difference limen
6. Acceptable noise level

Word recognition scores (WRS). Word recognition scores were used to characterize the speech perception abilities in the participants. A standardized Kannada word list for adults developed by Yathiraj and Vijayalakshmi (2005) was used for this purpose. The stimulus consisted of phonetically-balanced words spoken by a female speaker. Each participant was presented with 20 words monaurally at the most comfortable loudness level. Each word was assigned a score of 5%. The participants were instructed to repeat back the words that were heard. Total number of words correctly repeated by the participant was recorded and the percentage correct word identification score was computed for each ear separately.

Nonsense syllable identification scores in quiet and noise. A closed set identification task was used to determine the nonsense syllable identification ability in quiet and in the presence of noise. Twenty recorded Kannada monosyllables listed by Mayadevi (1974) was used as the stimulus. Consonants in the syllables were /p t k b ḍ g s ʃ dʒ tʃ k g n ṇ m y r l ḷ th/ and were always presented along with vowel /a/ in a VCV context. The stimulus was spoken by a male speaker and was presented at the most comfortable loudness level (MCL) of the patient. The same list was superimposed with speech shaped noise at 0 dB SNR. Each consonant was presented three times, with a total of 60 items presented in each condition. Apex 3.0 software was used to present the auditory stimulus along with the visual representation of the nonsense syllables (written in Kannada) on the laptop screen. The participants were instructed to click on the image of the syllable corresponding to the perceived syllable. The final score was computed by the software in terms of percent correct responses. The percent correct score for each ear was obtained. Figure 2.1 shows the snapshot of the Apex 3.0 display for syllable identification testing.

Figure 2.1. Snapshot of the Apex 3.0 display for nonsensesyllable identification testing.

Speech perception in noise. To document the speech perception ability in noise the SNR-50 was determined using the quick speech perception in noise test in Kannada (Mohamed & Kumar, 2013). The list 1 of the test comprising of 7 sentences was used. Each sentence was presented along with a competing stimulus which was a four-speaker multi talker babble developed by Kumar, Ameenudin, and Sangamanatha (2012). The first sentence had an SNR of +8 dB and it reduced in 3 dB steps for each of the following sentences. The sentences were presented at the most comfortable level. The participants were instructed to ignore the speech babble and repeat the main sentence verbatim. Each sentence had 5 key words and a score of 1 was assigned to each correct key word repeated. Finally, the score for all 7 sentences was documented and the SNR-50 value (in dB) was calculated using the Spearman-Karber equation, as:

$$SNR\text{-}50 = i + \tfrac{1}{2}(d) - (d)(\#\text{correct words})/w$$

Where,

i = initial presentation level (dB S/N)

d = Attenuation step size

correct = total number of correct key words

w = Total number of Key words

Gap detection threshold (GDT). GDT was measured using mlp toolbox in Matlab. Noise bursts of 750 ms duration with onset and offset linearly ramped at 20 ms was used for the estimation of GDT. A three-interval alternate forced choice task was used to determine the minimum gap to track a 77.2 % correct response criteria. Every trial involved the presentation of three noise bursts in which two were the standard stimuli and one was the variable or the target stimulus. The standard stimulus was a 750 ms broadband noise with no gap, whereas the variable stimulus contained the gap of varying duration at the centre of the noise. The initial gap size was always fixed at 64 ms and the gap size varied depending on the participant's response. The participant was instructed to identify the noise burst which had a gap in the centre. A practice trail was given for each participant for the familiarization of the task, prior to starting the experiment. The stimulus was presented at the most comfortable loudness levels of the participant. The gap detection threshold was determined for each ear separately.

Frequency modulation difference limen (FMDLs). FMDLs was estimated using mlp toolbox in Matlab. The minimum modulation depth perceptible was determined using a three interval alternate forced choice procedure in a total of 20 trials in each run. A 1000 Hz carrier tone was modulated using a 5 Hz tone was used as the target stimulus, whereas 1000 Hz pure tone with no modulation was used as the standard stimuli. Each stimulus had an overall duration of 750 ms with the rise/fall time of 20 ms. The inter stimulus interval was kept at 750 ms. Each trail contained two standard stimulus and one target stimulus. The Participant's task was to identify the interval which had a modulated tone. A practice trail was given for the familiarization of the task, prior to the starting of the experiment. The stimulus was presented at the most comfortable level of the participant and the FMDL was determined for each ear separately.

