EFFECT OF NOISE INDUCED HEARING LOSS ON DIFFERENCE LIMEN FOR FREQUENCY, INTENSITY AND DURATION

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This dissertation is submitted as a part fulfillment

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May-2019

CERTIFICATE

This is to certify that this dissertation entitled **"Effect of noise induced hearing loss on difference limen for frequency, intensity and duration."** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student Registration Number: 17AUD036. This has been carried out under the guidance of the faculty of the institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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May, 2019

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CERTIFICATE

This is to certify that this dissertation entitled **"Effect of noise induced hearing loss on difference limen for frequency, intensity and duration."** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Effect of noise induced hearing loss on difference limen for frequency, intensity and duration."** is the result of my own study under the guidance of Dr. N Devi, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Registration No: 17AUD036**

May, 2019

I would love to dedicate this Dissertation to my Appuppan, Ammumma, Jayamma, Thankom aunty, Mohan uncle, Josy chechi, achachan, Jincy chechi, Blessy & Wantei

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“I will praise you Lord, with all my heart, I will tell about the wonderful things you have done, you make me happy, so i will rejoice in you”

Psalm : 9:1

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Abstract

Extreme loud sounds may harm the ear which results in hearing loss called Noise Induced Hearing Loss (NIHL). Even sounds perceived as "comfortably" loud can be harmful when exposure to sound is higher in frequency (pitch), intensity (loudness) and duration (time). Several studies were carried out to see the outcome of psycho-acoustical tests on cochlear hearing loss and normal hearing individuals. However, none of the studies have extensively explored whether there is any change in difference limen for frequency (DLF), intensity (DLI) and duration (DLT) in NIHL. The aim of the study was to evaluate the effect of NIHL on DLF, DLI and DLT especially individuals who have mild to moderate hearing loss with 4 kHz notch (Group I) and high frequency mild to moderate sloping hearing loss (Group II). A total of 40 ears were included in the study. DLF, DLI and DLT were assessed for different frequencies (1 kHz, 2 kHz, 4 kHz and 6 kHz). Psycho-acoustical abilities were measured using ‘mlp’ tool box which implements a maximum likelihood procedure in MATLAB software. The results of the study indicate that there was no significant difference between both the groups except at 6 kHz in DLT. However there were marginal differences in DLF, DLI and DLT for the other frequencies between the groups. There was also a significant difference across frequencies within group. This could be because of reduced frequency selectivity, excitation pattern, broadening of auditory filter and loss of basal hair cells in the cochlea. Also reduction in the audibility alters the perception of sound due to structural variations.

Key words*: NIHL, DLF, DLI and DLT*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

Hearing is most important sense in human beings. It is one of the channels through which we communicate and interact with the society. Unfortunately there are multiple factors that can affect the hearing of an individual. Of the many factors, the most common factor which can have an adverse effect on our hearing is noise which can have a profound impact on the effectiveness of communication in several different ways. Noise can be defined as any undesired sound which causes unwanted disturbance within a useful frequency band (NIOSH, 1991). Noise may be continuous, intermittent, impulsive or explosive.

Loud noise not only causes damage to hearing but it is known to adversely affect people working in industry causing annoyance, decrease in work efficiency, sleep disturbance, psychological distress, physiologic changes (includes changes in heart rate, changes in blood pressure, decrease sodium level in blood). A direct primary auditory effect is the most significant cause for noise induced hearing loss (NIHL) that is the obvious interferences with speech communication due to the masking effect. Extreme loud sounds can also cause physical damage to the ear, resulting in hearing loss, tinnitus (ringing in the ear), and hyperacusis (painfully over sensitive hearing) (Basner et al., 2014). These conditions can be either temporary or permanent. Noise which is generating from sirens or firearms may cause asymmetric hearing loss. Acoustic trauma is a common condition; occur as the result of exposure to short term impulsive noise. Hence, ear plugs, ear muffs, canal caps and/ or ultra- fit ear plug are the devices which are used to reduce the noise reach the ears, subsequently protects the ears from damage and preventing hearing loss.

NIHL is the second most common form of sensorineural hearing deficit, after presbycusis. NIHL is a sensorineural hearing deficit that begins at the higher frequencies (3 kHz to 6 kHz) and progresses gradually as a result of chronic exposure to excessive sound levels. On an average, unilateral 4 kHz dip was almost twice as common as bilateral 4 kHz dip and that unilateral dip cases are equally common for the right ear and left ear. The 4 kHz dip cases were most predominantly occurs in the age of 40 and 50 year (approximately 35%), after which prevalence progressively diminished across the 60–80 year groups (Wilson, 2011).

Noise, like any other sound, is defined in terms of its frequency, intensity and duration. Sound intensity is measured as sound pressure level (SPL) in a logarithmic decibel (dB) scale (Table 1.1) (Rabinowitz, 2000). Noise exposure measurements are often expressed as dB (A), a scale weighted toward sounds at higher frequencies, to which the human ear is more sensitive. Permanent hearing loss occur when the noise exposure is an average SPL of 85 dB (A) for 8 hours period. Based on the logarithmic scale, a 3-dB increase in SPL represents a doubling of the sound intensity. Therefore, exposure to noise for 4 hours at 88dB(A) is measured to deliver the same noise "dose" as eight hours at 85dB(A), and a single gunshot, which is around 140 to 170 dB(A), has the same sound energy as 40 hours of 90-dB(A) noise.

Table 1.1: *Common Sources of Noise*

Sound	**Loudness (dB)**
Gunshot (peak level)	140 to 170
Jet take off	140
Rock concert, chain saw	110 to 120
Diesel locomotive, stereo headphones	100
Motorcycle, lawnmower	90
OSHA level for hearing conservation program	85 *
Conversation	60
Quiet room	50
Whisper	30 to 40

Note: Reprinted from Rabinowitz, (2000) Noise-induced hearing loss. American family physician, OSHA = Occupational Safety and Health Administration; dB = decibels; Measurement expressed as dB (A), a scale weighted toward sounds at higher frequencies. 8- hour time-weighted average.*

1.1. Pathophysiology of NIHL

For the sound to be perceived it must exert a force on the stereocilia of the hair cells on the basilar membrane of the cochlea. Excessive force can lead to cellular metabolic overload, hence cell damage and cell death. Noise-induced hearing loss therefore denotes unnecessary "wear and tear" on the delicate inner ear structures. Exposure to ototoxic substances, such as solvents and heavy metals, can increase the damage potential of noise. When exposure to higher noise level is dropped, additional significant development of hearing loss stops. Each individual's susceptibility to NIHL differs significantly, but few people are stronger to it whereas others are more susceptible for noise exposure.

The ear's extremely wide range of sensitivity is one of the most striking aspects of audition. The ear is sensitive to range of intensities from about 0 dB SPL (which is amplitude of vibration of about size of a hydrogen molecule) to roughly 140 dB (at which pain and damage to the auditory mechanism ensue). This dynamic range of the approximately 140 dB corresponds to pressure ratio of 107:1 (Gelfand, 2017). In other words, the most intense sound pressure that is bearable is on the order of 10 million times as great as the softest one that is perceivable under optimum listening condition. In terms of frequency, humans can hear tones as low as 2 Hz (although roughly 20 Hz is required for a perception of "tonality") and as high as about 20 kHz. The response pattern of basilar membrane varies from base to apex and is tuned to different frequencies at different points along its length. When OHCs are damaged, frequency tuning of basilar membrane becomes broader and shows reduced sensitivity to sounds and the compressive non-linearity is affected so that the input output function becomes progressively linear (Sellick, Patuzzi & Johnstone, 1982).

1.2. Psycho-acoustical abilities

Noise can be described in terms of intensity (perceived as loudness), frequency (perceived as pitch) and duration (perceived as time). These parameters of noise exposure determine the potential for damage to the hair cells of the inner ear. Even sounds perceived as "comfortably" loud can be harmful. The ability to discriminate changes in frequency, intensity and duration can be accounted psycho acoustically by measuring the Difference limen or Just Noticeable Difference (JND). It is the smallest perceivable difference between two stimuli, which is expressed as ΔI, ΔF and ΔT i.e. the minimum change in the absolute physical quantity in terms of intensity, frequency and duration, which is required to perceive two sounds as different. Many authors preferred to express this in relative terms as Weber fraction i.e. $\Delta I/I$ (Gelfand, 2007). The notion that the relative $\Delta I/I$ are constant is the Weber's law. However, it is not always true especially in case of pure tone signals (Mc Gill & Goldenberg, 1968). In terms of frequency discrimination the DLF data from most subjects exhibited a local reduction near the cut-off frequency (Mc Dermott, Lech, Kornblum & Irvine, 1998). DLFs for frequencies below 4 kHz are primarily determined by a temporal mechanism i.e. by information contained in the phase locking of neural responses. Frequency discrimination thresholds increased with noise than without noise especially for elderly hearing impairment [mild to moderate high-frequency sensorineural hearing loss with a pure-tone average (PTA at 0.5, 1, and 2 kHz) <50 dB HL with age range of above 60 years) (Bertoli, Smurzynski & Probst, 2005). Frequency selectivity and frequency discrimination of pure tone and complex tones are higher for individuals with moderate sensorineural hearing loss.

