PSYCHOACOUSTIC ABILITIES OF NORMAL EAR OF LISTENERS WITH UNILATERAL HEARING LOSS

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This Dissertation is submitted as part of fulfilment

for the Degree of Master of Science in Audiology

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MAY 2017

CERTIFICATE

This is to certify that this dissertation entitled "**Psychoacoustic Abilities of Normal Ear of Listeners with Unilateral Hearing loss**" is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD018. 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.

Mysuru
May, 2017

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DECLARATION

This is to certify that this dissertation entitled "**Psychoacoustic Abilities of Normal Ear of Listeners with Unilateral Hearing loss**" is the result of my own study under the guidance of Dr. **Jijo.P.M**, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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May, 2017

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Alone we can do so little, together we can do so much

-Helen Keller

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ABSTRACT

Aim: The study compared psychoacoustic abilities in the normal ear of individuals with unilateral hearing loss and that of individuals with bilateral normal hearing sensitivity. **Methods**: A total of 44 subjects were included in the study in which 22 were individuals with unilateral hearing loss who were ruled out for any middle ear and retro-cochlear pathologies. 22 were individuals with bilateral normal hearing sensitivity. All the participants were native speakers of Kannada language. Psychoacoustics tests like frequency discrimination (500 Hz, 1 kHz, 2 kHz and 4 kHz), intensity discrimination (500 Hz, 1 kHz, 2 kHz and 4 kHz), duration discrimination (250 ms) and gap detection were performed. These tests were administered using Matlab software. In addition, SNR-50 was also performed in the two groups. **Analysis:** Descriptive statistics and MANOVA were performed for statistical analysis. **Results**: The results revealed that frequency discrimination and intensity discrimination thresholds increased as the frequency increased in both the groups. It was found that individuals with unilateral hearing loss performed poorer than normal hearing individuals in all the psychoacoustic tasks. However, SNR-50 showed no statistically significant difference. Further, there was no correlation between psychoacoustic tests and SNR-50 in the participants. **Conclusion**: The study revealed that individuals with unilateral hearing loss in their normal ear needed a higher threshold than those with bilateral normal hearing in all the psychoacoustic tasks. However, duration of deafness did not show any relation to performance on these psychoacoustic tasks.

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Chapter 1

Introduction

Unilateral hearing loss (UHL) is defined as reduced hearing sensitivity ranging from mild- profound degree in one ear and a normal hearing sensitivity in the other ear. Unilateral hearing loss is seen in about 6.3% of individuals (Varshney, 2016). Its occurrence is usually sudden and causes can be due to neoplasms, stroke, demyelinating and autoimmune diseases, infection, perilymphatic fistula, and Meniere's disease or idiopathic. UHL can occur at any age. Hearing loss in UHL can be progressive or static.

Various studies have demonstrated poor speech perception in noise in individuals with unilateral hearing loss (UHL) in comparison to individuals having bilateral normal hearing. Ruscetta, Arjmand and Pratt (2005) studied speech recognition ability in noise in the good ear of 17 children with severe-profound unilateral hearing loss. Hearing in Noise Test-Children (HINT-C) and Nonsense Syllable Test (NST) along with multi-talker babble at 65 dB were used for the study. Children listened to speech in the presence of noise in different listening conditions such as from 0^0 azimuth, from right side and left side. Results showed that, children with UHL needed greater signal-to-noise ratio (SNR) compared to control group in most of the listening conditions for both the speech test. Authors concluded that children with UHL needed better listening condition to perform well.