Acceptable noise levels (ANL). The procedure recommended by Nabelek, Freyaldenhoven, Tampas, Burchfiel, and Muenchen (2006) was followed to calculate the ANL. A Kannada story titled 'Beda' recorded by a female speaker was used as the speech stimulus and the Participant had to indicate the most comfortable level. After the MCL was established a white noise was given to the same ear to determine the background noise level (BNL). BNL is defined as the maximum level of the background noise that a person is willing to accept or "put up with" without becoming tense or tired while listening to the target speech (Freyaldenhoven, Plyler, Thelin, & Hedrick, 2007).

A white noise was presented simultaneously starting at a level 15 dB below the most comfortable level and increasing in 5 dB steps. The participant was asked to indicate when the noise level became too loud and the participant could not follow the story any longer. The noise was then reduced in 5 dB steps till the participant indicated that the noise was too soft and the story was heard very clearly. The noise level was then increased and decreased in 2 dB steps till the participant indicated it had reached the maximum level till which he could accept noise while following the story clearly. This was taken as the BNL (dB). The BNL value was established in 2 trials and the average of both the trials was taken as the final BNL. The ANLs was calculated as the difference between MCL and BNL (in dB). This was executed using a custom made graphical user interface designed in MATLAB 2012 (Mathworks, Natick USA). Figure 2.2 shows the snapshot of the graphical user interface used to determine ANLs.

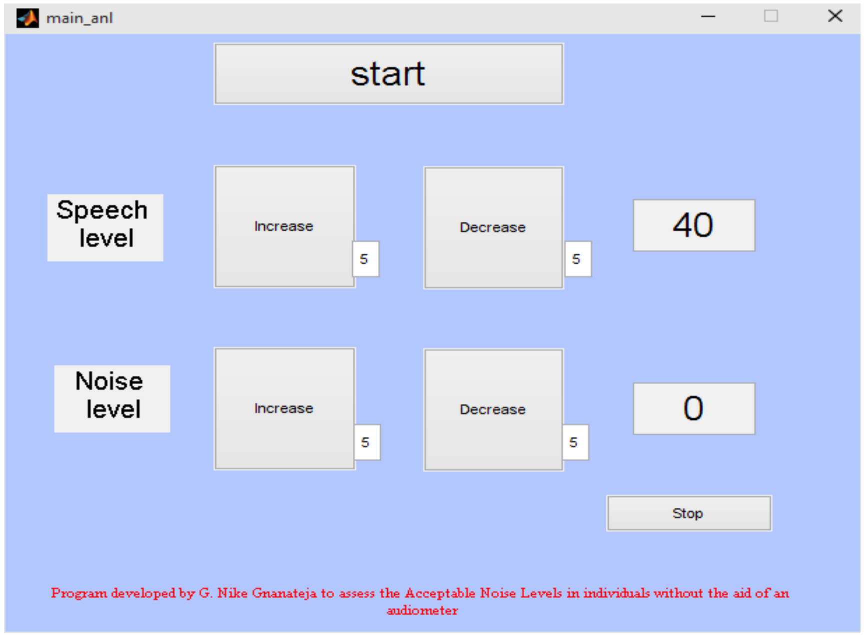


Figure 2.2. Snapshot of the graphical user interface used to determine ANLs.

2.7. Statistical Analyses

The data from the study was tabulated and subjecteded to statistical analyses using Statistical Package for Social Science (SPSS version 17.0). Descriptive analysis was done to estimate the mean and standard deviation of WRS, Nonsensesyllable identification in quiet and in noise, GDT, FMDLs and ANL. Correlation was done between the duration of hearing loss and each of the measured auditory perceptual skills using Spearman rank order correlation. To determine the cut off duration below and above which the effect of auditory deprivation significantly differed, the participant groups were divided based on duration of hearing loss. Mann-Whitney U test was used to compare the means between the groups for each of the auditory processing parameters measured in the study.

Chapter 3

Results

The present study aimed to determine the effects of duration of hearing loss on the auditory perceptual skills. For this, word recognition scores (WRSs), nonsense syllable identification in quiet, nonsense syllable identification in noise, SNR-50, gap detection threshold (GDT), frequency modulation difference limen (FMDL) and acceptable noise level (ANL) measures were obtained from 190 participants with varying degrees (mild, moderate, moderately severe) and types of hearing loss (conductive, mixed and sensorineural hearing loss). In the study auditory perceptual measures were the dependent variable and duration of hearing loss was the independent variable. The Kolmogorov–Smirnov test of normality was done to check for the normality of the data. The results revealed that the data for all the measures significantly differed from the normal distribution. Hence, non-parametric statistical analyses was done. The effect of duration of hearing loss on the temporal processing, speech perception measures and acceptable noise levels was tested in two ways. One, the participants in the clinical group were divided into subgroups based on their duration of hearing loss and each subgroup was separately compared with the control group. Considering that the duration of the hearing loss ranged from 3 months to 10 years among the clinical group, we divided the participants into 4 groups as those with duration less than 1 year (1 year group), between 1 and 2 years (2 years group), between 2 and 3 years (3 years group), and more than 4 years (4 years group). The details regarding number of ears tested in each group is given in Table 3.1. The one year interval was preferred in view of large number of participants in each group. Each of these groups was compared with the control group. A Mann Whitney U test was carried out to compare the performance of each of these groups with the control group for each of the measures. The Spearman rank order correlation was done to correlate the duration of hearing loss with each of the above mentioned measures. The results are discussed under the following headings:

- Effect of auditory deprivation on speech perception measures
- Effect of auditory deprivation on temporal perception measures
- Effect of auditory deprivation on measure of noise tolerance
- Role of degree of hearing loss on auditory deprivation

Table 3.1.

Number of ears tested in control and each clinical subgroupalong with various degree of hearing loss

Groups	*Number of ears tested*	*Mild HL*	*Moderate HL*	*Moderately severe HL*
Control	*52*	-	-	-
1 year	54	26	16	12
2 years	69	30	24	15
3 years	81	18	40	23
4 years	101	11	68	22

3.1. Effect of auditory deprivation on speech perception measures

Table 3.2 gives the mean, median and standard deviation (SD) of the 4 parameters of speech perception measures measured in the control and 4 clinical sub groups. Mean nonsense syllable identification in quiet as well as noise was lesser in clinical groups compared to control group. Within the clinical group, as the duration of hearing loss increased, there was a successive decrease in the speech identification scores (nonsense syllable identification in quiet as well as noise). No such trend was seen in word recognition scores. On the other hand, mean SNR-50 was higher in clinical subgroups compared to control groups. Furthermore, as the duration of the hearing loss increased, there was a successive increase in the SNR-50.

Table 3.2.

Mean, Median and SD of the 4 parameters of speech perception measures measured in the control group and 4 clinical sub groups

Dependent Variable		Control	Subgroups of Clinical group divided duration of hearing loss			
			1 year	2 years	3 years	4 years
WRS (%)	Mean	98.68	98.41	98.14	97.72	96.43
	Median	100.00	100.00	100.00	100.00	96.00
	SD	2.21	2.957	2.70	3.40	4.19
Nonsense syllable identification in quiet (%)	Mean	96.36	95.96	95.13	92.59	87.80
	Median	96.66	95.00	95.00	93.33	88.33
	SD	2.79	2.57	3.86	5.70	6.70
Nonsense syllable identification at 0dB SNR(%)	Mean	77.45	74.28	73.83	69.24	64.38
	Median	80.00	75.00	73.33	68.33	66.00
	SD	7.18	6.59	7.41	7.86	8.50
SNR-50 (dB)	Mean	5.80	5.90	6.10	6.53	7.23
	Median	5.9	5.9	6.1	6.5	7.1
	SD	0.31	0.34	0.44	0.51	0.55

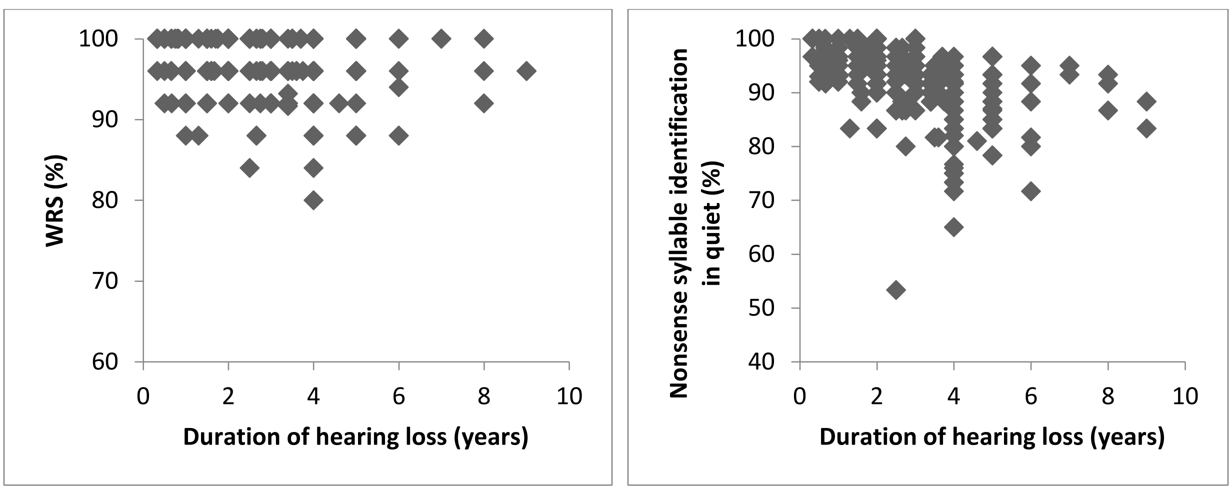
The Kruskal Wallis test was used to test the significance of difference between the means across the groups. Results showed that there was a significant main effect of group on all the four measures of speech perception (Table 3.3). Subsequent pair-wise comparisons were done using Mann Whitney U test for all the speech perception measures. In WRS, the 4 years group had significantly poorer scores from all the other groups except 3 years. There was no significant difference between any of the other pairs of groups. In the nonsensesyllable identification in quiet, both 3 and 4 years groups had significantly lesser scores compared to the other groups and the 4 years group had significantly poorer scores than 3 years group. The findings were similar in syllable identification scores in noise except that there was no difference between 3 and 4 years group. In SNR-50, all the groups were significantly different from each other, except for control and 1 year group.

