Comparison of Difference limen for Frequency, Intensity and Duration with and without amplification device

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CERTIFICATE

This is to certify that this dissertation entitled is the bonafide work "**Comparison of Difference limen for Frequency, Intensity and Duration with and without amplification device"** submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No: **13AUD003**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled "**Comparison of Difference limen for Frequency, Intensity and Duration with and without amplification device**s**"** the result of my own study under the guidance of Mrs. Devi. N., Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

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Dedicated to my Amma and my Guide

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Abstract

Individuals with sensorineural hearing loss shows abnormal frequency, intensity and duration discrimination which could be quantified in terms of the difference limen measures. Many studies focused on exploring the effect of different degree, configuration, type, long term effects of amplification on these discrimination measures. However, there is lack of evidences with regard to the immediate effect following the fitting of appropriate amplification device on discrimination measures in adults. Hence, the current study focused on exploring the influence of multichannel hearing aid with Wide Dynamic Compression on discrimination measures and whether it could restore the normal discrimination in 20 ears with moderate sensorineural hearing loss. The difference limen for intensity, frequency and duration were obtained using Psycon Software version 2.18 at two test frequencies of 750 and 1500 Hz at 20 dBSL in free field. These results were compared with 20 normal hearing ears. Appropriate non parametric tests were done to assess the statistical difference. The results revealed that there was a statistically significant deterioration in aided difference limen for intensity ($p < 0.05$) which could be due to the compression acting in the hearing aid and a significant improvement in difference limen for frequency and duration ($p < 0.05$) with aid. However, these improvement in aided difference limen scores were compared with the normal ears which showed statistically significant differences in difference limen for intensity and frequency. Hence, this study act as an evidence to prove that even with an adequate amplification, the normal perception in terms of difference limen may not be completely restored

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Chapter 1

Introduction

A normal cochlea because of its active mechanism by the outer hair cells shows several non-linearities such as compressive input–output functions (Sellick, Patuzzi, & Johnstone, 1982; Robles, Ruggero, & Rich, 1986), generation of combination tones (Ruggero, Robles, & Rich, 1991) and two tone suppression (Ruggero, Robles, & Rich, 1992). The response pattern of basilar membrane varies from base to apex; it is tuned to different frequencies at different points along its length. When these OHCs are damaged, frequency tuning of basilar membrane becomes broader and also shows reduced sensitivity to sounds and the compressive non-linearity is affected so that the input output function becomes progressively linear (Sellick et al., 1982). Cochlear hearing loss reduces the audibility as well as alters the perception of sound due to structural variations. People with cochlear damage often complaints that the sound being distorted, unclear and uncomfortably loud. Even if the sounds are being amplified it might increase the audibility however, the natural perception of sounds may not be restored completely (Moore, 1996).

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 the normal. 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 because of the reduced frequency selectivity in cochlear loss

(Kiang, Moxon, & Levine, 1970; Evans, 1975). 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 suprathreshold measures should also be incorporated to track the functional problems, not just the audibility alone (Brandt, 1967).

The ability to discriminate changes in frequency, intensity and duration can be accounted psychophysically 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).

Many models have been proposed to explain the frequency discrimination, the place model assumes that the perceived pitch is dependent on the place of the basilar membrane which gets excited most, and hence frequency discrimination is dependent on the sharpness of excitation pattern (Zwicker, 1970; Zwislocki & Nguyen, 1999). So, whenever there is a change in the frequency from a standard tone there is a shift in the excitation pattern along the length of the basilar membrane. This shift in the excitation pattern is the basis of detecting small changes in the frequency i.e. ΔF (Zwicker, 1970).

But the temporal theory assumes that it is due to the phase locking of the temporal fine structures (Siebert, 1970; Srulovicz & Goldstein, 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).

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 normals (Gengel, 1973; Tyler, Wood, & Fernandes, 1983; Hall & Wood, 1984; Freyman & Nelson, 1986; Moore & Peters, 1992; Simon & Yund, 1993). The Weber fraction for cochlear hearing loss depends on the degree and configuration of loss.

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. With several methods to measure the intensity discrimination, it is found that 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 the cochlear hearing loss perform similar or even better than that of normals (Buss, 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 normals (Fitzgibbons & Salant, 1994).

Many authors have explored the effect of amplification, on intensity discrimination and also studied the long term effect on level discrimination and the effect of compression parameters (Robinson & Gatehouse, 1995; Shufani, Walger, Wedel, & Meister, 2006) but there is a considerable controversy in this aspect and no any clear evidences are available in the current literature in order to substantiate on frequency and duration discrimination.

Hence, it is important to study the differences in intensity, frequency and duration discrimination thresholds on cochlear hearing loss subjects with hearing aid and it is also important to know the extent to which the current amplification technology can restore normal hearing.

1.1. Need for the study

Many studies focused on understanding the 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 unaided and aided conditions for the same individual who don't have previous experience with any amplification devices.

1.2. Aim of the study

The present study focused on exploring the impact of digital multichannel hearing aid on frequency, intensity and duration discrimination which could be reflected in the difference in scores in aided and unaided conditions for moderate sensorineural hearing loss.

1.3. Objectives of the study

a. To obtain the difference limen for frequency, intensity and duration in individuals with normal hearing and individuals with moderate sensorineural hearing loss.

b. To study the effect of moderate sensorineural hearing loss on difference limen measures.

c. To study the effect of amplification on difference limen measures in individuals with moderate sensorineural hearing loss.

d. To study whether the amplification would restore the difference limen measures in individuals with sensorineural hearing loss.

e. To study the effect of frequency on difference limen measures in normals and individuals with sensorineural hearing loss.

Chapter 2

Literature Review

The absolute threshold measures of audibility do not provide a complete picture of the functional status of cochlea. Hence, we need to tap on to certain suprathreshold measures like intensity, frequency and duration discrimination to understand more about the cochlear analysis (Brandt, 1967). Smallest perceivable change in a physical stimuli or sound can be called as difference limen or just noticeable difference (Green, 1976). The review of literature will be discussed under the following headings.

1. Difference limen for Intensity (DLI)
2. Difference limen for Frequency (DLF)
3. Difference limen for duration (DLD)

2.1. Difference limen for Intensity (DLI)

2.1.1. Difference limen for Intensity (DLI) in normals

The ability to detect small changes in intensity can be associated to the loudness sensations evoked by that sound. Different methods can be used to measure the smallest detectable change in intensity among which the three major methods used are a) modulation detection b) increment detection and c) intensity discrimination of gated or pulsed stimuli. The difference between the three methods are in modulation detection the stimuli will be amplitude modulated at a slow rate the subject has to detect the modulation wherein increment detection has to detect increment in background stimulus and in discrimination of pulsed stimuli, the subject has to detect the pulse which is more intense (Moore, 2007).

Fasti and Schorn (1981) reported that there could be difference in the discrimination values when the task is to detect modulation and when task is to compare and detect the pulsed tone which is higher in intensity. The results revealed that modulation detection mechanism can directly sense the increment or decrement but to detect the increment in pulsed tone, they have to store the standard tone, compare the successive tones with that of the standard hence becomes more complicated. Thereby, expected to have higher DL values. While using modulated tones, it taps only peripheral part while when pulsed tones were given, it taps memory and central lesions too.

2.1.1.1. *Different stimuli used for Difference Limen for Intensity*

a. *Noise*: For white noise and for narrow band noise the Weber's fraction $\Delta I/I$ (when expressed in dB $\Delta I=10\log[(I+\Delta I)/I]$) is roughly constant from 200- 100 dBSL and within this range if we plot 10 log ΔI against 10 log I (dB) will have a slope =1 (Miller, 1947) .

b. *Pure tones*: It was found that Weber's law is not always followed for all signals especially for pure tones (Riesz, 1928; Harris, 1963; Viemester, 1972; Jesteadt, Wier & Green, 1977) which is reported as **near miss to Weber's law** i.e. Weber Fraction decreases with increasing intensity and a plot of $10\log\Delta I/$ $10\log I$ has a slope of 0.9 (Mc Gill & Goldenberg, 1968). In other words, for pure tones and other low pass stimuli the Weber fraction decreases at higher intensities of the standard stimulus which do not follow the Weber's law (near miss) and with addition of a high pass noise whose cut off frequency is greater than that of the standard this trend is changed or it eliminates the near miss and will be in agreement with the Weber's law or Weber fraction becomes independent of the intensity of the standard (Florentine, 1983). Hence this could be interpreted in such a way that since Weber fraction aims at tapping single channel trend, the near miss at high SPLs could be because of the spread of excitation to higher frequencies (Schroder, Viemester & Nelson, 1994).