Sargent, Herrmann, Hollenbeak and Bankaitis (2001) observed the response of minimum speech test battery (MSTB) in 10 adults with UHL in 4 conditions; 1) in quite, 2) speech in good ear and noise in the ear with hearing loss, 3) speech in the ear with hearing loss and noise in the good ear, 4) bilateral speech and noise. Their performance was compared to 10 individuals with bilateral normal hearing. Results showed similar performance between groups in quiet. Poor performance was seen in individuals with UHL when noise was presented to the good ear and speech in the ear with hearing loss as well as bilateral speech and noise condition. Thus, poor performance in the presence of noise is reported even in adults having unilateral hearing loss. Welsh, Welsh, Rosen and Dragonette (2004) administered speech in noise (SIN) on 16 subjects with UHL between the age range of 7 to 73 years. Performance of UHL was worse when compared to bilateral hearing individual in SIN condition. These studies showed that UHL impairs auditory reception of speech in noise.

Glasberg and Moore (1989) studied the psychoacoustic abilities to understand speech in individuals with UHL and bilateral hearing loss. There were 9 individuals with moderate UHL and 6 having bilateral moderate hearing loss participated. They tested temporal gaps in band of noise and frequency discrimination for pure tones and complex tones. Their results suggest that speech perception in quiet is determined primarily by absolute thresholds as measured by the pure-tone audiogram. In the presence of noise, speech understanding is related more to supra-threshold discrimination abilities, such as the detection of temporal gaps in noise and the frequency discrimination of pure and complex tones. Thus, they recommend studying various psychoacoustic tasks for better understanding of speech perception in noise.

Psychoacoustic studies in individuals with UHL showed variable results on different psychoacoustic tasks. Sininger and de Bode (2008) studied temporal processing in the good ear of listeners with UHL. Their intention was to study lateralized processing of auditory stimuli by ear and the relationship between auditory task and stimulus type. Gap detection thresholds were determined in 30 right-handed listeners with normal hearing using wide-band noise markers (temporally complex), 400 Hz and 4000 Hz pure tones presented individually to the left and right ears. The same procedure was administered to listeners with early-onset, severe-to-profound unilateral deafness (seven left ear deaf and five right ear) in the hearing ear alone. Their results showed significant right ear advantage for gap detection threshold using noise maskers and a smaller left ear advantage for tonal stimuli. Listeners with unilateral deafness demonstrated that the hearing ear, left or right, performed in a manner similar to listeners with normal hearing.

Miller (2010) compared performance of individuals with UHL and normal hearing individuals using temporal modulation transfer function (TMTF) and Random Spectrogram Sound – Just Noticeable Difference (RSS-JND). They found no significant difference between UHL and normal ears for their amplitude modulation detection. RSS-JND also showed no significant difference. They concluded that monaural auditory input from unilateral hearing loss does not affect temporal processing abilities as assessed by amplitude modulation detection thresholds or just-noticeable-differences in temporal complexity of RSS stimuli.

A study by Maslin et al. (2015), investigated whether adults with late-onset, unilateral, profound deafness would exhibit changes in their intensity discrimination ability in their intact ear. They compared intensity discrimination abilities of 11 adults with UHL with age matched normal hearing participants. The results revealed decreased IDLs (intensity difference limen) among individuals with unilateral deafness, and these individuals had previously been found to exhibit greater auditory cortical response amplitudes (Maslin et al. 2015). Explanation given for the differences between groups is that alterations in central processing of the signal lead to improved intensity discrimination in individuals with profound unilateral deafness. Physiological data from the same participants supported this.

Similarly, Firszt, Uchanski, Burton and Reeder (2010) utilized Random Spectrogram Sound (RSS) stimuli (Schönwiesner, Rubsamen, & von Cramon, 2005) and found that better performance was observed in individual with bilateral normal hearing (when restricted to listening monaurally) compared to individuals with UHL.

From the above literature it is clear that individuals with UHL exhibit deficits in speech understanding in the presence of noise. They also showed impairment in various psychoacoustic tasks. However, role of different psychoacoustic tasks on speech perception in noise is not investigated in them. Further, the impact of duration of deafness on speech understanding and psychoacoustic performance may also be studied.