People with high-frequency hearing impairment, growth of loudness for tones presented near the cut-off frequency was less steep than that for tones presented at a lower frequency, although hearing thresholds were near normal at both frequencies, which assume that the upward spread of auditory excitation patterns is effectively truncated at a frequency near the cut-off. Growth of loudness at higher frequencies was steeper than at the cut-off frequency, consistent with the presence of recruitment where hearing thresholds were elevated (McDermott et al., 1998)

Cochlear hearing loss reduces the audibility as well as alters the perception of sound due to structural variations. When these OHCs are damaged, frequency tuning of basilar membrane becomes broader and also shows reduced sensitivity to sounds. Frequency discrimination is adversely affected in cochlear hearing loss or in other words, cochlear hearing loss subjects would show abnormally large DLF values compared to normal subjects (Freyman & Nelson, 1986; Gengel, 1973; Hall & Wood, 1984; Moore & Peters, 1992; Simon & Yund, 1993; Tyler, Wood, & Fernandes, 1983). For high frequencies the phase locking is poor which could be one of the reasons that the DLF values are higher at high frequencies (Palmer & Rusell, 1986).

In subjects with cochlear hearing loss, they show an abnormal loudness growth and the ability to detect small changes in the intensity depends on this, hence, it is expected that for a cochlear hearing loss the DLI would not be affected. Studies found that individuals with cochlear hearing loss performed worse than that of normal if the comparison is made at a given sound pressure level but if we are comparing at equal sensation levels individuals with cochlear hearing loss perform similar or even better than that of normal hearing individuals (Buus, Florentine, & Redden, 1982; Schroder, Viemeister, & Nelson, 1994). However many of the studies failed to show a significant effect of hearing loss on duration discrimination (or in DLD) tasks using difference limen for duration when compared to age matched normal hearing individuals (Fitzgibbons & Salant, 1994).

The subjects with cochlear hearing loss show a recruitment phenomenon (Fowler, 1936; Steinberg & Gardner, 1937) i.e. even if the absolute thresholds are poorer; the rate of loudness growth is faster than that of normal hearing. In fact, when the absolute threshold increases there is a decrement in the dynamic range of the person. When the sound is being presented at sensation levels there is a spread of excitation which will be more rapid than that of normal hearing individuals because of the reduced frequency selectivity in cochlear hearing loss (Evans, 1975; Kiang, Moxon, & Levine, 1970). However, the reduced frequency selectivity in loudness recruitment has only a minor role (Moore, 1996). This abnormal growth of loudness could be attributed to the loss of compressive nonlinearity of cochlea. With the understanding of the consequences of cochlear hearing loss it is recommended that supra threshold measures should also be incorporated to track the functional problems, not just the audibility alone (Brandt, 1967). It was found that our ability to detect small changes in pitch apparently begins to be affected at all the audible frequency ranges as early as the 4th decade of life. Between the ages of 25 and 55 years, the pitch discrimination performances seem to deteriorate in an approximately linear manner; after 55 years the size of the difference limen increases more abruptly. The increase in the size of the difference limen for frequency with advancing age appears to have some connection with the degeneration of some nerve fibers which normally participate actively in the transmission to the brain of the different tones.

The difference limen decreased to a greater or lesser degree by increase of the threshold of intensity at which difference limen was measured. Thus, Luscher and Zwislocki (1949) found the difference limen in individuals with normal hearing was ranging between 12% and 18% at intensity level of 20 dBHL and 3% and 4% at an intensity level of 80 dBHL. Freyman and Nelson (1986) found no consistent changes in DLF with sensation level (SL) that is when it is above 20 dB SL. Luscher and Zwislocki (1949) recommended test tone ranging from 0.25 kHz to 4 kHz, compared with the lower and higher frequencies these frequencies are more reliable. In normal hearing subjects DLI decreases as the SL increases, while above 70 dB SL, the DLI stays almost unchanged.

According to Meurmann (1954), for individual with cochlear pathology, the ΔF was affected by the degree of the hearing loss. As deafness increased, the ΔF increased more rapidly in proportion, i.e. exponentially and not linearly, but conductive hearing loss did not appreciably affect the ΔF. The highest DLF were noted for the Meniere patients in whom they differed much from the normal values, especially at the low frequencies. Hence, present study investigating the differences in intensity, frequency and duration discrimination thresholds on cochlear hearing loss especially individuals with exposure to noise.

Studies also reported that musicians have better frequency discrimination abilities than non-musicians (Zaltz, Globerson & Amir, 2017). Musicians detected pitch changes within one eighth of a difference in tone frequencies, whereas non-musicians required a pitch difference greater than one-fourth (half of a semitone) to discriminate between the tone complexes. DLF measures did not significantly differ between vocal (51.3%) and instrumental musicians (1.4%). All musicians had excellent pitch discrimination with minimal response variability (1–2 Hz) regardless of their music training (Nikjeh, Lister, & Frisch, 2008).

1.3. Need for the study

Studies found that frequency discrimination dependent on both frequency and sensation level (SL) (Wier, Jesteadt & Green, 1977). Study reported by Sek and Moore, (1995) explains that two mechanisms play a role in frequency discrimination. One based on changes in the excitation pattern (a "place" mechanism) and the other based on phase locking in the auditory nerve (a "temporal" mechanism). The temporal mechanism only operates below about 4 kHz and, within this range; it determines DLFs and DLCs (difference limen for change). The temporal mechanism is probably sluggish, and it affects FMDLs only for very low modulation rates. The place mechanism dominates for high frequencies, and for lower carrier frequencies when stimuli are frequency modulated at high rates. According to Meurmann (1954), measurement of the DLF is possible at routine examination and does not cause more technical difficulties than that of the DLI and the DLF is of the same size in normally hearing and conductively deafened persons. For the discrimination of temporal gaps a just noticeable difference in duration (ΔT) clearly depends on the stimulus marker, decreasing as its amplitude increases. For the discrimination of noise or tone burst, ΔT is independent of the magnitude of the stimulus (Abel, 1972). According to

Rabinowitz, Braida and Durlach (1977) it is assumed that all stimuli are equally loud at threshold and at the upper limit of the dynamic range. Sherrick (1959) revealed that only signal-to-noise ratio (SNR) as a significant factor affecting the difference limen. In addition, literature reported factors affecting the difference limens, the effect of different degrees and types of hearing loss on difference limen scores and the time course effect following the fitting of hearing aid, effect of compression parameters of hearing aid on difference limen scores; however, none of the studies have extensively explored whether there is any change in difference limen for frequency, intensity and duration in NIHL, especially individuals who have a 4 kHz notch and high frequency sloping hearing loss.

1.4. Aim of the study

To study the effect of noise induced hearing loss on difference limen for frequency, intensity and duration.

1.5. Objectives of the study

The objectives of the study are as follows:

1. To study the effect of NIHL on DLI, DLF and DLT in individuals with dip only at 4 KHz.
2. To study the effect of NIHL on DLI, DLF and DLT in individuals with high frequency hearing loss.
3. To compare the DLI, DLF and DLT between those individuals with only 4 kHz dip and those with high frequency hearing loss.

1.6. Hypotheses of the study

1.6.1. Null hypotheses:

1. There is no effect of NIHL on DLI, DLF and DLT in individuals with dip only at 4 kHz.
2. There is no effect of NIHL DLI, DLF and DLT in individuals with high frequency hearing loss.
3. There is no effect of noise induced hearing loss on DLI, DLF and DLT in individuals with only 4 kHz dip and those with high frequency hearing loss.

1.6.2. Alternative hypotheses:

1. There is an effect of NIHL on DLI, DLF and DLT in individuals with dip only at 4 kHz.
2. There is an effect of NIHL on DLI, DLF and DLT in individuals with high frequency hearing loss.
3. There is an effect of noise induced hearing loss on DLI, DLF and DLT in individuals with only 4 kHz dip and those with high frequency hearing loss.