2.1.1.2. *Factors affecting Difference Limen for Intensity*

Intensity of the standard stimulus: Rabinowitz, Braida and Durlach (1976) summarized the data of literature stating the intensity discrimination as function of the intensity of the standard stimulus. The general trend reported was that intensity resolution increases as intensity of the standard increases, but there are three distinct areas if we plot intensity discrimination Vs. stimulus level, which are a) there is a plateau from 10- 40 dBSL where the resolution is almost constant and Weber's law holds good in this range which was supported by data of Dimmick and Olson (1941) reported a plateau between 40-70dBSL b) below this range the resolution is poor and DLI is highest near threshold c) above this range i.e. above 40 dBSL, there is a linear increment and resolution improves with increase in intensity. Likewise, Viemester and Bacon (1988) reported that Weber's law holds good from 20-50 dBSL which could be plotted as a plateau, and above which the DL values decreases and proposed a theory for the same stating that at higher intensities there could be higher order distortion products which becomes audible and this could be cueing. Hence, absolute DL values decreases with increase in intensity of the standard stimulus. This trend in intensity resolution was supported by Reisz (1928) but did not report of a plateau.

Frequency of the standard stimulus: Jesteadt et al. (1977) reported that there is no change in the DLI values as a function of frequency of the standard, however, Florentine and Mason (1987) reported that Weber fraction is constant from 250-4KHz but is larger at high frequencies. This discrepancy in results could be because of the differences in the psychophysical procedure used.

Duration of the standard stimulus: Florentine and Mason (1987) reported that DL values are larger when the duration of the standard is less than 250 msec above which it remains almost constant and independent of the duration of the standard. This could be attributed to the temporal integration.

Type of stimulus: There is lots of variability in the difference limen across different stimuli. Viemester et al. (1988) reported that Weber's law holds good for broad band stimuli like white noise or click but not for narrow band stimuli or for sinusoids i.e. discrimination improves with intensity because more number of neural fibers begins to fire and hence DL decreases which is contradicting Weber's law.

2.1.2. Difference limen for Intensity (DLI) in cochlear hearing loss

Loudness growth is rapid in cochlear loss subjects (Luscher & Zwislocki, 1949; Denes & Nauntont, 1950). The absolute threshold of the cochlear loss is higher than that of normals when sound level is increased and is above 4-10 dBSL the rate of growth of loudness is rapid and increases with intensity but when it reaches a level of 90-100 dBSPL the perception of loudness growth is similar to that of normals (Moore, 2007).

Hence, they would have more loudness growth compared to normals and for this reason there could be better intensity discrimination and resulting in lower DL values for intensity, but this may not be always true. When we compare at equal and at low sensation levels 10-20, cochlear loss subjects show better discrimination but at equal and high SPLs cochlear loss subjects show equal or worser than normals (buus, Florentine & Redden, 1982; Schroder, Viemester & Nelson, 1994). Steeper the loudness growth, it would result in larger than normal loudness for a particular intensity but it is not necessary that it should increase the intensity discrimination (Zwislocki & Jordan, 1986).

Schroder et al. (1994) gave a comprehensive data and descriptive explanation with physiological basis for intensity discrimination in cochlear hearing loss when compared to normals. In order to obtain a comprehensive data, the tests were done at many levels, at different frequencies, for different configuration of cochlear loss and compared it with normals. The authors assessed the role of spread of excitation as the basis for trend of intensity discrimination in cochlear loss. The authors assessed the intensity discrimination for five cochlear loss subjects with moderate to severe degree and for three normal subjects using four intervals forced choice paradigm for 500 msec tone burst from 300 Hz to 3000Hz. The observation and possible explanation given by the authors is summarized in the following table:

Table 2.1: *The results and implication of intensity discrimination in quiet and noise for normals and cochlear hearing loss (Schroder et al., 1994)*

	Result	Implication
Normals	*In quiet*: Weber fraction decreases as the intensity of the standard tone increases. Hence, the data supported the near miss to weber's law *In the presence of high pass noise*: the Weber fraction was near constant.	The results were consistent with earlier reports suggesting that at high levels there is a discrepancy in the Weber fraction in quiet and in the presence of noise it is constant; truely supports the 'near miss'
Flat hearing loss	Weber fraction similar to that of normals and no significant difference between quiet and in the presence of background noise	Spread of excitation was not involved
High frequency hearing loss	Results dependent on the slope of hearing loss Steep high frequency loss – normal weber fraction in quiet and elevated in the presence of background noise	The results indicating use of spread of excitation

Schroder et al. (1994) suggested that Weber fraction is normal at mid to high intensities and gets elevated in the presence of high pass noise strongly suggesting the use of spread of excitation to frequencies higher than that of the standard as a cue, but the addition of high pass noise alleviate this possibility and it is this spread of excitation.

Hence, configuration of hearing loss should be considered as a primary determinant in interpreting results in cochlear loss.

This finding was supported by Florentine, Reed, Rabinowitz, Durlach and Buus (1993) who investigated the intensity discrimination for pulsed tone as a function of level for 13 cochlear loss subjects and 1 vestibular schwannoma, compared with that of normals and also simulated the loss using equivalent threshold masking. For normals, there was considerable variability in the results wherein this variability was attributed to variations in the non-sensory factors. As expected, for vestibular schwannoma the intensity discrimination was poorer than normals. At low sensation levels, for flat and for mildly sloping loss intensity resolution was almost similar to normals with falling pattern poor intensity resolution and for rising pattern, there was rapid increase with level and at equal SPL it was similar to normals. Hence, to conclude, not only the threshold at the test frequency but also configuration of loss is a primary factor.

2.1.2.1. *Intensity discrimination following the use of hearing aid*

Robinson and Gatehouse (1996) studied the time course effect following the monoaural fitting of hearing aid. As a preliminary evidence, the same authors observed that following long term monoaural amplification, the ear which was aided showed better intensity discrimination than the unaided ear at high SPLs however, the unaided ear showed better discrimination at low levels. This effect was dependent upon frequency of the stimulus which could be due to selective amplification of hearing aid. This study was conducted in sloping SNHL and no amplification was provided to low frequencies. The major drawback of the study was that there was that there was no any evidence of intensity discrimination thresholds prior to hearing aid fitting in order to comment that the change in discrimination is due to hearing aid fitting. Robinson and Gatehouse (1996) hypothesized the change in thresholds are due to perceptual acclimatization to explain the finding in long term hearing aid user that aided ear would perform better than the unaided ear at high presentation level because it gets acclimatized due to the stimulation given. His study showed that the acclimatization would take about 6 to 12 weeks.

The findings of Robinson and Gatehouse (1996) could be justified with a supporting evidence of plasticity by Munro, Walker and Purdy (2007) wherein the authors reported that the sensory areas of brain are plastic due to changes in our auditory experience, with the use of hearing aid which are ideally changing our auditory experience by stimulating a deprived system. The perceptual changes after hearing aid usage was because of learning induced plasticity within central auditory system which was being evidenced by electrophysiological and neurophysiological studies. They reported an elevation in Uncomfortable Loudness thresholds of older adults who had long term experience with the hearing aid provide evidence to adaptive plasticity in the auditory system. So with this one might conclude that there is an increment in level discrimination but with the use of current compression or AGC hearing aids this effect would be adverse.

Whitmer and Akeroyd (2011) studied the effect of hearing aid compression on level judgment for speech. The stimuli were stationary noise, monosyllabic words and sentences and used pedestal method to obtain the discrimination thresholds. It was a novel study which used speech as the stimuli and they found that the level discrimination of words was more difficult when compared to sentences and this was true in case of normals and cochlear impaired. The results revealed that the hearing aid compression ratio did not correlate with the poor performance with words over sentences. Hence, concluded that current hearing aid compression ratios are not large enough to cause a detrimental effect on depth perception tasks because there was no any significant difference in performance with and without hearing aids. However, Shufani, Walger, Wedel and Meister (2006) studied the effect of compressive hearing aids on interaural discrimination which was a hearing aid simulation study and reported an effect of compression ratio and attack time on JND in Interaural Level Difference (ILD). The task was to lateralize the stimuli which were a narrow band noise (500- 4000 Hz). The processed stimuli of compression ratio of 1:1, 3:1, 8:1 at 2 and 200ms attack time. The results revealed that there is no any significant effect of attack time on Just Noticeable Difference (JND) in ILD whereas they found that increasing the compression ratio from linear amplification would have a negative impact on level judgments.

To conclude, there are considerable controversies in literature stating whether the use of hearing aids would facilitate or worsen the level discrimination. The current study was designed to explore this.

2.2. Difference Limen for frequency (DLF)

The smallest perceivable difference between two stimuli which differ only in terms of its frequency is called Difference Limen for Frequency (DLF) can be represented in its absolute terms as Δf or in relative terms as $\Delta f/f$ where ‘f’ is the frequency of the standard (Green, 1976). As reported by Green (1976), it is quite difficult to compare difference limen values across different studies because absolute value differ by a factor of 10 or more from one study to other and the variability of frequency difference limen is more when compared to intensity difference limen. Wever (1976) this variability in discrimination partly depends on the psychophysical procedure and partly on individual's ability. The frequency difference limen can be used as a measure for differential diagnosis because DLF which would be adversely affected in those ears where resolving power of ear (cochlear loss) is disturbed (Campbell, 1970).