Need for the study

Although a few studies have investigated psychoacoustic abilities in the good ear of individuals with unilateral hearing loss (Miller, 2010; Nishihata et al., 2012; Sininger & de Bode, 2008), they have studied only a few psychoacoustic tasks. It is known that speech perception and different psychoacoustic abilities are related. Hence, there is a need to investigate psychoacoustic abilities such as intensity discrimination, frequency discrimination, and gap detection in individuals with unilateral hearing loss. There is a need to take into account the effect of duration of hearing loss on these psychoacoustic abilities. Therefore, the current study aimed to investigate psychoacoustic abilities of the good ear of individuals with unilateral hearing loss in comparison with monaural psychoacoustic function of normal hearing individuals.

Objectives

To compare good ear of individulas with unilatearl hearing loss and any one ear of individuals with normal hearing for their

- Frequency discrimination at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz
- Intensity discrimination at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz
- Duration discrimination at 1000 Hz for 250 ms
- Gap detection test
- SNR-50

To investigate the effect of duration of hearing loss on the aformentioned tasks.

Chapter 2

Review of Literature

Unilateral hearing loss can be defined as reduced hearing sensitivity in one ear and normal hearing in the other ear. Unilateral hearing loss can either be acquired or congenital in nature. Degree of hearing loss in the impaired ear can be mild to profound. Unilateral loss can be acquired at any age. Though unilateral hearing loss can be identified easily, its rehabilitation possess is a great challenge for the audiologist.

Sudden sensorineural hearing loss (SSHL) forms a considerable part of unilateral hearing loss clinically. SSHL is defined as loss of at least 30 dB at three consecutive frequencies within 3days of onset (Voelker & Chole, 2010). SSHL can be associated with tinnitus, vertigo and aural fullness (Hughes, Freedman, Haberkamp & Guay, 1996). Either partial or complete recovery is evidenced in around 30-65% of individuals. There are few indicators of poor prognosis in unilateral hearing loss, those are severe-profound hearing loss, high frequency hearing loss, vertigo and increased age (Shaia & Sheehy, 1976., Byl, 1984).

Although 75-85% of unilateral hearing loss are idiopathic in nature, there are a few disorders that causes unilateral hearing loss (Hughes, Freedman, Haberkamp & Guay, 1996). Acoustic neuroma is one of them which is reported to cause progressive unilateral sensorineural hearing loss. 10-26% of individual may present with sudden sensorineural hearing loss (Higgs,1973). These tumours cause high frequency hearing loss, although all type of audiogram configuration can be seen (Voelker & Chole, 2010). Along with it also the speech recognition score will be poor and will not be in agreement with pure tone average (Zeitoun et al, 2005).

Around 4-10% of individuals with multiple sclerosis are prone to be affected by SNHL which is sudden and unilateral in occurrence (Franklin, Coker & Jenkins, 1989). Unilateral hearing loss can either be caused by mechanical or acoustic trauma. Acoustic trauma usually causes unilateral hearing loss or asymmetric hearing loss due to damage of organ of corti or rupture of cochlear membrane (Zeitoun et al, 2005). Ototoxic drugs are mostly known to cause bilateral hearing loss, but also cause unilateral hearing loss. These drugs mostly cause high frequency sensorineural hearing loss. Individuals with labyrinthitis typically have vertigo and sudden unilateral hearing loss. Cytomegalovirus, mumps, measles and varicella zoster are viruses which when infected with can cause unilateral hearing loss (Voelker & Chole, 2010). There are other infections such as syphilis (Schuknecht, 1993) and Lyme diseases (Hanner, Rosenhall, Edstrome & Keijser, 1989) which also leads to unilateral hearing loss. Meniere's disease is also known to cause unilateral low frequency fluctuating hearing loss during early stage (Voelker & Chole, 2010).