Chapter 2

Review of literature

The impact of noise upon the auditory system has become a major problem in current technological society. Occupational hearing loss can be defined as a partial or complete hearing loss in one or both the ears as a result of an individual's employment (Nandi & Dhatrak, 2008). It includes acoustic trauma which results in sudden changes in hearing resulting from single exposure to a sudden burst of sound (ACOEM, 2003) and NIHL. The hearing loss may range from mild to profound, may result in tinnitus, and is cumulative over a life time. NIHL depends on an individual's susceptibility, amount and duration of noise exposure and initially it results in high tone hearing defect and later it spread to speech frequency region (Schwetz, Doppler, Schewezik, & Wellesxhik, 1980).

2.1. Effect of noise

Noise exposure can cause two kinds of health effects, they are: non auditory and auditory effects.

2.1.1. Non auditory effects

Evidence shows that exposure to excessive noise over prolonged periods produces both physiological and psychological changes in human beings. The physiological changes include disturbance and annoyance, cognitive impairment (mainly in children), sleep disturbance, and cardiovascular health. *Noise annoyance* can result from noise interfering with daily activities, feelings, thoughts, sleep, or rest, and might be accompanied by negative responses, such as anger, displeasure, exhaustion, and by stress-related symptoms (Ohrstrom, Skanberg, Svensson, &

Gunnarsson, 2006). WHO estimate that about 45000 disability adjusted life years are lost every year in high income western European countries for children aged 7–19 years because of environmental noise exposure. Advanced mechanisms for noise effects on children's *cognition* include communication difficulties, impaired attention, increased arousal, learned helplessness, frustration, noise annoyance, and consequences of *sleep disturbance* on their performance (Evans, 2006; Stansfeld, Haines, & Brown, 2000). Repeated noise-induced arousals interfere with sleep quality through changes in sleep structure, which include delayed sleep onset and early awakenings, reduced deep (slow-wave) and rapid eye movement sleep, and an increase in time spent awake and in superficial sleep stages (Basner, Müller, & Elmenhorst, 2011; Basner, Müller, & Griefahn, 2010). Long-term exposure to environmental noise affects the *cardiovascular system* and causes manifest diseases (including hypertension, ischemic heart diseases, and stroke) (Babisch, 2011). Chronic exposure can cause an imbalance in an organism's homoeostasis (allostatic load), which affects metabolism and the cardiovascular system, with increases in established cardiovascular disease risk factors such as blood pressure, blood lipid concentrations, blood viscosity, and blood glucose concentrations. These changes increase the risk of hypertension, arteriosclerosis, and are related to severe events, such as myocardial infarction and stroke. Investigators have repeatedly noted that noise exposure increases systolic and diastolic blood pressure, changes heart rate, and causes the release of stress hormones (including catecholamines & glucocorticoids) (Babisch, 2011).

2.1.2. Auditory effects

Due to noise exposure, there are two functional consequences to hearing: *Temporary Threshold Shift (TTS)* and *Permanent Threshold Shift (PTS)* (Plontke &

Tubingen, 2004). TTS refers to a transient sensorineural hearing loss lasting for hours to a few days. Hearing thresholds are depressed until the metabolic activity in the cochlea recovers. Hence prior to audiometric testing subjects should be out of noise for at least 24 hours if not 48 hours to avoid the effect of TTS on hearing (Bohne & Harding, 2000). NIHL cause damage to the outer hair cells of the cochlea resulting in a reduction of the amplification ability of the cochlea (Reshef, Attias, & Furst, 1993). Shortly after a damaging exposure, the cells and the tissues of the inner ear are in a dynamic state of injury, degeneration and / or repair. This has been termed as the acute phase of noise damage. WHO estimates that 10% of the world population is exposed to sound pressure levels that could potentially cause NIHL. In about half of these people, auditory damage can be attributed to exposure to intense noise (Oishi & Schacht, 2011). *Tinnitus* (change in sound perception), such as ringing, that cannot be attributed to an external source, often follows acute and chronic noise exposure, and persists in a high proportion of affected individuals for extended periods (Fritschi & Brown, 2011). Tinnitus can affect quality of life in several ways, including through sleep disturbance, depression, or the inability to sustain attention (Davis & Refaie, 2000). The fact that hearing loss and tinnitus are reported in combination suggests that both symptoms share common pathophysiological pathways.

2.2 Psycho-acoustical abilities

The psycho-acoustical abilities involve the perception of frequency, intensity and the temporal parameters of sound.

2.2.1 Frequency Discrimination Threshold

The minimum frequency difference to differentiate two stimuli is the frequency discrimination threshold. Carroll et al (2017) done a retrospective study using a questionnaire and audiometric tests for adult participants aged 20–69 years. Two years (2011-2012) data was collected from National Health and Nutrition Examination Survey (NHANES) to determine the presence of audiometric notches indicative of noise-induced hearing loss. The weighted prevalence of an audiometric notch among U.S. adults was 39.4 million or 24.4% (6.2% bilateral notch and 18.2% unilateral notch). The presence of an audiometric notch increased with age, ranging from 19.2% among persons aged 20–29 years to 27.3% among persons aged 50–59 years. The prevalence of notches was consistently higher in males than in females for both unilateral and bilateral notches.

In one of the Indian study done in Karnataka by Edward, Manohar, Somayaji and Kallikkadan, (2016), 14 out of 111 workers in plywood industry, 57 workers were confirmed with NIHL (51.4%). Among them 49 (44.15%) were bilateral and 8 (7.2%) were unilateral NIHL. The lowest age of the subject confirmed with NIHL is 20 years and the highest is of 66 years. With respect to degree of hearing loss, 32 workers (56.1%) had only a mild hearing loss and 22 (38.6%) had moderate hearing loss. The rest 3 workers (5.3%) have moderate to severe hearing loss. This study showed a positive correlation between duration of noise exposure and degree of hearing loss.

Moshammer et al in the year of 2015 reported that TTS at 4 kHz is a significant predictor of long-term NIHL, as measured by PTS at 4 kHz or the average PTS for 2–4 kHz. PTS was predicted by duration of noise exposure, frequency of wearing noise protectors and especially by the initial TTS at 4 kHz. Using 14 dB TTS as a cut-off had 82% sensitivity and 53% specificity to predict 20 dB or higher levels of NIHL.

In a retrospective study done by Wilson (2011) reported that Unilateral 4 kHz notches were almost twice as prevalent as bilateral 4 kHz notches and that unilateral notched audiograms are equally common for the left ear and right ear. In terms of the thresholds of the audiograms with 4000 Hz notches:

1) At 250–2000 Hz were at hearing levels 2– 3 dB lower,
2) At 3000 and 4000 Hz were at hearing levels 8–17 dB higher, and
3) At 8000 Hz were at hearing levels 3–4 dB lower;

Hence, the threshold differences were significant at all frequencies for both ears.

Mc Dermott et al (1998) reported that DLF for pulsed pure tone is elevated across frequencies for steeply sloping hearing loss than normal hearing individuals, but it showed a local reduction near the cut-off frequency in most subjects with high-frequency loss.

According to König (1957) there was a large difference limen at higher frequencies, and above 4 kHz most of the subjects experienced the greatest difficulty in judging the pitch of tones. The sensitivity to frequency differences increases with the sensation level however, above 40 dB of threshold the difference limens remains same even when sound intensity increases. With respect to age author reported that the ability to detect small changes in pitch apparently begins to be affected at all the audible frequency ranges as early as the 4th decade of life. Between the ages of 25 and 55 years, the pitch discrimination performances seem to deteriorate in an approximately linear manner with age; after 55 years the size of the difference limen increases more abruptly.

Lam et al (1997) reported that older individuals demonstrated poorer discrimination abilities than young subjects. The age-related difference was always largest at 0.5 kHz and decreased as frequency increased. Even with closely matched audiograms, the aged subjects demonstrated poorer discrimination abilities than the young subjects. Similarly Abel, Krever, and Alberti, (1990) compared Δf between aged and young subjects and found that elderly subjects showed poor frequency discrimination, regardless of hearing sensitivity. However, compared to the aged subjects with hearing loss, the aged normal-hearing subjects showed relatively less deficit at 4000 Hz than at 500 Hz. Moore and Peters (1992) reported that some aged subjects had very large Δf at low frequencies even with normal hearing and near-normal auditory filters. Florentine, Reed, Rabinowitz, Braida and Durlach, (1993) also found poorer DL thresholds in two normal-hearing, aged subjects (55–58 years old) compared to those of young subjects with similar hearing.