2.2.1 .Difference limen for frequency in normals

Kammath and Vyasamurthy (1989) studied the effect of frequency, sensation level, gender and ear difference on DLF for 40 normals using Madsen 08-822 Audiometer wherein increment was in terms of percentage. 5% increment size for 1000 Hz means that frequency is modulated between 1000±50 Hz and for 4 different sensation levels 20, 40, 60 and 80 from 500-4000 Hz. The authors reported no difference between DLF values for males and females and ear difference. The authors also reported that there is no significant difference across frequency and sensation level which is contradicting the literature.

Wier et al. (1977) reported that the difference limen for frequency increases as the frequency increases and decreases as the sensation level decreases. DLF decreases with increase in sensation level, but this trend is followed only till 40 dBSL and above which it is roughly constant and reported that presenting at 25 dBSL is most appropriate for DLF measurements (Harris, 1966; Henning, 1967). There are several models that explain the mechanism underlying in frequency discrimination like the place model (Henning, 1967; Siebert, 1970; Zwicker, 1970). They assumed that the frequency discrimination depends on the frequency selectivity which in turn depends on the sharpness of tuning at the level of basilar membrane.

Zwicker (1970) reported that a change in frequency is detectable whenever the excitation level at some point on the excitation pattern changes by more than a certain threshold value (which correspond to 1 dB) and this change in excitation level is maximum on steeply sloping side of low frequency. A small DLF at low frequencies reflect the use of temporal or phase locking information and phase locking information becomes less precise at frequencies above 1 KHz and is above 5 KHz this is lost which explains large DLF at high frequencies.

2.2.1.1. *Different stimuli used for Difference Limen for Frequency*

In order to estimate the DLF we can either use two tones in succession which vary only in terms of its frequency or can use Frequency Modulated (FM) tones which makes FMDL. Low frequencies have best DLF and FMDL measures and it increases with frequency. Moreover, DLF values are smallest for mid frequencies and are large for very high and very low frequencies. Both DLF and FMDL decrease with the sound level, but the clear cut shift in pitch with level is not clearly understood (Wier, Jesteadt, & Green, 1977). There is considerable variation in the DLF values obtained using FM signals and using pure tones; FM signals yield larger DLF when compared to pure tones because of its complex spectra (Stevens, 1954; Jesteadt & Sims, 1975; Moore, 1976).

2.2.2. Difference limen for frequency in cochlear loss

People with cochlear damage will have broader auditory filters and hence the excitation evoked by a particular tone will be broader than normal which would lead to impaired frequency discrimination in them in the light of place theory. However, in the light of temporal theory frequency discrimination would be adversely affected by reduced precision of phase locking that occur in case of cochlear damage or cochlear damage would adversely affects the mechanism responsible to decode the phase locking information (Moore, 2007). Several authors quoted that frequency discrimination is adversely affected in cochlear hearing loss (Gengel, 1973; Tyler, Wood, & Fernandes, 1983; Hall & Wood, 1984; Freyman & Nelson, 1987; Moore & Glasberg, 1986; Moore & Peters, 1992; Simon & Yund, 1993) but there are huge individual variabilities and does not show strong correlation with the absolute threshold at that frequency.

Simon and Yund (1993) found that DLFs could be markedly different between ears for bilateral cochlear damage where the absolute thresholds were same and DLFs could be similar even if the absolute thresholds between ears are different. Hence he concluded that there is no one to one relation between absolute thresholds and DLF though we assume that there will be an increase in DLF values or frequency discrimination becomes poorer as threshold increases. Even though we relate the frequency discrimination to the auditory filter bandwidth there were evidences to show that there is partial dissociation between frequency selectivity and frequency discrimination as in DLF. Tyler et al. (1983) compared DLF and frequency selectivity using PTC and found low correlation between the two.

Moore and Peters (1992) estimated the auditory filter shapes using the notch noise technique and related it to DLF for hearing impaired and normal group and he found that the DLF weakly correlated with sharpness of filter and broad filters at low frequencies had near normal DLF. These evidences show that the relation between the frequency discrimination to frequency selectivity of filter as explained by place models is not always true. Another way of justifying these observations of higher than normal DLF values for cochlear loss would be the loss of neural synchrony at the level of auditory nerve.

Goldstein and Srulovicz (1977) explained a model which could account for the variation in DLF depending on frequency and duration wherein he described that the frequency discrimination is based on the interspike intervals in the auditory nerve. Wakefield and Nelson (1985) done an extensive study to this model and he proved that the predictions made from the model could actually account for the effects of level on DLF. Hence, larger DLF could be also because of the loss of neural synchrony at the area of damage. Another possibility is the loss of temporal information as a consequence of impaired propagation of travelling wave along the length of basilar membrane which is important for decoding of phase locking information by the central mechanism accounting for the larger DLF (Loeb, White, & Merzenich, 1983).

Zureck and Formby (1979) estimated the DLF for pure tones for individuals with SNHL and tried to correlate between degree of hearing loss and its influence on DLF for 500msec pure tone from 125- 4000 Hz. The results revealed that even mild loss can produce 8-10 fold increase in DLF for a low frequency tone and a significant shift is noted when there is a moderate threshold shift onwards. These observations could be justified in such a way that for a low frequency tone there are two ways of encoding temporal and spatial wherein temporal coding is less resistant to damage. The second possible reason was that there is an asymmetry of excitation pattern, the excitation pattern at apical turn spreads to mid and basal turns too hence even if there is some amount of damage results in smaller threshold shift. However, intact receptors are required for good frequency discrimination. So despite of having good threshold, if there is any damage in the low frequency region, can have large DLF values. On the other hand, excitation pattern at basal turns are restricted, hence magnitude of loss is a possible indicator of amount of damage at high frequencies but not at low frequencies.

Hence, to conclude we cannot draw a one to one correlation with threshold and DLF values at all frequencies and even with the size of auditory filter. This area has to be extensively studied to draw an appropriate inference. Further, there is scarcity in literature which explored on if there is any difference when appropriate amplification is provided on frequency discrimination.

2.2.2.1. *Difference Limen for Frequency following the use of hearing aid*

Gabriel, Veuillet, Vesson and Collet (2006) studied the changes in Difference limen for frequency following the rehabilitation and also studied the time course effects following the fitting of hearing aid. Nine subjects participated in the study with high frequency steeply sloping hearing loss. 6/9 subjects were binaurally fitted and 3/9 were monoaurally fitted with digital hearing aid. The testing was done to obtain a baseline, 1 month, 3 months and 6 months post hearing aid fitting. Three parameters were obtained in each visit they are threshold, loudness matching and difference limen for frequency were obtained under headphones. Threshold measures were obtained at octaves and 1/8 octaves and estimated the edge frequency and DLF measures were obtained near the cut off frequency and estimated the best DLF and kept a track of the changes to the best DLF. The results revealed that the there was an improvement in best DLF following the rehabilitation which could be attributed to the acclimatization, central plasticity or reorganization and concluded that first three months following the fitting is most critical to plasticity.

2.3. Difference limen for duration (DLD)

The smallest difference in terms of time to distinguish two sounds which could be termed as the difference limen for duration (DLD) which is represented in its absolute terms as Δt and in its relative terms as $\Delta t/t$ and difference limen for duration increases as the overall duration of the signal increases and hence, Weber fraction is not constant in this case (Abel, 1972; Dooley & Moore, 1988).

Small and Campbell (1962) used the method of constant stimuli in order to obtain the discrimination threshold for white noise bursts and the variable stimuli was paired with standard stimuli of different duration which ranged from 0.4ms to 400ms and he found that the Δt values increased with the increase in the duration of the standard stimuli . The variable stimuli were either shorter or longer than the standard. In this experiment there were two cues to judge the differences the spectral and the temporal and it is very difficult to separate our discrimination abilities across the temporal and spectral domain hence they hypothesized that small DL values are due to subjects detecting the differences in the waveform of standard and the variable and as the duration of standard and variable stimuli increased, the differences in the waveforms reduces and the listeners have to rely more on temporal difference the on the spectral differences. This could have been the possible reason for larger DLs when the duration of the standard was increased.

2.3.1. Difference limen for duration in sensorineural hearing loss

Tyler, Summerfield, Wood and Fernandes (1982) studied the temporal processes in hearing impaired and normals using psychoacoustic and phonetic stimuli. The tasks were temporal difference limen, Gap detection, speech identification, VOT difference limen, PTC and temporal integration. For temporal integration, Difference limen and gap detection the stimuli used was narrow band noise of 500 and 4000 Hz of 30 msec reference duration. Tyler et al. (1982) found that there is minimal dependence on frequency of stimuli for temporal difference limen and there is an increase in difference limen for low intensities of 25-30 dBSL for normal hearing individuals. Out of the 16 participants in hearing impaired group the degree of loss varied and a wide range of subjects were considered from 33- 72 years hence, it is difficult to rule out age and hearing loss effects. The results revealed a large variability in temporal processing abilities i.e. some of the individuals showed a significant effect of hearing loss on temporal processes like temporal integration, gap detection and temporal difference limen, large VOT difference limen and there was a strong correlation of gap detection and temporal discrimination on the speech reception scores. These findings evidenced that the duration discrimination and gap detection are two important processes that would contribute to poor speech perception in hearing impaired.