It is reported that 17-33% of individual with idiopathic unilateral hearing loss, can have virus like infection in the upper respiratory track one month prior to the onset of hearing loss (Shaia & Sheehy, 1976). Further researches have been carried out to find out more causes for unilateral hearing loss. Finding out the cause plays a major role in deciding the rehabilitation to be carried out.

Psychoacoustic abilities of normal ear have been studied in individuals with unilateral hearing loss. These studies investigated intensity, frequency and temporal processing abilities in them. This review of literature describes such studies.

Frequency Discrimination Threshold

The minimum frequency difference to differentiate two stimuli is the frequency discrimination threshold. Kammath and Vyasamurthy (1989) studied the effect of frequency, sensation level, gender and ear difference on difference limen frequency (DLF) for 40 normal hearing subjects wherein increment was in terms of percentage. 5% increment 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 author reported there was no difference between DLF for males and females and ear difference.

Jesteadt et al. (1977) reported that the frequency discrimination threshold increases as the frequency increases and decreases as the sensation level decreases. Frequency discrimination threshold decreases with increase in sensation level, but this trend is followed only till 40 dB SL and above which it is roughly constant and reported that presenting at 25 dB SL is most appropriate for frequency discrimination measurements. There are many models that explains the mechanism underlying in frequency discrimination like place model (Henning, 1967; Siebert, 1979; Zwicker, 1970). They assumed that the frequency discrimination depends on the frequency selectivity which in turn depends on the sharpness of the tuning at the level of basilar membrane.

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

Glasberg and Moore (2006) reported frequency discrimination in 9 unilateral hearing loss individuals and 6 bilateral hearing loss individuals. Frequency discrimination was estimated for tone pulse and complex tone. Results showed that both pulsed and modulated tone tends to have larger frequency discrimination threshold for their impaired ear than for their normal ears, whether compared at equal SPL or equal SL. Sound level had little effect on the normal ears. Individuals with bilateral impairment performed similar to normal. This reflects the underlying pathologies for two different groups and also indicates that cochlear pathology is sometimes, but not always associated with impaired frequency discrimination.

Intensity Discrimination Threshold

Intensity discrimination is the ability to detect the smallest change between stimuli which varies only in loudness. Fasti and Schorn (1981) reported that there could be a difference in the discrimination values when the task is to detect modulation and when task was to compare and detect the pulsed tone which was 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 become more complicated. Thereby, expected to have higher DL values. While using modulated tones, it taps only peripheral part while when pulsed - tone were given, it taps memory and central lesions too.

Dimmick and Olson (1941) reported a plateau between 40-70 dB SL and below this range the resolution was poor and the DLI was higher near threshold. Above this range i.e. 40 dB SL, there was a linear increment and resolution improves with increase in intensity. 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.

Glasberg and Moore (2006) reported intensity discrimination in 9 individuals with unilateral hearing loss and 6 individuals with bilateral hearing loss. Results revealed that at equal SPL, threshold are sometimes larger for impaired ear compared to normal ear, and are sometimes smaller. At equal SL, thresholds are consistently smaller for the impaired ear.

Maslin, Taylor, Plack and Munro (2015) determined intensity discrimination threshold for 11 individuals with unilateral hearing loss. The authors reported an increase cortical activity to sound heard in the intact ear. There was significant smaller intensity discrimination threshold observed compared with controls. These results provide evidence of the perceptual consequences of plasticity in human following unilateral deafness.

Duration Discrimination Threshold

The smallest difference in terms of time to distinguish two sounds which could be termed as the duration discrimination threshold. Fitzgibbons and Salant (1994) hypothesized that duration discrimination is independent of hearing loss and is dependent on the 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 and other two groups of young adults with and without hearing loss. The stimuli used were tone burst of 250 ms and 500 ms. Results revealed that with 250 ms 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 shoed abnormally large difference limen.