Zwicker (1956, 1970) generalized the mechanisms for both frequency and intensity discrimination in an excitation pattern model, in which differences in frequency or intensity can be perceived by changes in the output of any single auditory filter. This place theory has been extended to a multiple-filter version for frequency discrimination (Dai et al., 1995) and for intensity discrimination (Buus & Florentine, 1982; Florentine et al., 1987).

Freigang et al (2011) found JND for frequency, intensity, and signal duration increased for older people (65–89 years) compare to younger people (20–29 years). Freyman and Nelson (1991) Frequency difference limen was measured for 7 normal-hearing subjects and 16 ears of 12 listeners with sensorineural hearing losses (moderate hearing loss at one or more frequencies, exhibited a steep high-frequency hearing loss, 6 ears exhibited a mid-frequency "cookie bite" hearing loss with better hearing at low and high frequencies, 4 ears exhibited relatively flat hearing losses, and 1 ear demonstrated a low-frequency hearing loss with normal hearing above 2 kHz. They found that majority of subjects with sensorineural hearing impairment have larger frequency difference limens for pure tones than the normal-hearing subjects. For people with normal hearing sensitivity, as frequency increases DLF also increases. For individuals with hearing impaired, some data are fall within the normal range. However correlation between the DLF deficit and the amount of hearing loss at the test frequency was not strong.

Simon and Yund (1993) measured frequency difference limen (FDL) for each ear on 34 participants with bilateral cochlear hearing loss. They reported that FDLs could be different for the two ears when the absolute thresholds were same and FDLs could be same when the thresholds of the two ears were different. Turner and Nelson (1982) evaluated the frequency discrimination for normal hearing individuals and hearing impaired individuals with various amounts of hearing loss existed at frequencies above 1.5 kHz in the age range of 20-29 years. DLFs were measured at 0.3 kHz, 1.2 kHz, and 3 kHz. They found that the differences between normal and impaired DLFs would be large. At 3 kHz there was a larger DLF associated with greater sensitivity losses at the test frequency. Even though the listeners having approximately the same sensitivity thresholds at the 3 kHz, a large spread of DLF values was seen evidently. This might be that those listeners with sharply sloping sensitivity losses in the region of the test frequency used loudness difference cues to aid in their discrimination judgements. The larger DLF at high frequencies may be because of loss of sensitivity at higher frequencies.

Mc Dermott et al (1998) assessed 5 subjects with normal hearing sensitivity and 5 subjects with steeply sloping hearing loss in the age range of 21- 42 years. The DLF measured for frequencies of 0.25 kHz, 0.5 kHz, 1 kHz, 1.5 kHz, 2 kHz, and 4 kHz. Results revealed that DLFs are a non-monotonic function of frequency. At frequencies well below the cut off frequency, DLFs are higher than the mean DLFs for sloping as well as normal hearing subjects. Whereas at frequencies well above the cut off frequency, increase in DLFs with frequency. DLFs are reduced near the cutoff frequency relative to those at surrounding frequencies.

Thai-van, Micheyl, Norena, and Collet, (2002) done a study to evaluate whether the effect of auditory frequency discrimination is present in subjects with various degree of hearing loss. DLF was done for 20 individuals with high frequency hearing loss in that 3 subject with notched hearing loss. The DLF was done between 0.25 kHz and 8 kHz at intervals of 1/2 octave. They found that there was a significant difference in DLF across frequency. DLFs were significantly smaller in frequency band 1/4 octave and wide centered on cut off frequency than in other frequency band. Moreover, the average DLF measured in this band proved to be negatively correlated with the slope of the hearing loss.

2.2.2 Intensity Discrimination Threshold

It is the ability of a person to detect small changes in intensity. Florentine et al. (1993) measured intensity difference limen (IDL) on two older listeners and they reported that IDL was larger in older adults compared to those of young listeners with comparable hearing sensitivity. He, Dubno and Mills, (1998) compared IDL for 13 participants with normal hearing sensitivity (7 young & 6 elderly). Difference Limen was measured at 0.5 kHz, 1 kHz, 2 kHz and 4 kHz using the maximum likelihood procedure starting at 40 dB SPL followed by 80 dB SPL. DL was uniform across participants and frequency with an overall mean of 2.98 dB. Elderly adults showed larger inter-subject variability than younger adults and age related difference was greater at lower than at high frequency. Gelfand (2009) reported that the DLs for intensity reduce as the sensation level increases for mid-frequency stimuli. Miller (1947) measured DL for white noise in participants with normal hearing sensitivity and he reported that DL in level was constant regardless of the absolute level. The value was about 0.5-1 dB for white noise, presented at 20 dB to 100 dB above absolute threshold in normal hearing individuals. Another study by Jesteadt, Wier and Green, (1977) also supported the same results. It has also been reported that with increase in intensity the change in DL was less for pulsed tone than modulated tone (Moore, 1995).

Intensity discrimination was measured for various frequencies and various sensation levels by Jesteadt et al (1977) and it is reported that log ($\Delta I/I$) decreases linearly as a function of sensation level and is independent of signal frequency. Buus, et al (1982a, 1982b), measured intensity DL in hearing impaired individuals. The results reported that the DL was better in individuals with cochlear damage compared to normal hearing individuals when testing was done at equal sensation levels. Similarly, Turner, Zwislocki and Filion (1989) measured the DL for pure tones with gated and continuous-pedestal paradigms in individuals with normal hearing sensitivity and individuals with cochlear hearing loss. The experiments were performed at 0.5 Hz, 2 kHz and 6 kHz at a wide range of SLs by means of an adaptive two alternative forced-choice procedure. Results revealed that the individuals with hearing loss had smaller DL values than the individuals with normal hearing for both pedestal paradigms at equal SLs. However, when the comparisons were made on the basis of equal SPLs both groups showed similar values for moderate and high SPLs. At relatively low SPLs, the group with hearing loss had a higher DL value.

Thus, it is evident from the above study that DL of intensity reduces at equal sensation level in individuals with cochlear hearing loss compared to individuals with normal hearing sensitivity. Humes (1996) reported in his study that older participants had poorer IDL compared to younger participants and when the hearing levels between the two groups were minimized by adding a high pass masker for younger subjects, IDL difference became negligible.

2.2.3 Duration Discrimination Threshold

It is the skill of the auditory system to detect minute changes in the duration of acoustic stimuli. Creelman (1962) reported that the smallest detectable change in duration of a stimulus (ΔT) increases with increase in baseline duration (T) of a stimulus. Shylaja (2005) measured duration discrimination on normal hearing adults using 1000 Hz anchor tone having duration of 50 ms at 40 dB SL using a gated method. The results indicated that the participants could differentiate 15 to 25 ms difference in duration between the two stimuli.

Duration discrimination has been studied to examine whether there is any age related difference. Fitzgibbons and Gordon-Salant (1994) studied duration discrimination on 40 participants in four groups consisting of elderly listeners and young listeners with normal hearing sensitivity and with mild to moderate sloping sensorineural hearing loss. Duration discrimination was measured for a tone burst of 0.5 kHz and 4 kHz using reference duration of 250 ms at 85 dB SPL. Results indicated that average discrimination for elderly listeners was larger than for younger listeners. However, there was no effect of hearing loss on discrimination ability.

In another study, Phillips, Gordon-Salant, Fitzgibbons and Yeni-Komshian (1994) compared duration discrimination in young and elderly participants with normal hearing sensitivity. DL for duration was measured between a standard 1 kHz tone of 40 ms and a comparison tone of longer duration. The duration discrimination paradigm was presented with a tonal masker following the tonal stimulus at three delay times: 80 ms, 240 ms & 720 ms and complex stimulus. Age effects were observed on the duration discrimination task with interference, but not on the initial duration discrimination task without interference. These results suggested that the time required to process the duration characteristics of acoustic stimuli is prolonged in elderly listeners.

Kumar and Sangamanatha (2011) measured duration discrimination on 176 participants (20 to 85 years) with normal hearing sensitivity using an anchor stimulus of 250 ms white noise. Scores were similar for individuals in the age range of 20-30 years and 31 - 40 years. Individuals above 70 years had poorer scores compared to all other age groups. It can be concluded that duration discrimination ability deteriorates with age and elderly individual above 70 years showed poorest discrimination ability.

Kumar, Ameenudin and Sangamanatha (2012) had done a study on individuals who are exposed to occupational noise of more than 80 dBA. The aim of the study was to evaluated temporal processing and speech perception Skills and compared individuals who are exposed to noise (118 people into 3 different age groups) and individuals who are not exposed to noise (30 in each age group). Temporal processing was evaluated using gap detection, modulation detection, and duration pattern tests.