Tyler et al. (1982) attributed their findings of poor temporal processes and its correlation to speech scores to differences in coding of temporal information in hearing impaired i.e. poor phase locking and defective channel capacity to separate the onset and offset of stimuli.

Fitzgibbons and Salant (1994) hypothesized that duration discrimination is independent of hearing loss and is dependent on age related changes so that a study was designed to examine the influence of hearing loss and age related changes on duration discrimination. Forty subjects participated and were divided into 4 groups among which two groups of older adults with and without hearing loss (mild to moderate sloping SNHL) and other two groups of young adults with and without hearing loss (with same loss as that of older age group). The stimuli used were tone burst of 250 msec of 500 and 4000 Hz studied temporal difference limen and gap detection. The results revealed that with 250 msec as the reference signal duration, the young adults with and without hearing loss showed similar results, however few subjects with hearing loss showed abnormally large difference limen. Likewise, similar results were observed for older adults too, but comparing the scores of young and older adults, the older adults showed abnormally large difference limen.

The absence of an effect of hearing loss on duration discrimination was reported by Abel, Krever and Alberti (1990) which could be because the coding of signal duration differences to occur within Central Auditory Nervous System (Creelman, 1962; Abel, 1972). However, the evidences in this aspect are limited to draw a conclusion from the current literature about duration difference limen.

The current study was designed considering these evidences in order to explore on the differences between aided and unaided discrimination abilities for frequency, intensity and duration using difference limen measures.

Chapter 3

Method

3.1.Participants and their selection criteria

A total number of 40 ears were included in the study. The participants were divided into two groups, a control group (Group I) and an experimental group (Group II) with equal number of participants in each groups and the mean age for both the groups were same (Mean age: 38.27 years; SD: 10.11). The participants for the experimental group were selected based on the following criteria:

a. Moderate sensorineural hearing loss for the frequency range of 250 Hz to 8 KHz in either of the ears (air conduction thresholds in the range of 41-55 dBHL and air bone gap of ≤ 10 dBHL).
b. Age range between 18-55yrs.
c. Native speakers of Kannada
d. Digitally aided Speech recognition scores ≥ 70%.
e. No otological or neurological problems
f. No previous experience with any hearing aid.

3.2. Instrumentation

The following instruments were used for the study:

a. A caliberated Diagnostic Audiometer (GSI -61 Clinical Audiometer) for the measurement of hearing thresholds in all octave frequencies to ensure that the participant satisfied the criteria of the degree of hearing loss.

b. A caliberated Immittance audiometer (GSI-Tympstar) to make sure that the subject does not have any conductive component on the day of testing.

c. A four channel digital non -linear behind the ear hearing aid suited for moderate loss

d. A PC with the NOAH software and a Hi Pro Link to connect the hearing aid and the PC.

e. A caliberated hearing aid analyzer for real ear measurement (FONIX 7000)

f. Psycon software (Version 2.18)

Testing was carried out in a sound treated room (ANSI S3.1, 1999). Prior to the testings, a written consent was obtained from all the participants for their willingness to participate in the study.

3.3. Test Procedure

The study was conducted in different steps:

3.3.1. Obtaining thresholds

Pure Tone Audiometry was carried out using GSI 61 Clinical Audiometer for Air conduction and Bone conduction thresholds for frequencies between 250 Hz to 8 KHz and from 250 Hz to 4 KHz respectively using Modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Immittance audiometry was carried out using GSI Tympstar to rule out any middle ear pathologies on the day of testing.

3.3.2. Hearing aid programming

A digital non-linear four channel behind the ear programmable hearing aid was used for the study. The hearing aid was selected based on the availability and considering the technical specifications (OSPL90, the fitting range, the full on gain, time constants, distortions and equivalent input noise). To ensure that the selected aid agrees with the technical specifications Electroacoustic measurements for the same was done.

The hearing aid was connected to the PC via Hi Pro, wherein the PC was installed with NOAH software. The hearing aid gain was set based on the NAL- NL1 prescriptive formula (Dillon 1999; Byrne, Dillon, Ching, Katsch, & Keidser, 2001) which is a non-linear fitting formula based on threshold. The rationale behind the formula is loudness equalization i.e. to equalize the loudness in all frequency bands which occurs while normalizing the overall loudness in order to perceive speech in a manner similar to normals, so that there will be an improvement in speech recognition and weightage is given to improve speech intelligibility. Since it aims at maximizing the speech intelligibility at all input levels and to ensure that the overall loudness of speech does not exceed the normal limits, this prescriptive approach to was used to set the gain. Moreover, it prescribes the cross over frequency, the compression threshold, compression ratio, and gain at different input levels of 50, 65 and 80 dBSPL for a multichannel hearing aid.

The acclimatization level was set to 2. The compression threshold and compression ratio was modified to provide a Wide Dynamic Range Compression (WDRC) which was kept constant across participants. In order to verify adequate amplification, Real ear measurement was used. Even if many verification methods are available, the real ear measurements were used because it help us to assure how much amplification the patient is receiving at different input levels, objectivity and it also accounts for individual specific variations in output and bandwidth due to impedance characteristics of ear, natural resonance of ear canal and acoustic properties of ear mould and tubing.

3.3.3. Aided and unaided speech recognition scores

Unaided and aided speech recognition scores were obtained for the experimental group**.** Twenty five words from Phonetically Balanced word list developed by Yathiraj and Vijayalakshmi (2005) were used as the stimuli for speech recognition scores. Those subjects, who scored ≥ 70% in aided speech recognition scores with the optimum gain according to the prescriptive procedure NAL-NL1, were considered for the study. In case of asymmetrical (or) unilateral hearing loss, where the non-test ear thresholds are better, then it was masked.

3.3.4. Verification of fitting

Prior to the testing, probe microphone caliberation was done. The caliberation was done by placing the probe tube inlet at the center of the sound inlet of the reference microphone and together placed in front of the loud speaker. The real ear analyzer FONIX 7000 equalizes the probe microphone response so that it matches with the response of the reference microphone. Hence, Leveling of the system was carried out to ensure a flat frequency output from the real ear analyzer.

An otoscopic examination was done before placing the probe tube in the ear canal to rule out debris or any other conductive pathology. The patient was positioned at a distance of about 0.5m from the loudspeaker, this distance was maintained and the probe tube was inserted within 5mm of the tympanic membrane to avoid standing waves. For the correct placement ear mould method was used i.e. the ridge of the ear mould/ ear tip where it corresponds to the intertragal notch was identified and placed the probe tube such that the probe tube extends 5mm beyond the tip of the mould. Digi speech signal was used as the stimuli. The real ear measurement procedure was carried out according to ANSI S3.46 (1997). The thresholds and the prescriptive formula were entered in the database of the real ear analyzer and it automatically displayed the target gain curve according to the formula.

Real Ear Unaided Response (REUR) was measured by placing the probe tube in the ear canal but without the hearing aid in place and was measured as the SPL as a function of frequency at a specified measurement point in the unoccluded ear canal for a specified sound field. This served as the reference value for insertion gain and reflects the natural amplification provided by the ear canal, head and torso.

Real Ear Aided Response (REAR) was obtained i.e. the difference in decibel as a function of frequency between the SPL at a specified point in the ear canal for a specified sound field when hearing aid is its place and turned on. It is the direct measurement of how hearing aid will perform in a real ear. REAR – input SPL gives the Real Ear Aided Gain.

Real Ear Insertion Gain (REIG) was obtained which is the difference between the REAG and REUG at a specific frequency, helps us to verify whether the predetermined target has been achieved. The REIG for all the input levels for the desired frequencies were noted down from the data table and optimization was done if the gain provided was less.

3.3.5. Difference limen testing

Difference limen test for frequency, intensity and duration were carried out using Psycon software version 2.18 installed in laptop (Sony Vaio, model-SVE14IJ11W). The sound card of the laptop was caliberated and volume set to 85% to yield a maximum of 90 dBSPL i.e. the maximum output from the software was 90 dBSPL. The software considered 0 dBSPL as the upper limit in its representation, hence values obtained for threshods were in negative.

Pure tone signal of 750 Hz and 1500 Hz of 500 msec duration with ramp duration of 80 msec was the stimuli used. These stimulus frequencies were selected based on the consideration that the test frequency does not interfere with the cross over frequencies of the channels in the multichannel aid used for this study and also aiming at a low- mid frequency range. Pure tone signals were considered as it gives frequency specific information, a primary stimuli. The stimuli were generated by the Psycon software which was installed to the laptop, presented at 20 dBSL and was delivered through the speakers oriented at an angle of 0 degree azimuth. In case of cochlear hearing loss participants, the stimuli were presented 20 dB above their aided threshold at the desired frequency for aided difference limen measurements.