Gap Detection Threshold

One of the psychophysical methods of measuring auditory temporal processing is the gap detection paradigm. Gap detection is a well-established measure that determines the ability of the listener to detect brief temporal gap separating two successive stimuli. It is the most commonly used measure of temporal resolution. Gap detection test provides a description of temporal resolution based on a single threshold; whereas other methods require multiple threshold estimates. Another advantage is that the gap detection is easy to measure in naïve listeners, including infants. The gap detection threshold obtained from naïve listeners are close to those obtained from well-trained listeners (Werner, Marean, Halpen, Spetner & Gillenwater, 1992)

The detection of gap in broad noise has been studied using a variety of physiological and psychological techniques, which have provided similar measure of temporal acuity (Plomp,1964; Green & Forrest, 1989; Snell, 1997; Florentine, Buus & Geng, 1999). Broadband noise stimuli are popular since they can be varied in duration or interrupted for precise specification without causing significant change in the stimulus energy spectrum.

Humans detect gaps in BBN according to effective gap duration without much additional cues from abrupt envelope changes. The advantage of using BBN as a signal is that any spectral splatter resulting from the abrupt cessation of sound during the gap will be masked. Its major disadvantage is that it is not possible to specify the frequency region, the listener is using for detection. Several studies indicated that the gap detection in BBN is primarily based on the high frequency components of the noise (Fitzgibbons, 1983; Shailer & Moore, 1983; Buus & Florentine, 1985; Formby & Muir, 1988).

SNR-50

Ruschetta, Arjmand and Pratt (2005) tested for speech recognition abilities in noise for children with severe-profound unilateral hearing impairment. There were 20 individuals with unilateral loss involved in the study. Results showed that individuals with unilateral loss needed greater SNRs than normal listeners. Children with unilateral hearing loss require better listening condition to perform similar to normal listeners. In contrast, Sargent, Herrmann, Hollenbeak and Bankaitis (2001) performed speech test on 10 adults with unilateral profound hearing loss. The testing was performed in both quiet and noise condition. Results revealed that there was no difference between groups in quiet conditions. Unilateral group performed significantly worse than controls in presence of noise.

Unilateral hearing loss is defined as reduced hearing sensitivity in one ear and normal hearing in the other ear. Many pathologies might lead to unilateral hearing loss which might be congenital or acquired. Degree of loss in the poorer ear might vary from mild-profound. Few of psychoacoustic tests are considered in the present study which includes frequency discrimination, intensity discrimination, duration discrimination and gap detection. Along with it SNR-50 is also considered. Frequency discrimination studies have shown no effect of gender and ear effect. However, there is frequency and intensity effect seen i.e. frequency discrimination threshold increases with increase in frequency and decreases in intensity. This is assumed to be because of frequency selectivity. Using two different signal it was found FM yield larger DLF compared to pure tome due to complex spectrum. Another study showed frequency discrimination thresholds were larger for impaired ear compared to normal both SL and SPL. Intensity discrimination showed a linear increment above 40 dB SL. DLI decreased with increase in intensity of standard stimulus. DLI thresholds for impaired ear are larger than normal ear at equal SPLs whereas it is smaller for impaired ear compared to normal ear at equal SLs. Normal ear of unilateral hearing loss had smaller DLI compared to bilateral normal hearing in a study which is due to increased cortical activity in the intact ear. Duration discrimination is independent of hearing loss but dependent on age related changes. It was found older individuals had larger duration discrimination threshold than young adult in both normal and hearing impaired groups. For a gap detection threshold using BBN as stimulus is a great advantage any spectral splatter resulting from abrupt cessation of short gap are masked. Individual with unilateral hearing loss has greater difficulty in noisy situation. Hence, they need a higher SNR compared to normal hearing subjects.

Chapter 3

Methods

The aim of the study was to compare psychoacoustic abilities of good ear of individulas with unilatearl hearing loss and any one ear of individuals with normal hearing sensitivity. The study also evaluated the impact of duration of hearing loss on psychoacoustic abilities. The psychoacoustic abilities investigated were discrimination thresholds for frequency, intensity, duration, gap detection ability and SNR-50. An experimental research study using stardard group comparison was carried out.