Table 3.3.

Results of Kruskal Wallis test showing the effect of group on speech perception measures

Dependent Variable	Chi square	df	p
WRS (%)	22.570	4(354)	<0.001
Nonsense syllable identification in quiet (%)	126.887	4 (354)	<0.001
Nonsense syllable identification at 0dB SNR(%)	100.572	4 (354)	<0.001
SNR-50 (dB)	209.089	4 (354)	<0.001

Spearman's rank order correlation was done to assess the relation between the duration of hearing loss on each of the parameters. Results of correlation showed a significant correlation in WRS (ρ = -0.218, $p \leq 0.001$), nonsensesyllable identification in quiet (ρ = -0.580, $p \leq 0.001$), nonsensesyllable identification in noise (ρ = -0.478, $p \leq 0.0001$) as well as SNR-50 (ρ = 0.691, $p \leq 0.001$). Figure 3.1 shows the scatter plots for the significant correlations of all the 4 measures of speech perception.



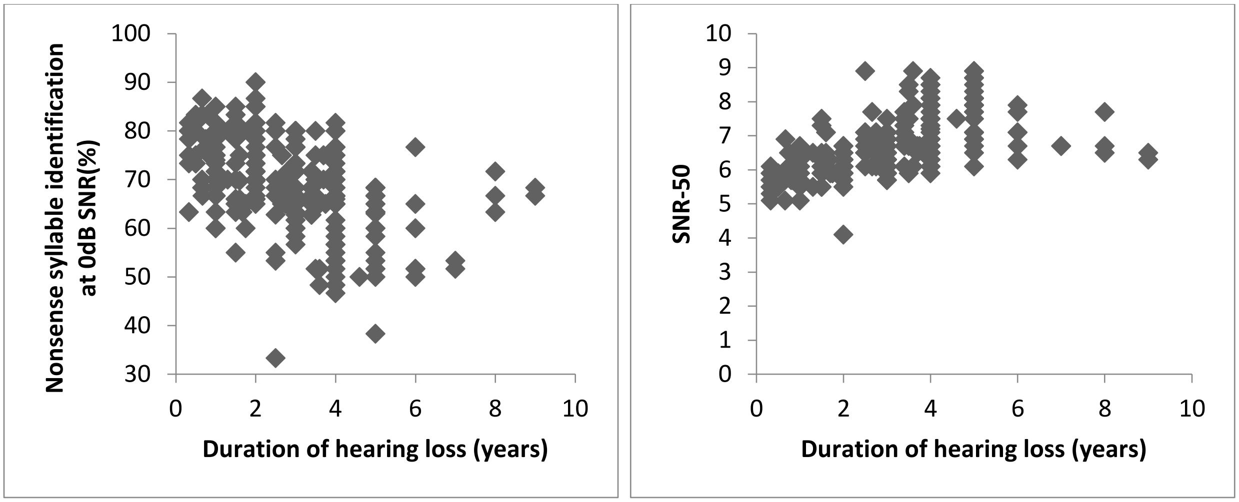


Figure 3.1. Scatter plots of WRS, Nonsense syllable identification in quiet, Nonsense syllable identification at 0dB SNR and SNR-50 as a function of duration of hearing loss.

3.2. Effect of auditory deprivation on temporal perception measures

Table 3.4 gives the mean, median and SD of the GDT (in ms) and FMDL (in Hz) measured in the control group and 4 clinical sub groups. It can be noted from the table that both GDT and FMDL was more in clinical groups compared to control group. The Kruskal Wallis test showed that there was a significant main effect of group on on GDT [$\chi2$ (4,354) =223.496, $p<0.001$] as well as FMDL [$\chi2$ (4,354) =133.478, $p<0.001$]. Pairwise comparison between the groups was done using a Mann Whiney U test which showed that there was a significant difference in mean GDT across all the groups except between control and 1 year group. On the other hand, in FMDL, there was no significant difference between control and 1 year group, and also between 1 year and 2 years group. The other pairs of groups differed significantly.