A three interval alternate forced choice (3IAFC) method was used for all three measures with 2 down 1 up procedure to achieve 70.7% response on the psychometric function (Levitt, 1971). The adaptive procedure was selected to obtain a precise measure. The session was limited to 100 trials, out of which final four reversals were considered to obtain the mean score and standard deviation. If the standard deviation was more than 2.5 the run was repeated. All the participants were given 3 practice trials and demonstrated the correct response at 40 dBSL which was clearly audible and could understand the task better. Later, the test trials were done at 20 dBSL. The sampling rate was set to 44000 Hz and inter stimulus interval was set to 500 msec and inter trial interval of 400 msec.

Aided scores were considered to be of prime importance for the study hence all measures like threshold and difference limen were performed in free field for both the groups. However, for participants in control group (normal hearing) to obtain monoaural response, the non test ear was masked using broad band nosie routed through GSI 61 clinical audiometer through ER 3A insert earphones. Similarly, if the participant is having unilateral or asymmetrical hearing loss and if the non test ear is better, it was masked to avoid its participation.

3.3.5.1.*Threshold estimation using adaptive procedure at 750 and 1500 Hz*

Prior to the difference limen testing, thresholds at 750 and 1500 Hz were obtained using adaptive procedure, which was taken as the reference for presenting at 20 dBSL. Since the software considered 0 dBSPL as the upper limit in its notion, the thresholds obtained were in negative values. For eg: threshold of -80 dBSPL is equal to 10 dBSPL because we need to subtract the obtained threshold from the upper limit to show the exact threshold. The step size used was 5 dB down and 1 dB up for threshold estimation.

The participants were instructed that “you will be seeing three blocks on the screen, out of the three blocks that arrives, one of the block has a tone, you have to press the block which has the tone. Suppose if you hear the tone contingent with the second block you need to press on the second block. Initially the tone that you will hear will be louder and then as trials increases the loudness decreases. You need to listen carefully and press appropriate block even if the sound is softer”. The participants were given appropriate feedback (written/ verbal stating whether the response was correct or wrong).

Formula used

Reference: silence(500)

Variable: stereo(db(v)*ramp(tone(750,500),80), silence(500)).

3.3.5.2. *Difference Limen for Frequency (DLF)*

Measurement of difference limen for frequency was carried for both control and the experimental group at 750 Hz and 1500 Hz at 20 dBSL for 500 msec pure tone. Even though many conventional studies for DLF measurement were carried out for more than two frequencies (Brandt & Small,1963; Wier, Jesteadt & Green, 1977) because of the time constraints, in the current study DLF was estimated only for two frequencies. Two tones were generated one of it served as the reference and other as variable. In case of DLF, the variable and reference tones were of the same intensity and duration; however, differs in terms of frequency. During the initial few trilas, the difference between the reference and variable tones were larger i.e. in about 100 Hz difference so that participants can clearly separate the two tones. Hence, the initial value was kept as 100 Hz difference and a descending procedure was used. A 2 down 1 up procedure was used with three interval alternate forced choice paradigm (3IAFC). The step size was down 10 Hz and up 5 Hz. For each trial, the frequency of the variable tone was varied. ΔF i.e. the absolute difference limen was calculated as the minimum difference in frequency between the standard and the variable tone which could be discriminated. The smaller the DL values better is the discrimination. The mean of final four reversals was considered as the absolute difference limen for frequency. For the experimental group the DLF values were obtained for unaided and aided condition with hearing aid gain set to optimum.

The participants were instructed that "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".

Formula used:

Reference: stereo(db(-65)*ramp(tone(750,500),80), silence(500))

Variable: stereo(db(-65)*ramp(tone(750+v,500),80), silence(500))

Note, -65 in the formula is an example, should be done at 20 dB above adaptive threshold.

3.3.5.3. *Difference limen for intensity (DLI)*

Measurement of Difference Limen for Intensity (DLI) was carried for 750 Hz and 1500 Hz at 20dBSL. This sensation level was selected because the differential limen for intensity increases moderately above the threshold (Reisz, 1928). Initial value was kept as 10 dB increments and used a descending procedure and 2 down 1 up procedure was used with the step size of down 5 dB and up 2 dB increments. For difference limen for intensity the reference and variable tones shared the same frequency and duration and differed only in terms of intensity. The absolute DLI (ΔI) was noted as the mean of final four reversals which was the minimum difference in intensity between the standard and the variable tone which could be discriminated.

The participants were instructed that that " 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 louder among the three presented".

Formula used
Reference: stereo(db(-65)*ramp(tone(750,500),80), silence(500))
Variable: stereo(db(-65+v)*ramp(tone(750,500),80), silence(500))

3.3.5.4. *Difference limen for duration (DLD)*

Difference Limen for duration (DLD) was obtained for 500 msec tone at 750 Hz and 1500 Hz pure tone of 500msec duration. The starting value for the run was set to 100 msec and the step size was 30 msec down and 10 msec up using a descending procedure. Here, the reference and variable tones differed only in terms of duration while other characteristics are constant. The absolute value ΔT was calculated as mean of final four reversals which is indicating the minimum difference in duration between the standard and variable tone that can be detected.

The participants were instructed that "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 more longer in duration among the three blocks presented".

Formula used

Reference: stereo(db(-65)*ramp(tone(750,500),80), silence(500))

Variable: stereo(db(-65)*ramp(tone(750,500+v),80), silence(500))

3.3.6. Documentation

The thresholds obtained using the adaptive procedure with Psycon Version 2.18 at 750 and 1500 Hz were noted. Since the software considers 0 dBSPL as the upper limit the values obtained for thresholds were negative value. Consider the thresholds as -80 and -30, here since they are negative values, -80 would be better than -30. The software representation is such a way that how much amount we need to subtract from the upper limit to get the exact threshold. In the above example we need to subtract 80 to get the threshold, so it would be 10 dBSPL because 90 dBSPL is the maximum output from the software.

The absolute difference limen scores for intensity (dBSPL), frequency (Hz) and duration (msec) were documented.

3.3.7. Statistical Analysis

The data obtained were tabulated and then analyzed using Statistical Package for Social Sciences (SPSS) version 17 software. In order to test the significance. Shapiro Wilk test of normaility was done using the software whwich showed that the normal distribution was not met for parametric test. Hence, Non parametric tests were administered such as to compare two different parameters within the same group, like unaided and aided difference limen scores within Group II, Wilcoxon Signed Rank test was used and for comparisons across the groups, Mann Whitney U test was administered.

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Chapter 4

Results

Total of 40 ears were considered for the study (N = 40) which were grouped into two Group I – ears with normal hearing thresholds i.e. control group; Group II – ears with moderate sensorineural hearing loss i.e. the experimental group; with equal number in both the groups (n=20). The absolute value of difference limen for intensity (ΔI), difference limen for frequency (ΔF) and difference limen for time or duration (ΔT) were estimated for two different test frequencies i.e.750 and 1500 Hz at one sensation level i.e. at 20 dBSL for both the groups. For the experimental group i.e. Group II, the measures were obtained under two different conditions aided and unaided.

The measures obtained for both the groups were T750- Threshold at 750 Hz using adaptive procedure, in dBSPL, ΔI750-absolute difference limen for intensity, in dBSPL, ΔF750- absolute difference limen for frequency at 750 Hz, in Hz, ΔT750- absolute difference limen for duration or time at 750 Hz, in msec, similarly for 1500 -T1500, ΔI1500, ΔF1500, ΔT1500 which are threshold, absolute value of difference limen for intensity, frequency and duration respectively at 1500 Hz. These measures were done in two conditions that is aided and unaided for Group II. The following parameters were compared using appropriate statistical measures

a. Comparison of Unaided absolute difference limen scores of Group II with that of Group
b. Comparison of Aided absolute difference limen scores of Group II with that of Group I

c. Comparison of Aided and Unaided absolute difference limen scores within Group II

d. Comparison of differences in the absolute difference limen scores between 750 Hz and 1500 Hz within Group I and Group II

4.1. Comparison of Unaided absolute difference limen scores of Group II with that of Group I

Comparison of absolute difference limen scores of Group II (experimental) with that of Group I (control) was done under two different conditions i.e. unaided scores of difference limen of Group II with that of Group I and in aided conditions. This was done to estimate the amount of deviancies for those with moderate SNHL from normal control group in terms of their difference limen scores. The descriptive statistics of unaided difference limen scores for Group I and Group II are depicted in table 4.1.