The results revealed that reduced temporal processing skills in individuals with noise exposure. Abel (1972) measured duration discrimination using stimuli with baseline durations of 10, 100 and 1000 ms and ΔT was found to be around 4, 15 and 60 ms respectively. The results were relatively independent of the overall level of the stimuli and were 23 also similar for noise bursts of various widths and 1000 Hz tone burst.

These are the various review of literature that has been reported regarding the difference limen measures on different groups of individuals with hearing impairment as well as normal hearing individuals. However, there is dearth on literature pertaining to the psychoacoustic abilities of different limen with effect on NIHL.

Chapter 3

Method

3.1 Participants

A total number of 40 ears with the age range of 20 to 45 years were included in the study. The participants were divided into two groups, (Group I: 20 individuals exposure to noise and pure tone thresholds having only 4 kHz dip (mean age: 40.57years, SD: 6.30) and Group II: individuals exposure to noise and having high frequency hearing loss (mean age; 43.1years, SD: 9.55). The participants were selected based on the following criteria:

- Mild to moderate sensorineural hearing loss for the frequency range of 0.25 kHz to 8 kHz in (air conduction thresholds in the range of 26-55 dB HL and air bone gap of ≤ 10 dBHL) for group two individuals.
- Age range between 20 to 45 years.
- No otological or neurological problems.
- Normal cognitive ability to understand the task.
- Exposed to noise (8 hours/ day) minimum for 3 years
- No reported complaint of tinnitus.

3.2 Instruments

Inventis piano dual channel diagnostic audiometer was used to estimate the pure tone thresholds. The signals were presented over headphones HDA200. Calibrated Immittance audiometer (GSI-Tympstar) was used to make sure that the subject does not have any conductive component on the day of testing. All the difference limen measures were performed using ‘mlp’ loaded on MATLAB software, version 21.

3.3 Test Procedure

Written informed consent was taken from all the participants for willingly participating in the investigation. The study was carried out as follows:

a) Detailed case history

Detailed case history was taken as a closed set interview about the auditory and the vestibular disorders symptomatology, presence of tinnitus, as well as ototoxic drugs and general health conditions.

b) Otoscopy

Otoscopy was carried out before the testing. It is done to visually inspect the status of the external ear canal and tympanic membrane.

c) Obtaining thresholds

Pure Tone Audiometry was carried out using Inventis piano dual channel diagnostic audiometer to estimate Air conduction and Bone conduction thresholds for frequencies between 0.25 kHz to 8 kHz and from 0.25 kHz to 4 kHz respectively using Modified Hughson and Westlake procedure (Carhart & Jerger, 1959)

d) Acoustic Immittance audiometry

Immittance audiometry was carried out using GSI Tympstar to rule out any middle ear pathologies. Tympanometry was done using a 226 Hz probe tone using a calibrated middle ear analyser. Acoustic reflex threshold were determined for 0.5 kHz, 1 kHz, 2 kHz and 4 kHz both ipsilaterally and contralaterally.

e) Assessment of difference limen abilities

All psycho-acoustical tests were carried out using ‘mlp’ toolbox, which implements maximum likelihood procedure for threshold estimation in MATLAB

(Grassi and Soranzo, 2009). The ‘mlp’ make use of a large number of participant’s psychometric functions and following every trial, it estimates the likelihood of arriving at the listener’s response for all the stimuli that had been presented. Further, the psychometric function that gives the highest likelihood is used to decide the stimulus to be presented in the next trial. It is reported that within 12 trials, the ‘mlp’ generally meets the fairly stable approximation of the most probable psychometric function, which can be used to approximate thresholds (Grassi & Soranzo 2009; Green, 1990, 1993). This procedure has been widely used to assess psycho-acoustical abilities and found to have good reliability and validity Kumar and Sangamanatha, (2011).

Stimuli for all psycho- acoustical tests were generated at 44,100 Hz sampling rate. All the tests were performed using a three-interval alternate forced-choice technique to track a 79.4% correct response criterion (Levitt, 1971). Each trial consists of three blocks, wherein, two blocks had the standard stimulus and the other block had the variable stimulus. The participant’s task was to identify the block containing the variable stimulus. All the psycho-acoustical tests were performing as per the procedure stated above and the presentation of the stimulus and acquisition of the response was controlled by the ‘mlp’ toolbox. Before the beginning of the each test two to three practice items were given. The tests were performed in a randomized order across participants to avoid potential order effect. The stimulus for all difference limen tests were presented at 85 dB SPL. Headphone was calibrated to produce desired output level (70 dBHL). Details of the stimuli and procedure used for individual tests are provided below:

3.3.1. Frequency difference limen (DLF)

In this task, the minimum frequency difference necessary to discriminate two closely spaced frequencies were assessed. Frequency difference limen (FDL) was measured at 1 kHz, 2 kHz, 4 kHz and 6 kHz. Both the standard and variable stimuli were of 250 ms long pure tones with the onset and offsets of 10 ms raised cosine ramp (Grassi & Soranzo 2009; Jain, Mohamed & Kumar, 2014). The procedure was carried out using a Three Interval Alternate Forced Choice Method (3-IAFC) in which each trial had two blocks of pure tones at a standard frequency and other one comprised of a pure tone of variable frequency (variable frequency was always higher than the standard frequency). The minimum and maximum frequency deviation of the variable stimulus was 0.1 Hz and 200 Hz respectively. The participants were instructed as follows:

"Three blocks will be appearing on the screen and you will be hearing three tones sequentially i.e.one tone in each block, but one among the tone will be different while other two would be similar, you have to select the block/ tell which has a different tone among the three blocks presented or three tones heard".

A three-down, one-up rule was used to approximate the frequency difference corresponding to the 79.4% point of the psychometric function (Levitt, 1971)

3.3.1. Intensity difference limen (DLI)

In this task, the minimum intensity difference necessary to discriminate two closely spaced intensities were assessed. Intensity difference limen (IDL) was measured at 1 kHz, 2 kHz, 4 kHz and 6 kHz. Both the standard and variable stimuli were of 250 ms long pure tones with 10 ms raised cosine ramps at onset and offsets (Grassi & Soranzo, 2009; Jain et al., 2014). The minimum and maximum intensity deviation was used at 0.99 dB and 10 dB respectively. The procedure was carried out using a Three Interval Alternate Forced Choice Method (3-IAFC) where each trial had two blocks of pure tones at a standard intensity and other one comprised of a pure tone of variable intensity (variable intensity was always higher than the standard intensity). The participants were instructed as follows:

"Three blocks will be appearing on the screen and you will be hearing tones in all the three blocks, but one among them is different in terms of its loudness, you have to select the block which is more loudly among the three tones heard".

A three-down, one-up rule was used to estimate the intensity difference corresponding to the 79.4% point of the psychometric function (Levitt, 1971).

3.3.3. Duration discrimination test (DDT)

In this task, the minimum duration difference necessary to discriminate two tons of closely spaced duration were assessed. Time difference limen (TDL) was measured at 1 kHz, 2 kHz, 4 kHz and 6 kHz. Both the standard stimuli were of 250 ms long, pure tones with 10 ms raised cosine ramp at onset and offsets (Grassi & Soranzo, 2009; Jain et al., 2014). And the variable stimuli changed in its duration from 0.1 msec to 200.1 msec. On each trial of three blocks, two blocks had pure tones of a standard duration and other block contained a random pure tone of variable duration, which was always longer than the standard duration. The participants were instructed as follows:

"Three blocks will be appearing on the screen and you will be hearing tones in all the three blocks, but one among them is different in terms of its duration, you have to select the block which has a different tone or which is longer in duration among the three blocks presented".

A three-down, one-up rule was used to estimate the duration difference corresponding to the 79.4% point of the psychometric (Levitt, 1971).

3.4 Statistical Analyses

The data obtained from the study was subjected to statistical analyses using the statistical package for the social science (version 21). Descriptive statistics was carried out to estimate the mean and standard deviation for all the parameters. Following this normality and other assumptions of parametric tests were assessed. Independent t sample test was carried out to compare the DLF, DLI and DLT between both the groups. Repeated measure ANOVA was carried out to measure the within group comparison across different frequencies.

Chapter 4

Results

In the present study, two groups of participants were included. Group I had 14 individuals who were exposed to noise and having of 4 kHz dip in the pure tone threshold with mild to moderate degree of loss and group II had 10 individuals who were exposed to noise and having high frequency hearing loss with mild to moderate degree of loss. A total of 40 ears were considered for the study. For the groups, differential limen for frequency (DLF), intensity (DLI) and time DLT) were assessed using "mlp" toolbox which implements a maximum likelihood procedure in MATLAB. The data obtained was tabulated and then analyzed using statistical package of social science (SPSS) software version 21.