Table 3.4.

Mean, Median and SD of the GDT (in ms) and FMDL (in Hz) measured in the control group and 4 clinical sub groups.

Dependent Variable		Control	Subgroups of Clinical group divided duration of hearing loss			
			1 year	2 years	3 years	4 years
GDT (ms)	Mean	3.86	4.39	5.34	6.86	8.46
	Median	3.75	4.25	5.21	6.76	8.45
	SD	1.27	1.22	1.19	1.47	1.53
FMDL (Hz)	Mean	4.57	4.99	5.96	7.24	8.72
	Median	4.75	4.75	6.25	7.50	8.50
	SD	1.65	1.51	2.00	2.19	2.51

The effect of duration of hearing loss on temporal processing measures when tested with Spearman rank correlation showed a significant correlation in GDT ($\rho = 0.771$, $p \leq 0.0001$) as well as FMDL ($\rho = 0.553$, $p \leq 0.0001$). Figure 3.2 shows the scatter plots of temporal processing measures as a function of duration of hearing loss.

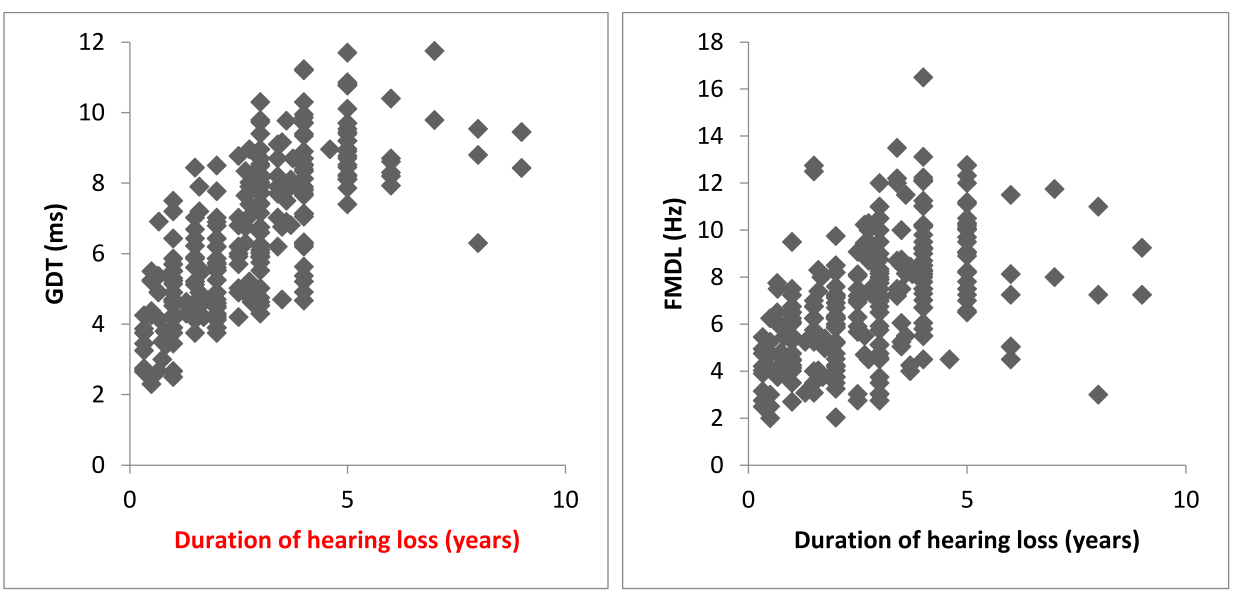


Figure 3.2. Scatter plots of GDT and FMDL as a function of duration of hearing loss.

3.3. Effect of auditory deprivation on measure of noise tolerance

Table 3.5 gives the mean, median and SD of ANL measured in the control group and 4 clinical sub groups. Mean ANL in the 3 and 4 year groups were higher than that in the other groups. The Kruskal Wallis test showed that there was a significant main effect of group on mean ANL [$\chi2$ (4,354) =150.571, $p<0.001$]. The subsequent pairwise comparison using Mann Whitney U test showed that 3 year and 4 year groups had significantly higher ANL compared to the other groups. There was a significant difference between these two groups while there was no significant difference among control, 1 year and 2 year groups in their mean ANL.

Table 3.5.

Mean, Median and SD of the ANL measured in the control group and 4 clinical sub groups.