Table 4.1: *Mean, Standard deviation and Median of absolute difference limen scores of intensity, frequency and duration of GroupI and Group II*

Parameter (Unaided)	Group I Mean	SD	Median	Group II Mean	SD	Median
T750(dBSPL)	-81.33	8.69	-82.50	-39.42	7.81	-39.00
ΔI750(dBSPL)	3.61	1.87	3.00	2.77	0.93	3.00
ΔF750(Hz)	12.94	3.80	15.00	61.50	18.07	55.50
ΔT750(msec)	87.17	11.70	85.15	119.40	23.24	120.00
T1500(dBSPL)	-81.26	8.20	-83.75	-41.32	9.04	-39.75
ΔI1500(dBSPL)	3.40	1.50	3.00	2.52	1.26	2.75
ΔF1500(Hz)	23.38	9.01	25.00	64.98	18.80	59.50
ΔT1500(msec)	93.94	12.90	97.00	108.15	16.21	107.00

Note. T750, T1500- Threshold at 750 and 1500 Hz; ΔI750, ΔI1500- absolute difference limen for intensity at 750 Hz and 1500 Hz; ΔF750, ΔF1500- absolute difference limen for frequency at 750 and 1500 Hz; ΔT750, ΔT1500- absolute difference limen for duration at 750 and 1500 Hz respectively.

For Group I (control): Absolute difference limen for intensity ranged from 1.5- 6 dBSPL for both 750 Hz and 1500 Hz. The absolute difference limen for frequency ranged from 7.5-20 Hz at 750 Hz and 5- 31 Hz for 1500 Hz. The absolute difference limen for duration ranged from 72.5-105 msec at 750 Hz and ranged from 75 – 120 msec at 1500 Hz. It can be inferred that even for normals all difference limen values followed a wide range.

For Group II (experimental): The absolute difference limen for intensity ranged from 1-4 dBSPL at 750 Hz and 1500 Hz. The absolute difference limen for frequency ranged from 45-100 Hz at both the frequencies. A wide range was observed for absolute difference limen for duration which ranged from 80-198 msec at 750 Hz and 80-120 msec at 1500 Hz. It can be inferred from table 4.1 that the magnitude of difference limen scores for Group II is larger than that of Group I except for difference limen for intensity which is not showing much difference between both the groups.

Test of normality (Shapiro-Wilk test) was done to check whether the scores followed normal distribution for parametric tests. Since, the values were not following the normal distribution hence, non-parametric tests were done. The statistical analysis was done using Statistical Package for the Social Sciences (SPSS) software version 17. In order to check whether these differences were statistically significant, Mann Whitney U test was administered and the results are depicted in Table 4.2.

Table 4.2: *Results of Mann Whitney U test of difference limen scores between Group I and Group II (unaided)*

Parameter (Unaided)	Z	p value
T750	-5.420	.000
ΔI750	-0.945	.345
ΔF750	-5.445	.000
ΔT750	-4.616	.000
T1500	-5.416	.000
ΔI1500	-1.766	.077
ΔF1500	-5.358	.000
ΔT1500	-2.790	.005

It can be inferred from the results using Mann Whitney U test that there was a significant difference between Group II and Group I in threshold, difference limen for frequency and duration ($p < 0.05$); however, there was no significant difference between Group II and Group I in terms of difference limen for intensity ($p > 0.05$).

4.2. Comparison of Aided absolute difference limen scores of Group II with that of Group I

The aided absolute difference limen scores of Group II was compared with the unaided scores of Group I so as to check whether with the appropriate amplification difference limen scores are restored or not. The descriptive statistics including Mean, Standard deviation and Median of aided absolute difference limen scores of Group II and Group I is depicted in Table 4.3.

Table 4.3: *The Mean , Standard Deviation (SD) and Median of difference limen scores of Group I and Group II (aided*)

Parameter	Group I Mean	SD	Median	Group II Mean	SD	Median
T750(dBSPL)	-81.33	8.69	-82.50	-55.22	28.61	-62.15
ΔI750(dBSPL)	3.61	1.87	3.00	5.18	2.37	5.00
ΔF750(Hz)	12.94	3.80	15.00	43.50	17.82	38.25
ΔT750(msec)	87.17	11.70	85.15	94.32	13.60	96.50
T1500(dBSPL)	-81.26	8.20	-83.75	-57.63	10.54	-60.00
ΔI1500(dBSPL)	3.40	1.50	3.00	5.15	2.15	4.50
ΔF1500(Hz)	23.38	9.01	25.00	47.48	18.66	41.75
ΔT1500(msec)	93.94	12.90	97.00	91.10	9.71	89.50

It can be inferred from the Table 4.3 that even with optimum amplification, the difference limen for frequency showed a large difference between Group II and Group I; Group II showing poorer scores or in other words individuals within Group II required larger differences in stimuli in terms of frequency to discriminate between them. With amplification, the aided absolute difference limen for intensity deteriorated and became poorer than normals. There is no much difference between the values obtained for difference limen for duration between Group II and Group I.

In short, there is a large difference between Group II (aided) and Group I with respect to absolute difference limen for frequency and the deteriorated difference limen for intensity however, there is no much difference with respect to difference limen for duration. Mann Whitney U test was used to test the significance between both the groups with respect to absolute difference limen scores. The results are depicted in Table 4.4.

Table 4.4: *Results of Mann Whitney U test of difference limen scores beween Group I and Group II(aided)*

Parameter	Z	p value
T 750(dBSPL)	-4.87	.000
ΔI750(dBSPL)	-2.51	.012
ΔF750(Hz)	-5.39	.000
ΔT750(msec)	-1.58	.112
T1500(dBSPL)	-5.01	.000
ΔI1500(dBSPL)	-2.80	.005
ΔF1500(Hz)	-4.35	.000
ΔT1500(msec)	-.90	.363

The test statistics using Mann Whitney U test between both the groups revealed that there is a significant difference between Group II with amplification and Group I with respect to threshold, absolute difference limen for frequency and intensity ($p < 0.05$). However, there was no significant difference between both the groups in terms of difference limen for duration ($p > 0.05$) for both the frequencies.

4.3. Comparison of Aided and Unaided absolute difference limen scores within Group II

Aided absolute difference limen scores were obtained using a four channel digital behind the ear hearing aid programmed and optimized according to the loss of the participant. The aided absolute difference limen scores were obtained at 20 dBSL for the test frequencies of 750 and 1500 Hz with reference to the aided threshold at that frequency. This score was compared with that of the unaided scores. The table 4.5 shows the descriptive statistics for unaided and aided conditions at 750 Hz and 1500 Hz within Group II.

Table 4.5: *Mean, Standard Deviation (SD) and Median for threshold, DLI, DLF and DLD at 750 Hz and 1500 Hz in unaided and aided conditions for Group II*

Parameter	Unaided			Aided		
	Mean	**SD**	**Median**	**Mean**	**SD**	**Median**
T750(dBSPL)	-39.42	7.81	-39.00	-55.22	28.61	-62.15
ΔI750(dBSPL)	2.77	0.93	3.00	5.18	2.37	5.00
ΔF750(Hz)	61.50	18.07	55.50	43.50	17.82	38.25
ΔT750(msec)	119.40	23.24	120.00	94.32	13.60	96.50
T1500(dBSPL)	-41.32	9.04	-39.75	-57.63	10.54	-60.00
ΔI1500(dBSPL)	2.52	1.26	2.75	5.15	2.15	4.50
ΔF1500(Hz)	64.98	18.80	59.50	47.48	18.66	41.75
ΔT1500(msec)	108.15	16.21	107	91.10	9.71	89.50

It can be inferred from table 4.5 that the aided scores are less than unaided scores for absolute difference limen for frequency and duration both at 750 Hz and 1500 Hz which indicates an improvement in frequency and duration difference limen with amplification. However; the absolute difference limen for intensity in aided condition is greater than that of unaided condition showing an increase in the magnitude of intensity difference limen at 750 and 1500 Hz in other words, DLI deteriorated with amplification.

Wilcoxon Signed Ranks test was used to test for the significance between aided and unaided difference limen scores within Group II. The results of Wilcoxon signed rank test is depicted in Table 4.6.

Table 4.6: *Results of Wilcoxon Signed Rank Test of Group II participants for aided and unaided difference limen scores*

Parameter	Z	p value
AT750 Vs. UT750	-3.180	.001
AΔI750 Vs. UΔI750	-3.831	.000
AΔF750 Vs.UΔF750	-3.921	.000
AΔT750 Vs. UΔT750	-3.921	.000
AT1500 Vs. UT1500	-3.922	.000
AΔI1500 Vs.UΔI1500	-3.936	.000
AΔF1500 Vs. UΔF1500	-3.921	.000
AΔT1500 Vs. UΔT1500	-3.824	.000

Note: U- unaided, A- aided, T- threshold, ΔI- absolute difference limen for intensity, ΔF- absolute difference limen for frequency and ΔT- absolute difference limen for duration.

It can be inferred from table 4.6 that there is a significant difference between aided and unaided conditions for absolute difference limen for intensity, frequency and duration at 750 and 1500 Hz ($p < 0.05$) using Wilcoxon Signed Ranks test i.e. there is a significant amount of improvement in difference limen for frequency and duration; however, there is a significant amount of deterioration in difference limen for intensity in aided condition within Group II as indicated by the values.

4.4. Comparison of differences in the difference limen scores between 750 Hz and 1500 Hz within Group I and Group II

4.4.1. Comparison of difference limen scores between 750 and 1500 Hz Within Group I

The differences between 750 and 1500 Hz in terms of the difference limen scores were studied for both the groups. The descriptive statistics for the same within Group I is depicted in Table 4.7.