4.1 Test of normality

Shapiro-Wilk's test of normality was used to check whether the scores fulfilled the assumptions of normal distribution for parametric tests. The results revealed that both the group data followed normal distribution ($p > 0.05$). Hence a parametric test was used to compare the DLI, DLF and DLT scores across frequencies and between the groups.

The results of the study are explained under following headings:

1. To study the effect of NIHL on DLI, DLF and DLT in individuals with dip only at 4 kHz.
2. To study the effect of NIHL on DLI, DLF and DLT in individuals with high frequency hearing loss.
3. To compare the DLI, DLF and DLT between those individuals with only 4 kHz dip and those with high frequency hearing

4.2 Mean and standard deviation (SD) for group I and group II for DLF, DLI and DLT

Descriptive statistics was done to calculate the mean and standard deviation (SD) for the tabulated data. The mean and SD of DLF, DLI and DLT across frequencies such as 1 kHz, 2 kHz, 4 kHz and 6 kHz in group I and in group II are shown in the Figure 4.1, 4.2, and 4.3 respectively.

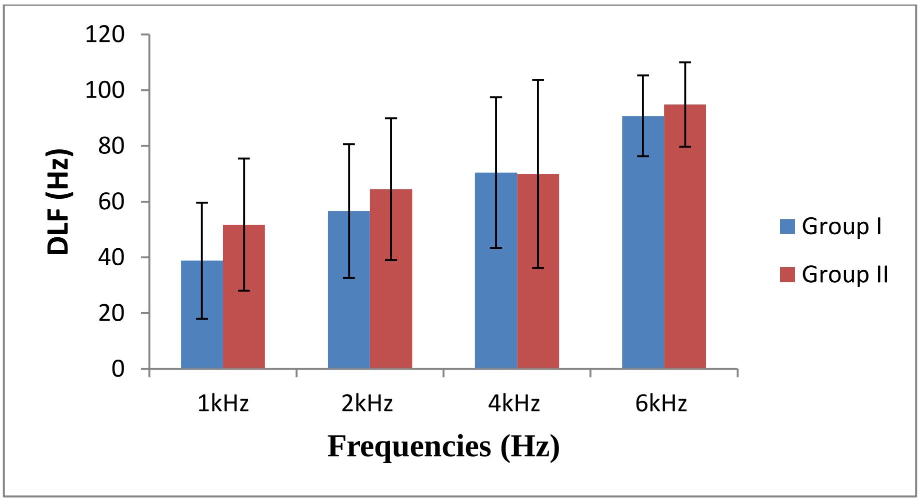

Figure 4.1: Mean and SD for DLF between group I and group II for each test frequencies

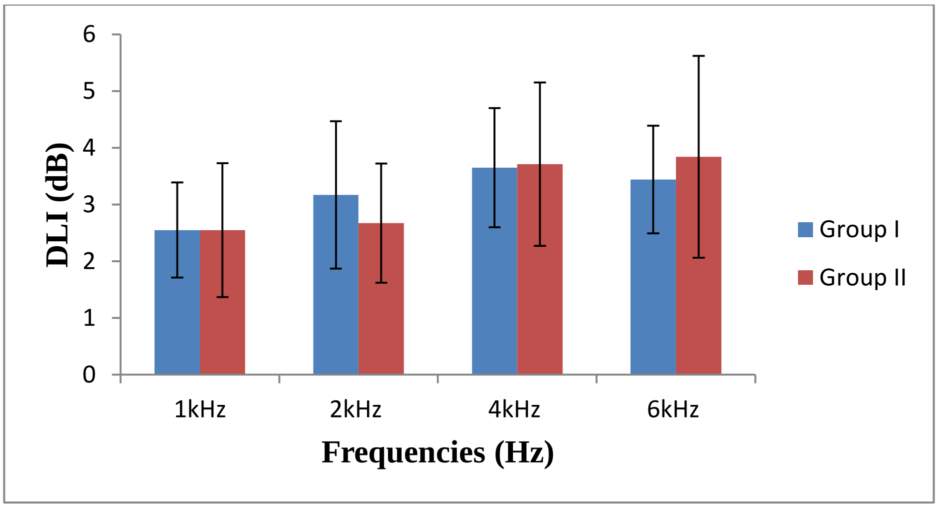

Figure 4.2: Mean and SD for DLI between group I and group II for each test frequencies

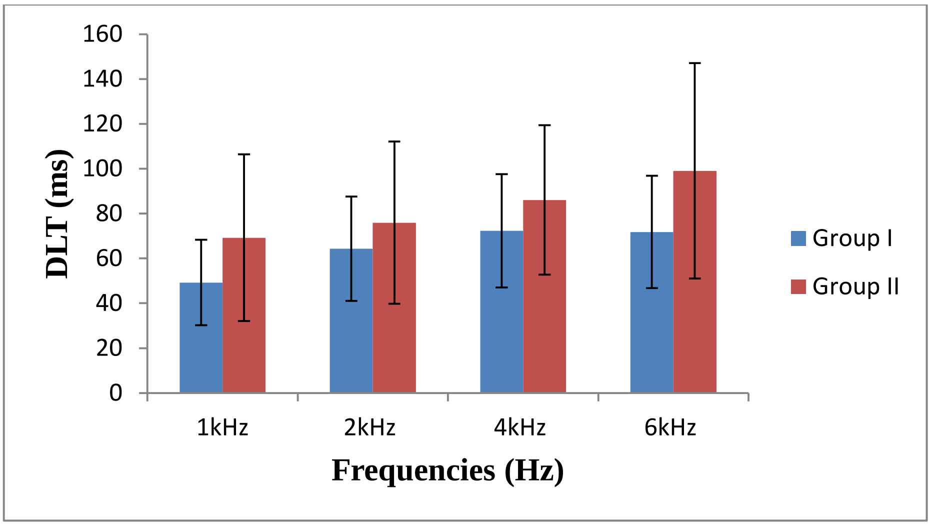

Figure 4.3: Mean and SD for DLT between group I and group II for each test frequencies

Descriptive statistics including the mean and SD of DLF, DLI and DLT for both the groups are depicted in figure 4.1, 4.2 and 4.3 respectively. It can be seen from the figures, that DLF and DLT of individual with group I were better than the participants scores in group II, but DLI were different between the groups only at 2 kHz and 6 kHz.

4.3. Effect of NIHL on DLI, DLF and DLT in individuals with dip only at 4 kHz (Group I).

This section addresses the objective 1 of the study. The result for the effect of NIHL on DLF, DLI and DLT for individuals in group I is discussed below.

4.3.1. Frequency difference limen

The mean and SD of frequency difference limen across all the four frequencies are shown in Figure 4.1. From the figure it can be inferred that DLF increases with frequencies. Repeated measure ANOVA was done to assess the statistical significance of these differences in DLF across different frequencies. Results showed that there is a significant main effect of frequencies [F (3, 17) = 31.27, $p < 0.01$] on DLF. Since there was significant difference between frequencies, pair wise comparison was done across different frequencies. Table 4.1 shows the result of pair wise comparison at all the four frequencies using Bonferroni's corrections for multiple comparisons.

Table 4.1*: Pair wise comparison of DLF across frequencies within group I*

Frequency(kHz)	**1**	**2**	**4**	**6**
1		NS	SD	SD
2			NS	SD
4				NS
6				

Note: SD= Significant difference (p < 0.05), NS= No significant difference (p > 0.05)

From the Table 4.1 it can be noted that there was a significant difference in DLF between 4 kHz and 1 kHz also between 6 kHz and 1 kHz, hence there in an effect of frequency on DLF of individuals in group 1 only between higher and lower frequencies which are 2 octaves apart, Whereas the DLF worsens as the frequency increases.

4.3.2. Intensity difference limen

Intensity difference limen was assessed at 1 kHz, 2 kHz, 4 kHz and 6 kHz. The mean and SD of DLI across for all the four frequencies depicted in Figure 4.2. From the figure it can be noted that DLI increases with frequency except at 6 kHz. Repeated measure ANOVA was done to assess the statistical significance of these differences in DLI across different frequencies. Results showed that there is a significant main effect of frequencies [F (3, 17) = 11.23, $p < 0.01$] on DLI. Since there was significant difference between frequencies, pair wise comparison was done across different frequencies. Table 4.2 shows the result of pair wise comparison at all the four frequencies using Bonferroni's corrections for multiple comparisons.