Dependent Variable		Control	Subgroups of Clinical group divided duration of hearing loss			
			1 year	2 years	3 years	4 years
ANL	Mean	4.56	4.19	3.89	6.13	8.67
	Median	4.00	4.00	4.00	6.00	8.00
	SD	0.95	1.77	1.70	2.07	3.42

Spearman rank correlation also showed a significant correlation between duration of hearing loss and the way ANL varied ($\rho = 0.636$, $p \leq 0.0001$). Figure 3.3 shows the scatter plot of ANL as a function of duration of hearing loss.

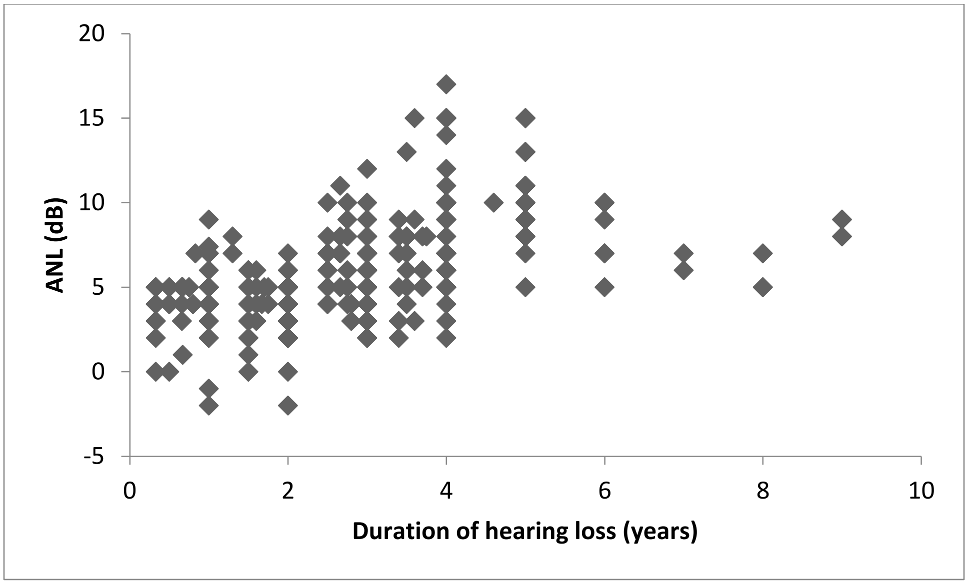


Figure 3.3. Scatter plot of ANL as a function of duration of hearing loss

3.4. Role of degree of hearing loss on auditory deprivation.

To assess the effect of degree of hearing loss on the resulting auditory deprivation, the participants were divided into 3 groups based on their degree of hearing loss, that is mild, moderate and moderately severe degrees of hearing loss. The participants in each of these groups were further divided into 4 subgroups based on the duration of untreated hearing loss. The cut off durations for dividing the group was 1, 2, 3 and 4 years with hearing loss. A Mann Whitney U test was carried out to compare the performance of each of these groups with the control group for each of the measures. The results are discussed under the following heads.

- Effect of Auditory deprivation in Mild hearing loss group
- Effect of Auditory deprivation in Moderate hearing loss group
- Effect of Auditory deprivation in Moderately-severe hearing loss group.

3.4.1. Effect of Auditory deprivation in Mild hearing loss group.

When the duration of hearing loss was one year, Mann Whitney U test showed a significant difference between the control group and clinical group on GDT ($Z = -5.24$, $p < 0.001$), FMDL ($Z = -3.359$, $p < 0.01$). With 2 years as cut off duration there was a significant group difference on GDT ($Z = -5.984$, $p < 0.001$), FMDL ($Z = -4.157$, $p < 0.001$) and SNR-50 ($Z = -5.060$, $p < 0.01$), while all the other measures were comparable with the control group. With three years as cut off duration, group differences were observed in GDT ($Z = -3.904$, $p < 0.001$), FMDL ($Z = -3.889$, $p < 0.001$), SNR-50 ($Z = -3.708$, $p < 0.001$) along with ANL ($Z = -3.113$, $p < 0.01$) and nonsense syllable identification in noise ($Z = -2.482$, $p < 0.05$). With 4 years cut off, the two groups differed in all the aforementioned measures along with the nonsense syllable identification in quiet ($Z = -2.933$, $p < 0.01$). However, the WRSs were always comparable to the control group for all the cut off durations. These results are tabulated in Table 3.6.

Table 3.6.