Participants

A total of 44 participants were considered for the study in which 22 individuals with unilateral hearing loss and 22 individuals with bilateral normal hearing sensitivity were involved. Demographic and audiologic details of the participants can be found in Table 1 and Table 2. Subjects between age range of 12-40 years(mean 25.59) were considered. This age range was chosen as it has been reported that psycho-acoustic abilities reach a plateau in normal individuals by the age of 12 years (Werner, & Gray, 1998). Further, deterioration in temporal processing abilities reported after 40 years (Kumar & Sangamanatha, 2011). All the participants were native speakers of Kannada-a south indian language. Audiological evaluation structured interview were carried out to choose the participants who meet the following criteria:

Clinical group

- Participants having normal hearing sensitivity in one ear and the other ear having severe-profound hearing loss.
- No indication of Retrocochlear pathology

- Not using hearing aids in the poor ear
- No history of head trauma or middle ear infection

Table 1: Demographic and audiologic details of UHL participants

Age/Gender	Duration	PTA		SIS		Tympanogram	Reflexes (ipsi)	
		R	L	R	L	Bilateral	R	L
26/M	3 years	2.8	>90	100	CNT	A	present	Absent
16/M	12 years	7.5	>90	100	CNT	A	Present	Absent
26/M	2 months	7.5	>90	100	CNT	A	Present	Absent
40/M	35 years	10	>90	100	CNT	A	Present	Absent
33/F	3 years	10	>90	100	CNT	A	Present	Absent
34/M	34 years	10	>90	100	CNT	A	Present	Absent
33/M	3 months	11.5	>90	100	CNT	A	Present	Absent
19/F	18 years	15	>90	100	40	A	Present	Absent
33/M	15 years	>90	3.75	CNT	100	A	Absent	Present
40/M	25 years	>90	12.5	CNT	100	A	Absent	Present
30/M	13 years	>90	15	CNT	100	A	Absent	Present
24/M	10 years	>90	7.5	CNT	100	A	Absent	Present
14/F	10 years	>90	10	CNT	100	A	Absent	Present
40/M	1year	>90	10	CNT	100	A	Absent	Present
16/M	10 years	>90	10	CNT	100	A	Absent	Present
20/F	20 years	>90	5	24	100	A	Absent	Present
20/M	7 years	>90	12	CNT	100	A	Absent	Present
14/M	10 years	>90	12	CNT	100	A	Absent	Present
14/M	10 years	>90	15	CNT	100	A	Absent	Present
28/M	2 months	>90	10	40	100	A	Absent	Present
25/M	20 years	>90	15	CNT	100	A	Absent	Present
18/M	7 years	>90	5	CNT	100	A	Absent	present

Note: M= Male; F= Female; PTA =Pure tone average; SIS = Speech identification score; CNT =Could not be tested

Control group

- Bilateral normal hearing sensitivity
- Tympanometry showing ‘A’ type tympanogram with reflex present in both ears
- No history of head trauma or middle ear infection.

Table 2: Demographic and audiologic details of normal hearing participants

Age/Gender	PTA		SIS		Tympanogram	Reflexes (ipsi)	
	R	L	R	L	Bilateral	R	L
26/M	2.8	7.5	100	100	A	present	present
16/M	7.5	10	100	100	A	Present	present
26/M	7.5	12	100	100	A	Present	present
40/M	10	8.5	100	100	A	Present	present
33/F	10	10	100	100	A	Present	present
34/M	10	7.5	100	100	A	Present	present
33/M	11.5	15	100	100	A	Present	present
19/F	15	10	100	100	A	Present	present
33/M	5.8	3.75	100	100	A	Present	Present
40/M	7.5	12.5	100	100	A	Present	Present
30/M	10	15	100	100	A	Present	Present
24/M	12.5	7.5	100	100	A	Present	Present
14/F	15	10	100	100	A	Present	Present
40/M	5.8	10	100	100	A	Present	Present
16/M	3.7	10	100	100	A	Present	Present
20/F	10	5	100	100	A	Present	Present
20/M	10	12	100	100	A	Present	Present
14/M	7.5	12	100	100	A	Present	Present
14/M	7.5	15	100	100	A	Present	Present
28/M	5	10	100	100	A	Present	Present
25/M	12	15	100	100	A	Present	Present
18/M	3.7	5	100	100	A	Present	present