Table 4.2: *Pair wise comparison of DLI across frequencies within group I*

Frequency (kHz)	**1**	**2**	**4**	**6**
1		SD	SD	SD
2			NS	SD
4				SD
6				

Note: SD= Significant difference (p < 0.05), NS= No significant difference (p > 0.05)

From the Table 4.2 it can be noted that DLI was significantly different between 1 kHz with other test frequencies, 2 kHz is different from 6 kHz, and 4 kHz is different from 6 kHz.

4.3.3. Duration difference limen

Duration difference limen was assessed at 1 kHz, 2 kHz, 4 kHz and 6 kHz. The mean and SD of DLT across for all the four frequencies depicted in Figure 4.3. From the figure it can be noted that DLT increases with frequency. But there is no difference between 4 kHz and 6 kHz. Repeated measure ANOVA was done to assess the statistical significance of these differences in DLT across different frequencies. Results showed that there is a significant main effect of frequencies [F (3, 17) = 4.69, $p < 0.01$] on DLT. Since there was significant difference between frequencies, pair wise comparison was done across different frequencies. Table 4.3 shows the result of pair wise comparison at all the four frequencies using Bonferroni's corrections for multiple comparisons.

Table 4.3: *Pair wise comparison of DLT across frequencies within group I*

Frequency (kHz)	1	2	4	6
1		NS	SD	SD
2			NS	NS
4				NS
6				

Note: SD= Significant difference (p< 0.05), NS= No significant difference (p >0.05)

From the Table 4.3 it can be noted that DLT significantly different between 1 kHz, 4 kHz and 6 kHz. Since there is a significant difference across frequencies for DLF, DLI and DLT the null hypothesis, that "there is no effect of NIHL on DLI, DLF and DLT in individuals with dip only at 4 kHz" was rejected.

4.4 Effect of NIHL on DLI, DLF and DLT in individuals with high frequency hearing loss (Group II).

This section addresses the objective 2 of the study. The result for the effect of noise induced hearing loss on DLF, DLI and DLT in group II is discussed below.

4.4.1. Frequency difference limen

The mean and SD of frequency difference limen across all the four frequencies are shown in Figure 4.1. From the figure it can be inferred that DLF increases with frequencies. Repeated measure ANOVA was done to assess the statistical significance of these differences in DLF across different frequencies. Results showed that there is a significant main effect of frequencies [F (3, 17) = 25.40, p < 0.01] on DLF. Since there was significant difference between frequencies, pair wise comparison was done across different frequencies. Table 4.4 shows the result of pair wise comparison at all the four frequencies using Bonferroni's corrections for multiple comparisons.

Table 4.4: *Pair wise comparison of DLF across frequencies within group II*

Frequency (kHz)	1	2	4	6
1		NS	NS	SD
2			NS	SD
4				SD
6				

Note: SD= Significant difference ($p < 0.05$), NS= No significant difference ($p > 0.05$)

From the Table 4.4 it can be noted that DLF at 6 kHz was significantly different than 1 kHz, 2 kHz and 4 kHz.

4.4.2. Intensity difference limen

Intensity difference limen was assessed at 1 kHz, 2 kHz, 4 kHz and 6 kHz. The mean and SD of DLI across for all the four frequencies depicted in Figure 4.2. From the figure it can be noted that DLI increases with frequency, but there is a slight difference between 1 kHz & 2 kHz and the same way 4 kHz & 6 kHz. Repeated measure ANOVA was done to assess the statistical significance of these differences in DLI across different frequencies. Results showed that there is a significant main effect of frequencies [$F (3, 17) = 7.79$, $p < 0.01$] on DLI. Since there was significant difference between frequencies, pair wise comparison was done across different frequencies. Table 4.5 shows the result of pair wise comparison at all the four frequencies using Bonferroni's corrections for multiple comparisons.

Table 4.5**:** *Pair wise comparison of DLI across frequencies within group II*

Frequency (kHz)	**1**	**2**	**4**	**6**
1		NS	SD	SD
2			SD	SD
4				NS
6				

Note: SD= Significant difference ($p < 0.05$), NS= No significant difference ($p > 0.05$)

From the Table 4.5 it can be noted that DLI at 4 kHz and 6 kHz were significantly different than DLI at 1 kHz and 2 kHz.

4.4.3 Duration difference limen

Duration difference limen was assessed at 1 kHz, 2 kHz, 4 kHz and 6 kHz. The mean and SD of DLT across for all the four frequencies depicted in figure 4.3. From the figure it can be noted that DLT increases with frequency. Repeated measure ANOVA was done to assess the statistical significance of these differences in DLT across different frequencies. Results showed that there is a significant main effect of frequencies [$F(3, 17) = 8.10$, $p< 0.01$] on DLT. Since there was significant difference between frequencies, pair wise comparison was done across different frequencies. Table 4.6 shows the result of pair wise comparison at all the four frequencies using Bonferroni's corrections for multiple comparisons.

Table 4.6**:** *Pair wise comparison of DLT across frequencies within group II*

Frequency (kHz)	1	2	4	6
1		NS	SD	SD
2			NS	SD
4				NS
6				

Note: SD= Significant difference ($p < 0.05$), NS= No significant difference ($p > 0.05$)

From the Table 4.6 it can be noted that DLT was significantly different between 1 kHz and 4 kHz, also between 2 kHz and 6 kHz, that is DLT becomes poorer when the frequencies increases by 2 octaves. Since there is a significant difference across frequencies for DLF, DLI and DLT for individuals in group 2, hence, the null hypothesis is rejected.

4.5 Comparison of DLI, DLF and DLT between group I and group II

As the data followed normal distribution, independent t- test was used to compare the scores between the groups. The result revealed that there was a significant difference between both the groups as depicted in the Table 4.7 below.

Table 4.7: *'t' values for DLF, DLI and DLT across frequencies between groups*

Freq. / Measures	t value			
	1 kHz	**2 kHz**	**4 kHz**	**6 kHz**
DLF	1.84	0.99	-0.47	0.86
DLI	0.15	-1.32	0.15	0.88
DLT	2.14	1.21	1.47	2.25*

***Note:* ****p* < 0.05*(significant difference)*

Table 4.7 shows that there is significant difference between both groups in DLT at high frequencies only at 6 kHz. Since there is a significant difference across frequencies for DLT for individuals in both the groups, the null hypothesis is partially rejected.

Chapter 5

Discussion

The aim of the present study was to assess the effect of NIHL on difference limen for frequency, intensity and duration. A total number of 40 ears with the age range of 20 to 45 years were included in the study. The group I had 14 individuals who were exposed to noise and having mild to moderate sensory-neural hearing loss with 4 kHz dip and group II had 10 individuals who are exposed to noise and having mild to moderate high frequency hearing loss. Within group comparison across frequencies also was studied. Independent t sample test was used to compare between groups and repeated measure ANOVA was used to compare within group across different frequencies. The results of the study are discussed below.

5.1 Effect of NIHL on DLI, DLF and DLT in individuals with dip at 4 kHz (Group I).

5.1.1. Frequency difference limen

The present study investigated the effect of NIHL on all three domain of sound: frequency, intensity and duration. All three domains were investigated by measuring just noticeable difference using 'mlp'. Results indicated that DLF increases with frequencies i.e. larger DLF at higher test frequencies. Also it is noted that there was a significant difference in DLF between 1 kHz and 4 kHz also between 1 kHz and 6 kHz, hence there in an effect of frequency on DLF of individuals in group I, only between higher and lower frequencies which are 2 octaves apart, Whereas the DLF worsens as the frequency increases.

The possible reason could be that the DLF below 4 kHz are primarily determined by a temporal mechanism i.e., by information contained in the phase locking of neural responses. This mechanism allows fine frequency discrimination and allows the direction of a frequency change to be identified at lower frequencies. Above 4 kHz, phase-locking information is not usable, or is only weakly usable. Hence, DLF increase considerably (Sek & Moore, 1995). Also König (1957) reported that even most of the normal hearing subjects experience the greatest difficulty in judging the pitch of tones when there is a large difference limen at higher frequencies and (or) above 4 kHz. These results support spectral and spectro-temporal theories of pitch perception

5.1.2. Intensity difference limen

The effect of NIHL on DLI revealed that DLI increases with frequencies except at 6 kHz. Pair wise comparison results of the study discovered that DLI at 4 kHz was significantly poorer than 1 kHz and 6 kHz.

Our results are consistent with the previous results the better performance in cochlear hearing loss explained in the literature is due to abnormal loudness growth (recruitment) function in individuals with cochlear hearing loss. But it is also important to mention that recruitment may not be seen for all individuals with cochlear hearing loss. Also in sensorineural group, it is difficult to have any clear delineation between neural and sensory components. It could also be possible that the DLI is significantly poorer at 4 kHz compare to 1 kHz and 6 kHz might be because of the poorer threshold at 4 k Hz.