List of perceptual measures in which clinical subgroups (with mild hearling loss) of different duration of hearing loss (1,2 3 and 4 years of duration) were significantly different compared to the control group

Cut off duration of hearing loss			
1 year	**2 years**	**3 years**	**4 years**
GDT	GDT	GDT	GDT
FMDL	FMDL	FMDL	FMDL
	SNR-50	SNR-50	SNR-50
		ANL	ANL
		Nonsense syllable identification in Noise	Nonsense syllable identification in Noise
			Nonsense syllable identification in quiet

3.4.2. Effect of Auditory deprivation in Moderate hearing loss group.

Results of the Mann Whitney U test revealed a significant difference in GDT (Z = -2.849, p< 0.01), FMDL (Z = -3.109, p< 0.01), nonsensesyllable identification in noise (Z = -2.337, p< 0.01) and SNR- 50 (Z = -3.548, p< 0.01) in the group with 1 year cut off duration of hearing loss when compared to the control group. However, no significant difference was seen in the other measures. In the group with 2 years of cut off duration a significantly poor performance was seen in ANL (Z= -4.995, p<0.001), WRSs (Z=-2.38, p<0.05) and nonsense syllable identification in quiet (Z= -4.074, p<0.001) along with further deterioration in GDT (Z = -5.478, p<0.001), FMDL (Z = -4.333, p<0.001) nonsense syllable identification in noise (Z = -3.665, p< 0.001) and SNR-50 (Z = -4.32, p< 0.001). The results of the groups with 3 year and 4 year of hearing loss showed more deterioration in the aforementioned parameters.These results are tabulated in Table 3.7.

Table 3.7.

List of perceptual measures in which clinical subgroups (with moderate hearling loss) of different duration of hearing loss (1,2 3 and 4 years of duration) were significantly different compared to the control group

Cut off duration of hearing loss			
1 year	**2 years**	**3 years**	**4 years**
GDT	GDT	GDT	GDT
FMDL	FMDL	FMDL	FMDL
Nonsense syllable identification in noise	Nonsense syllable identification in noise	Nonsense syllable identification in noise	Nonsense syllable identification in noise
SNR-50	SNR-50	SNR-50	SNR-50
	ANL	ANL	ANL
	WRS	WRS	WRS

	Nonsense syllable identification in quiet	Nonsense syllable identification in quiet	Nonsense syllable identification in quiet

3.4.3. Effect of Auditory deprivation in Moderately Severe hearing loss group.

Results on Mann Whitney U test showed a significant increase in the mean GDT (Z = -3.264, p< 0.001), FMDL (Z = -2.863, p< 0.01) nonsense syllable identification in noise (Z = -2.980, p< 0.01) and SNR-50 (Z = -2.985, p< 0.01) right in the first year of hearing loss. Whereas the other measures remained comparable to the control group. The groups with 2 years of untreated hearing loss showed significant increase in the mean GDT (Z= -3.904, p<0.001), FMDL (Z = -3.794, p<0.001) nonsense syllable identification in noise (Z = -4.063, p< 0.001) and SNR-50 (Z = -3.863, p< 0.001) similar to the group 1. But in addition, showed poor performance in ANL (Z=-3.938, p<0.001), WRSs (Z=-3.091, p<0.01) and nonsense syllable Identification in quiet (Z= -4.074, p<0.001). The results of the groups with 3 years and 4 years of hearing loss showed more deterioration in the aforementioned parameters. These results are tabulated in Table 3.8.

Table 3.8.

List of perceptual measures in which clinical subgroups (with moderately severe hearling loss) of different duration of hearing loss (1,2 3 and 4 years of duration) were significantly different compared to the control group

Cut off duration of hearing loss			
1 year	**2 years**	**3 years**	**4 years**
GDT	GDT	GDT	GDT
FMDL	FMDL	FMDL	FMDL
Nonsense syllable Identification in Noise	Nonsense syllable Identification in Noise	Nonsense syllable Identification in Noise	Nonsense syllable Identification in Noise
SNR-50	SNR-50	SNR-50	SNR-50
	ANL	ANL	ANL
	WRS	WRS	WRS
	Nonsense syllable identification in quiet	Nonsense syllable identification in quiet	Nonsense syllable identification in quiet

Overall, the results showed that the degree of hearing loss plays a role on resulting auditory deprivation. Greater effect of auditory deprivation was seen in groups with moderate and moderately severe hearing loss than in the mild hearing loss group.

Chapter 4

Discussion

The aim of the current study was to systematically study the effect of auditory deprivation on auditory perceptual abilities in individuals with hearing loss. The results of the present study is discussed below:

4.1. Effect of auditory deprivation on auditory perceptual measures

The results showed that the duration of auditory deprivation had a significant effect on temporal processing and speech perception measures. As the duration of unattended hearing loss increased, the temporal processing skills and the speech perception skills showed deterioration. This is in line with the studies in early onset otitis media wherein longer duration of hearing loss has been shown to lead to greater auditory deprivation. Gravel and Wallace (1992) in his study showed that the children with the history of otitis media had poorer performance on speech in competing noise test and auditory memory task compared to the control group. They concluded that the poorer performance in auditory processing abilities could be due to the mild recurrent conductive hearing loss in the critical developmental age that was associated with otitis media with effusion.