Table 4.7: *The Mean, SD and Median for threshold, difference limen scores for Intensity, Frequency and Duration between 750 Hz and 1500 Hz within Group I*

Parameter	**At 750 Hz**			**At 1500 Hz**		
	Mean	**SD**	**Median**	**Mean**	**SD**	**Median**
T(dBSPL)	-81.33	-8.69	-82.50	-81.26	8.200	83.75
ΔI(dBSPL)	3.61	1.87	3.00	3.40	1.50	3.00
ΔF(Hz)	12.94	3.80	15.00	23.38	9.01	25.00
ΔT(msec)	87.17	11.70	85.15	93.94	12.90	97.00

It can be inferred from table 4.7 that there is much difference between 750 and 1500 Hz in terms of difference limen for frequency. Moreover, there is difference in terms of difference limen for duration between the frequencies. However, there is no much difference between the frequencies for difference limen for intensity and threshold.

Wilcoxon Signed Ranks test was used to test whether there is a significant difference between 750 and 1500 Hz with respect to difference limen scores within Group I. The results of this are depicted in table 4.8.

Table 4.8: *Results of Wilcoxon Signed Ranks test between 750 and 1500Hz within Group I*

	Threshold	ΔI	ΔF	ΔT
Z	-.035	-.416	-3.30	-2.15
p value	.97	.67	.001	.031

It can be inferred from the test statistics that there is a significant difference between 750 and 1500 Hz with respect to difference limen for frequency and duration ($p < 0.05$). However, there is no significant difference between 750 and 1500 Hz in terms of threshold and difference limen for intensity ($p > 0.05$).

4.4.2. Comparison of difference limen scores between 750 and 1500 Hz within Group II (unaided)

The scores obtained for difference limen and threshold was compared between 750 and 1500 Hz within Group II in unaided condition. The descriptive statistics for the same is depicted in table 4.9.

Table 4.9: *The Mean, SD and Median for difference limen scores between 750 and 1500 Hz within Group II (unaided)*

Parameter	750 Hz			1500 Hz		
	Mean	SD	median	mean	SD	Median
threshold	-39.42	7.81	-39.00	-41.32	9.04	-39.75
ΔI	2.77	0.93	3.00	2.52	1.26	2.75
ΔF	61.50	18.07	55.50	64.98	18.80	59.50
ΔT	119.40	23.24	120.00	108.15	16.21	107.00

It can be inferred that unlike Group I, there is no much difference in magnitude between 750 and 1500 Hz in terms of Threshold, Difference limen for frequency and difference limen for intensity; however, there is a great difference between 750 and 1500 Hz in terms of difference limen for duration at 750 Hz and 1500 Hz.

Wilcoxon Signed Ranks test was used to test the significance between 750 and 1500 Hz within Group II. The results of Wilcoxon Signed Ranks test is represented in table 4.10.

Table 4.10: *The results of Wilcoxon Signed Ranks test of unaided difference limen scores of Group II between 750 and 1500 Hz*

	Threshold	**ΔI**	**ΔF**	**ΔD**
Z	-1.551	-1.122	-1.429	-2.521
p value	.121	.262	.153	.012

The Wilcoxon Signed Ranks test of significance revealed that there is a significant difference between 750 and 1500 Hz only in terms of difference limen for duration ($p < 0.05$). However, there is no significant difference between 750 Hz and 1500 Hz in terms of threshold, difference limen for intensity and frequency ($p > 0.05$).A comparison of results obtained for different parameters are shown in table 4.12

Table 4.11: Comparison of results obtained for different parameters considered for the study

Parameter	**DLI**	**DLF**	**DLD**
Aided Vs. unaided within Group II	**	**	**
Group II (unaided) Vs. Group I	*	**	**
Group II (aided) Vs. Group I	**	**	*
750 Hz Vs. 1500 Hz Group I	*	**	**
750 Hz Vs. 1500 Hz within Group II	*	*	**

Note. ** -significantly different and * -not significantly different.

Chapter 5

Discussion

In individuals with sensorineural hearing loss, the perception of sound is being altered and this is not only limited to the reduced audibility. Hence, it has been suggested that the normal perception of sound cannot be completely restored even with an adequate amplification (Moore, 1996). The threshold measures would not always replicate the functional status of cochlea hence; discrimination measures which would provide much more information than just audibility (Brandt, 1967). The smallest perceivable difference between two signals is termed as difference limen or just noticeable difference (Green, 1976). It could be either in terms of frequency, intensity or duration. However, this ability to discriminate depends on the characteristics of the reference signal and also on individual's ability (Wever, 1976). The literature proved that this ability to discriminate small changes will be adversely affected in those with sensorineural hearing loss where the resolving power of the ear is compromised (Campbell, 1970). Hence, the present study was designed to check whether an adequate amplification, using a multichannel programmable digital hearing aid would restore the normal discrimination in post lingual adults with moderate sensorineural hearing loss.

Twenty ears with normal hearing (Group I) and twenty ears with moderate sensorineural hearing loss (Group II) were considered for the study. Routine procedures including Pure tone audiometry, Immittance audiometry, Otoscopic evaluation and Speech audiometry was done prior to the difference limen measures for subject selection. The difference limen measures were carried out using Psycon software version 2.18 using a forced choice paradigm. There could be a difference in thresholds obtained using the software and audiometer because the former is caliberated in dBSPL and latter in dBHL. Hence, thresholds were obtained using the Psycon software using an adaptive procedure i.e. 2 down 1 up three interval alternate forced choice method. The adaptive procedure was incorporated targeting on the precision. The stimuli used were 750 and 1500 pure tones presented through loudspeaker oriented at 0 degree azimuth. These frequencies were selected such that the target frequencies should be in the mid frequency range and should not overlap with the cross over frequency of the hearing aid channel separation.

For both the groups the difference limen measures were administered for both desired test frequencies of 750 and 1500 at 20 dBSL (re: threshold using adaptive procedure). Group II individuals were fitted with a digital programmable hearing of 4 channels and the hearing aid was selected based on its electroacoustic characteristics to suit moderate degree of hearing loss. The hearing aid was programmed for each individual, optimized the gain and verified using Real Ear measures. The hearing aid was kept constant for all the participants in Group II. Unaided and Aided difference limen scores were obtained for participants in Group II. The absolute difference limen scores for frequency, intensity and duration were obtained for both the groups at 750 and 1500 Hz.

Statistical analysis was done using Statistical Package for social sciences version 17. Two between group comparisons were done i.e. comparison of difference limen scores of Group I with that of Group II which were 1) unaided difference limen scores of Group II with that of Group I and 2) aided difference limen scores of Group II with that of Group I. The former comparison was made to estimate the amount of deviancies for difference limen scores between both the groups and the latter comparison was made to check whether an appropriate amplification would restore the discrimination in moderate sensorineural hearing loss. Mann Whitney U test was used to check the significance between the groups which were as follows:

5.1. Comparison of unaided difference limen scores of Group II with that of Group I

There was a significant difference between the difference limen scores of frequency and duration. However, the difference in terms of difference limen for intensity was not statistically significant ($p > 0.05$) at both the frequencies. This was contradicting the previous literature, as the comparison was made at low sensation levels, Group II individuals were expected to show better performance than Group I according to the previous literature (Buus, Florentine & Redden, 1982; Glasberg & Moore, 1989; Zwislocki & Fillon, 1989; Schroder, Viemester& Nelson, 1994). 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 its difficult to have any clear delineation between neural and sensory components. Hence, this could be the possible reason for huge variability in the group performance i.e. there were huge variability in group performance ranging from 1-4 dBSPL for those with sensorineural hearing loss and 1.5-6 dBSPL for normals. Hence, when considering as a group, there was no statistically significant difference in terms of difference limen for intensity.

As expected, the difference limen for frequency is adversely affected or abnormally large in Group II which was found to be statistically significant ($p < 0.05$). This could be because of the decreased frequency resolution in individuals with sensorineural hearing loss due to widened auditory filters in them, as a consequence of structural damage which is supported by the literature (Gengel 1973; Tyler, Wood & Fernandes, 1983; Hall & Wood, 1984; Freyman & Nelson, 1986, 1987, 1991; Moore & Glasberg 1986; Moore & Peters, 1992; Simon & Yund, 1993). The absolute DLF (ΔF) for normals ranged from 7.5-20 Hz and 5-31 Hz at 750 and 1500 Hz respectively and we can infer that there is a wide range even for normals. This could be because of the individual variabilities in attention, memory, motivation etc. which would influence the test procedure. Apart from this, the individuals with sensorineural hearing loss showed a clear difference from normals with a range of 45-100 Hz. Again, the data showed huge variabilities. Even with similar degree of hearing loss the individuals showed a wide range which is supported by the findings of Simon and Yund (1993) who reported that there was no one to one correlation between the threshold and the DLF which could be the differences in the filter bandwidth. However, there is no one to one correlation even with filter bandwidth and DLF as reported (Moore & Peters, 1992) or it could be the changes in the phase locking information for large DLFs (Loeb, White & Merzenich, 1983). But it was not expected to get large DLF as that of 100 Hz. But, this was more specifically seen in those individuals with asymmetric hearing loss; hence this could be attributed to diplacusis in them which could be evident as the stimuli were presented in free field. However, further research is required to substantiate these findings.