Data from the other study contradicting with our results, that indicate the Weber fraction, $\Delta I/I$, is independent of signal frequency, over the range of frequencies and intensities tested (Jesteadt et al., 1997).

5.1.3 Duration difference limen

The results of the present study showed that the DLT increases with frequency. But there is no significant difference between 4 kHz and 6 kHz. DLT at 2 kHz, 4 kHz and 6 kHz were significantly poorer than 1 kHz.

Several factors might have contributed to the deficits in temporal processing. A loss of OHCs could have resulted in a reduced precision of phase locking (Woolf, Ryan & Bone, 1981). However, this is controversial, as other studies did not find evidence for such phase-locking anomalies because low frequency performance is better when compare high frequency. Also, a loss of OHCs might have altered the spatiotemporal response pattern of the basilar membrane (Strelcyk & Dau, 2009). This could also affect the DLT.

Individuals with cochlear hearing loss are able to use temporal fine structure information at lower frequencies (Hopkins & Moore, 2011). And the deficit in temporal fine structure processing was responsible for the poor performance by hearing impaired subjects. The results have reported that the hearing impaired subjects with moderate cochlear hearing loss have very little or no ability to use temporal fine structure cues to discrimination ability.

5.2 Effect of NIHL on DLI, DLF and DLT in individuals with high frequency hearing loss (Group II).

5.2.1 Frequency difference limen

In the current study the effect of NIHL on DLF, DLI and DLT in individuals with sloping hearing loss. The results revealed that DLF increases with frequencies in high frequency sloping hearing loss. DLF at 6 kHz was significantly poorer than 1 kHz, 2 kHz and 4 kHz.

Our results supporting with previous studies Turner and Nelson (1982); Mc Dermott, et al (1998); Thai-van, et al, (2002) which stats that at the lower frequencies the thresholds were near normal hence it is likely that the elevation in the corresponding DLFs is related to a loss of hearing sensitivity. Similar elevations of DLFs associated with various degrees of hearing loss have been reported previously (Moore & Peters, 1992; Turner & Nelson, 1982)To interpret the DLF data at the higher frequencies is based on auditory excitation patterns (Zwicker, 1970; Moore, 1996; Moore & Glasberg, 1989). The excitation pattern for a pure-tone stimulus is roughly triangular, with the peak located at a place corresponding to the frequency of the tone. A change in the stimulus frequency causes a shift in the excitation pattern, and consequently a change in excitation levels in the regions on each side of the peak. Because the slope of the excitation pattern is steeper on the low frequency side of the peak, it has been suggested by some researchers that detection of changes in excitation level in that region might be sufficient to enable discrimination of changes in the stimulus frequency.

For individuals with sloping hearing loss for stimulus frequencies below the cut off frequency, reduced information would be available from higher frequency regions. For frequencies close to cut off frequency, only information from the lower-frequency portion of the excitation pattern would be available. The larger DLF at high frequencies may be because of loss of sensitivity at higher frequencies.

Turner and Nelson (1982) also supports the present study that in case of cochlear hearing loss, the pathology responsible for the sensitivity loss at high frequencies may alter the stimulus related firing patterns from basal end neurons that normally contribute to acuity at lower frequencies. Or, the cochlear pathology responsible for a high frequency sensitivity loss may also alter the mechanical properties of the traveling wave in the cochlea so as to affect frequency discriminations based on information from low and middle frequency regions of the cochlea. In cases of high frequency, noise induced sensitivity loss the sensory deficits in lower frequency regions of the cochlea may simply not be indicated by elevated thresholds at those lower frequencies. Evidence of normal sensitivity thresholds associated with a partial loss of sensory elements has been presented by Schuknecht and Woellner (1955), Citron, Dix, Hallpike, and Hood (1963), and Stebbins, Hawkins, Johnsson, and Moody (1979).

5.2.2 Intensity difference limen

For individuals with high frequency sloping hearing loss showed increased DLI with frequency, but there is a slight difference between 1 kHz & 2 kHz and the same way 4 kHz & 6 kHz in sloping hearing loss. DLI at 4 kHz and 6 kHz were significantly poorer than DLI at 1 kHz and 2 kHz.

Cochlear hearing loss is usually associated with damage to the active mechanism in the cochlea. This result in reduced frequency selectivity, which contributes to reduced cochlear compression, which is probably the main cause of loudness recruitment (Moore, 2002). As there is not much literature about the DLI on the function frequency, it can be concluded that the increase in DLI with frequency might be due to the poorer threshold at higher frequencies.

5.2.3 Duration difference limen

The results of the study showed the DLT increases with frequency. DLT was significantly different between 1 kHz and 4 kHz, also between 2 kHz and 6 kHz; that is DLT becomes poorer when the frequency increases by 2 octaves. This is supported by (Woolf et al., 1981; Tyler et al. 1982) who related this to poor phase locking and defective channel capacity to separate the onset and offset of stimuli by hearing impaired individuals. It is possible that deterioration in phase locking following due to loss of basal turns of OHC would similarly disrupt the temporal coding of signal.

5.3 Comparison of DLI, DLF and DLT between group I and group II

The psycho- acousticl abilities such as DLF, DLI and DLT were compared between individuals with 4 kHz dip and individuals with high frequency sloping hearing loss using independent t sample test. The result revealed that there was a significant difference between both the groups in only DLT. The results also discovered that there is a significant difference between both groups in DLT at high frequency such as at 6 kHz. Due to exposure to noise, initially the basal turn of the cochlea is affected more than the apex this could also influence the performance between both the groups. Dawson, Aalto, Simko and Vainio, (2017) recovered that it may be that hearing impaired has a greater effect on the ability to use temporal fine structure information at high than at low frequencies, perhaps because the precision of phase locking is reduced for frequencies above about 1 kHz, even in the normal hearing.

Chapter 6

Summary and Conclusion

Studies showed that factors affecting the difference limens, the effect of different degrees and types of hearing loss on difference limen scores and the time course effect following the fitting of hearing aid, effect of compression parameters of hearing aid on difference limen scores; however, none of the studies have extensively explored whether there is any change in difference limen for frequency, intensity and duration in NIHL, especially individual who have 4 kHz notch and high frequency sloping hearing loss. Hence, the aim of the study was to evaluate the effect of NIHL on difference limen for frequency, intensity and duration, especially individuals who have only 4 kHz notch with mild to moderate degree of hearing loss (Group I) and high frequency sloping mild to moderate hearing loss (Group II). A total of 40 ears were included in the study. DLF, DLI and DLT were assessed for different frequencies (1 kHz, 2 kHz, 4 kHz & 6 kHz).

The results of the study revealed:

- There was no significant difference between both the groups on DLF, DLI and DLT except at 6 kHz in DLT. This could be due to the widening of the auditory filters and loss of hair cells at the basal region of the cochlea. However there were marginal differences in DLF, DLI and DLT for the other frequencies between groups. Fundamental frequency and intensity each have influence on duration judgment.
- There was a significant difference across frequencies within groups. This could be because the audibility acuity of both the group is different. And also the phase locking properties at lower frequency region and higher frequency region is different. i.e., at lower frequency the phase locking properties may help to get better performance than higher frequencies. Due to exposure to noise, initially the basal turn of the cochlea is

affected more than the apex this could also influence the frequency difference between both the groups.

6.1. Implication of the Study

- This study will provide information regarding the decision about their auditory abilities in individuals exposed to noise with suspected auditory perceptual deficit.
- Information about the specific deficit of acoustical parameters which differentiate normal hearing individuals from those with NIHL (with and without 4 kHz notch) also will be provided.
- This information will help in guiding the clinicians during the assessment and testing of individuals with sensorineural hearing loss and its causes.
- This study will help in better understanding of differential sensitivity in patients with NIHL.
- The study would help in understanding the changes in psycho-acoustical abilities due to auditory damage (if any) in individuals with noise exposure.

6.2 Limitations

- The sample size considered for the present study is less.
- The results of the study are restricted only for young adults. The study should be carried out on other age groups for better generalization of the results.

6.3 Future directions

- Correlation of differential sensitivity deficits with quality of life to be done.
- The results of the psycho-acoustical (behavioural) measures could be correlated with the electrophysiological measures for better validation.
- This study is conducted only with mild – moderate degree of hearing loss, hence, the study has to be extended to different degrees and configuration of hearing loss.

- Effects on difference limen across different years of exposure to noise need to be further studied.

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