However, such studies were done in children with resolved otitis media and mainly focused on the effect of hearing loss and auditory deprivation in the developing auditory systems. The hearing loss resulting from otitis media in the developmental period affects the auditory neural maturation thus impede the normal development of the auditory system. Experimental studies have been carried out on animals in order to account for the effect of the brief duration of inadequate sensory experience during the developmental period on the structure and function of central nervous system in animals. Mowery, Kotak and Sanes (2015) reported a diminished Action potential (AP) amplitude, increased AP width, changes in resting membrane potential (RMP) and decreased firing rate following a brief duration of auditory deprivation in 132 gerbils during their critical development period.

The present study involved adult participants who did not have any history of otitis media in childhood. Therefore the effect observed in the present study cannot be due to impaired neural maturation rather it might be a consequence of the underlying hearing loss. There are studies that suggest that the auditory system undergoes structural and functional changes following a peripheral damage (Moore, 2008). These changes are due to the neural plasticity leading to changes in neuronal wiring and networks which occurs as a result of reduced auditory stimulation.

Salvi (1996) suggested that damage to the sensory structures prompts the neural plasticity in the central auditory system which effects the perception of auditory input from the peripheral level. However, these studies did not consider the effect of the duration of hearing loss on the auditory system. Based on the findings of the current study and the previous ones it can be suggested that extended periods of auditory deprivation, leads to lesser neural stimulation resulting in a change in the sensitivity patterns of neurons owing to their plastic nature. An alternate explanation could be that lack of stimulation over a long period of time, might lead to reduced neuronal firing and possible degeneration, which might lead to perceptual deficits (Gatehouse, 1990). In the current study, effect of auditory deprivation was manifested as a decline in WRS, nonsense syllable identification in quiet and noise and poorer performance in the GDT, FMDL, ANL and SNR-50. The results suggested that temporal processing and speech perception in noise are most susceptible to the effect of auditory deprivation.

4.2. Role of degree of hearing loss on auditory deprivation.

In the present study, the effects of auditory deprivation are more pronounced if untreated, with the increase in the duration of hearing loss and is more widespread. It also suggested that over the years the auditory deprivation effects the peripheral functioning to the functioning of higher centers in the auditory pathway.

Silman, Gelfand, and Silverman (1984) suggested that the effect of auditory deprivation can be due to the structural and functional changes in the peripheral as well as the higher auditory system. Leake and Hradek (1988) in their study induced sensorineural hearing loss in cats and observed the morphological changes in cochlea as a result of auditory deprivation. They reported that with increase in the duration of induced deafness, there was a significant progressive reduction in the spiral ganglion cell count and a progressive degeneration in the cochlear structures. Also, demyelination of the peripheral and central neurons was also observed leading to alterations in the temporal characteristics of neural response. The findings show that auditory deprivation effects start by the second year of hearing loss and the negative effects on temporal processing and speech perception become more serious if left untreated.

Chapter 5

Summary and Conclusion

The aim of the current study was to systematically document the effect of auditory deprivation on temporal processing and speech perception abilities. A total of 220 individuals in the age range of 16 to 60 years participated in the study. They were divided into two groups; 30 participants with normal hearing sensitivity in the control group and 190 participants in clinical group with varying degrees and duration of hearing loss. Their auditory processing and perceptual abilities were tested using word recognition scores, nonsensesyllable identification in quiet and noise, gap detection test, difference limen for frequency modulation, acceptable noise levels and SNR-50 measures.

Results showed that the effect of auditory deprivation was manifested as a decline in word recognition scores, nonsensesyllable identification in quiet and noise and poorer performance in gap detection test, difference limen for frequency modulation, acceptable noise levels and SNR-50 measures. The results suggest that temporal processing and speech perception in noise are most susceptible to the effect of auditory deprivation. Further, the effects of auditory deprivation are more pronounced if untreated, with the increase in the duration of hearing loss and is more widespread. It also suggested that over the years the auditory deprivation effects the peripheral functioning to the functioning of higher centers in the auditory pathway. The findings show that auditory deprivation effects start by the second year of hearing loss and the negative effects on temporal processing and speech perception become more serious if left untreated. The findings can be used to justify early rehabilitation of adventitious hearing loss and in counseling the patients.

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