The difference limen for duration is found to be significantly different in both the groups ($p < 0.05$) with the Group II showing abnormally large absolute difference limen for duration. This is supported by 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.

5.2. Comparison of aided difference limen scores of Group II with that of Group I

The aided difference limen scores of Group II was compared with that of Group I using Mann Whitney U test to check whether the amplification the scores is restored to normal values. The results revealed that there was a significant difference ($p < 0.05$) between both the groups in terms of difference limen for frequency with normals showing a better performance than the aided DLF of individuals with sensorineural hearing loss.

The difference limen for intensity deteriorated in the aided condition. This difference was statistically significant ($p < 0.05$). However, there was no statistically significant difference between the groups in terms of difference limen for duration ($p > 0.05$). It can be inferred from the results that even with amplification it is difficult to restore the normal perception which is evidenced by the poor frequency difference limen even with aid which is supported by Moore (1996) that the normal perception of sound cannot be completely restored even with an adequate amplification. The compression systems in hearing aids would reduce the intensity discrimination in turn we can infer that the abnormal loudness growth due to recruitment can be controlled.

Three within group comparisons were done: aided difference limen scores and unaided scores within Group II, scores between 750 and 1500 Hz within Group I and Group II.

5.3. Comparison of aided and unaided difference limen scores within Group II

The aided and unaided difference limen scores were compared within Group II using Wilcoxon Signed Rank test. The results revealed that there was a significant difference between unaided and aided Difference Limen scores for Intensity, frequency and duration ($p < 0.05$).There was a considerable improvement in the difference limen scores for frequency and duration between both the conditions which could be because of the increase in audibility with aid. The number of channels could also influence on the absolute DLF scores. However, there is scarcity of literature to support this view point and further research has to be done in order to know the effect of number of channels on difference limen for frequency. There was a significant decrement in the difference limen for intensity i.e. aided difference limen for intensity showing poorer scores than unaided condition. This could be because of the Wide Dynamic Range Compression acting on the hearing aid which is supported by the findings of Shufani et al. (2006) who reported that increasing the compression ratio from linear amplification would have a negative impact on level judgments.

5.4. Comparison of differences in the difference limen scores between 750 Hz and 1500 Hz within Group I and Group II

Difference limen scores for 750 and 1500 Hz were compared within both the groups using Wilcoxon Signed rank test. In case of normals, significant difference between the scores at 750 and 1500 Hz was obtained for frequency and for duration ($p < 0.05$), however there was no statistically significant difference in terms of difference limen for intensity ($p > 0.05$). The significant difference between the difference limen for frequency at 750 and 1500 Hz could be attributed to the precise frequency selectivity of normal cochlea. The independence of intensity discrimination on frequency of the standard was reported by Wier, Jesteadt and Green (1977), however, the significant difference in terms of difference limen for duration between the frequencies were not expected and is contradicting the findings of Tyler et al. (1982).

The comparison of difference limen scores between 750 and 1500 Hz within Group II showed a significant difference only in terms of duration difference limen and not in terms of intensity and frequency difference limen. The DLF at 750 and 1500 Hz did not show any statistically significant difference ($p > 0.05$) due to the widened filter bandwidth which is supported by the literature.

There could be various other factors which would have influenced the study such as heterogeneity of the participants in terms of onset and cause of hearing loss, recruitment, diplacusis; other non audiological factors like motivation, attention, memory etc. Further studies are required to validate the results of the study.

Chapter 6

Summary and Conclusion

The individuals with cochlear damage experience reduced audibility to sounds; moreover the natural perception of sound is altered. Hence, just by measuring the threshold of audibility do not provide us with the complete picture of cochlear damage. So, suprathreshold measures gained its importance, which includes the speech tests, suprathreshold special tests like Short Increment Sensitivity Index etc. The basics of these are that the need to know how they are able to detect changes in stimuli, one sound from other; which is 'discrimination'. Cochlea analyses an incoming signal in terms of its frequency, intensity and duration. Hence, it is important to know the effect of sensorineural hearing loss on frequency, intensity and duration discrimination; which is a field that is being explored since decades. Few authors in the recent years explored the effect of amplification on frequency and intensity discrimination. However, these results are inconclusive because they have not aimed at the immediate effect of amplification instead focused on the acclimatization and associated plasticity.

The present study focused on the immediate effect of amplification i.e. a four channel programmable digital behind the ear hearing aid on frequency, intensity and duration discrimination. For this, two groups of participants were considered Group I – control group with normal hearing and Group II- experimental with moderate sensorineural hearing loss. Absolute difference limen for frequency, Intensity and duration difference limen were measured at 750 and 1500 Hz at 20 dBSL for both the groups. For Group II these measures were done at two conditions i.e. aided and unaided.

Aided and unaided difference limen scores for Group II was compared with that of Group I which was done to quantify the difference between two groups and to test whether an appropriate amplification would restore the normal discrimination. Aided and unaided scores within Group II were compared to test whether there is a benefit of amplification on discrimination. To check whether there is a frequency effect on difference limen for intensity, frequency and duration scores obtained at 750 and 1500 Hz were compared within both the groups.

The results of the study revealed that:

a. There was a significant difference between both the groups in terms of frequency, duration discrimination but not in intensity discrimination. This could be because of a wide range in the absolute values showed by both the groups; hence the measure of central tendency values were not significant.

b. There was a significant difference between aided difference limen scores of Group II when compared to normals in the domains of intensity and frequency discrimination but not in duration difference limen which showed that even with the amplification the frequency and duration discrimination is not restored. However, the intensity discrimination deteriorated with compression aids which could be considered positive such that with compression there will be a decrement in the recruitment.

c. There was a significant improvement in the absolute difference limen scores with amplification device in frequency and duration difference limen. However, the absolute intensity difference limen deteriorated. It could be because of the Wide Dynamic Range Compression in the hearing aid.

d. A significant difference of scores was obtained between the test frequencies except for difference limen for intensity in normals.

e. A significant difference between 750 and1500 Hz was obtained only in the domain of duration discrimination and not in intensity or frequency limen for Group II.

6.1. Implications of the study

a. Individuals with sensorineural hearing loss show poor frequency and duration discrimination

b. Even with an optimum gain and amplification device the discrimination was not restored equivalent to the normal ears.

c. With a nonlinear AGC hearing aid, individuals will not experience the recruitment, hence the intensity difference limen scores deteriorates. However, there is a considerable improvement in duration and frequency discrimination.

6.2. Limitations and future recommendations

a. The decrement in intensity difference limen was attributed to the compression acting in the hearing aid used. However, the current data is not sufficient to substantiate this. For this, we need to validate the results at different compression thresholds, compression ratios and compare the results with linear hearing aids.

b. The scores of frequency and duration difference limen improved which was attributed to the use of amplification device. However, with the use of just one hearing aid, one cannot generalize this finding. Hence, the results have to be validated using different multichannel aids varying in the number of channels, different types of aids etc.

c. Considering the time constraints, the study was conducted only in two mid octave frequencies i.e. 750 and 1500 Hz and only in one intensity level i.e. at 20 dBSL. This study has to be extended to check the frequency and intensity effects.

d. This study was conducted only in one group of participants with moderate sensorineural hearing loss and only in one age group. Hence, the study has to be extended to different degrees, configuration of hearing loss and to different age groups.

e. The study could have been better if a double blinded design was used.

f. The study considered a basic pure tone as the stimuli, which should be extended to different types of complex stimuli like modulated signals, noise and speech.

6.3. Clinical applications

a. *Counseling tool*: Creating realistic expectations in patients and family is a difficult task, because most often there is a misconception that with the hearing aid the normal perception would be restored. This study can be presented as an evidence to show that even with amplification the normal perception could not be completely restored, however, there is a benefit from amplification and an overall improvement.

b. *Hearing aid benefit*: In hearing aid trials, to check whether a particular hearing aid is beneficial or not we do speech tests, aided thresholds or real ear measurements.

If the subject is non-verbal and speech tests could not be done, along with pure tone aided thresholds, these measures can be done so that it gives more information rather than just audibility. If there is an improvement in the discrimination abilities, this could be even reflected in the real life situations.

c. *Monitoring of hearing aid use:* many studies have shown that there will be an overall improvement in the discrimination scores in frequency domain with acclimatization. If we are using a pure tone to quantify this there may not be significant change in the aided thresholds and is difficult to monitor it, if we are using a speech material to monitor, the subjects can get used to the material used and shows better scores. But with this measure of discrimination the chance factor of false response and the chance to adapt to the material is minimal. Hence, it serves as a good measure to account for the effect of acclimatization.

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