Note: M= Male; F= Female; PTA =Pure tone average; SIS = Speech identification score.

Prior to collection of data, Pure-tone thresholds were obtained via the modified Hughson and Westlake procedure (Carhart & Jerger, 1959), using a calibrated diagnostic audiometer. Calibrated immittance instrument was used to obtain tympanograms and acoustic reflex thresholds. Speech identification scores were obtained using a phonemically balanced word developed by Yathiraj and Vijayalakshmi (2005). To rule out any retro-cochlear pathology, site of lesion testing was carried out using ABR. Entire study was adhering to the ethical guidlines of the institute (Basavaraj & Venkatesan, 2009) and an informed consent was taken from each participant.

Test Environment

The study was carried out in an acoustically treated air-conditioned room with permissible noise level as per ANSI S3.1, (1999).

Stimuli

Stimuli for discrimination of frequency, intensity, duration and gap detection were generated using maximum likelihood procedure toolbox (mlp toolbox) implemented in Matlab 7.10 (Mathworks Inc. USA) software. The mlp makes 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 has 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).

Stimuli for all psychophysical tests were generated at 44,100 Hz sampling rate. A three-interval alternate forced-choice technique was used to track a 79.4% correct response criterion for all the tests performed. Each trial had 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. Before beginning each test 5 -6 practice items were given. The tests were performed in a randomized order across participants to avoid potential order effect. In order to determine SNR-50, six lists of sentences were taken from the recorded version of a phonetically balanced sentence test in Kannada (Geetha, Sharath, Manjula & Pavan, 2014).

Procedure

The stimuli were presented through a headphone that was calibrated for both tone and speech. The stimuli were presented at 40 dB SL (ref: SRT).While testing normal listeners, to avoid participation of the non-test ear, headphone on one of the ear was disabled. . In order to eliminate the hemispheric-laterality to certain auditory stimuli, testing was carried out in 8 right and 12 left ear.

Frequency discrimination. The minimum frequency difference necessary to discriminate two closely spaced frequencies were assessed at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Both the standard and variable stimuli were of 250 ms duration with the onset and offsets duration of 10 ms (Grassi & Soranzo, 2009). Three interval forced choice method was used where on each trial subject has to identify one from three blocks which has the variable stimuli. Blocks were presented in random order. A psychometric function criterion was set at 79.4% which was calculated using mlp.

Intensity discrimination. The minimum intensity difference necessary to discriminate two closely spaced intensities were assessed at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Both standard and variable stimuli were of 250 ms duration with the onset and offsets duration of 10 ms (Grassi & Soranzo, 2009; Jain, Mohamed, & Kumar, 2014). Three interval forced choice method was used where on each trial subject has to identify one from three blocks which has the variable stimuli. Blocks were presented in random order. A psychometric function criterion was set at 79.4% which was calculated using mlp.

Duration discrimination. In this task, the minimum difference in duration that can be discriminated was assessed. This was measured at 1000 Hz (Abel, 1972) tone with the duration of 250 ms and onset and offset duration of 10 ms (Kumar & Sangamanatha, 2011). Three interval forced choice method was used where on each trial subject has to identify one from three blocks which has the variable stimuli. Blocks were presented in random order. A psychometric function criterion was set at 79.4% which was calculated using mlp.

Gap detection thresholds. In this task participant's ability in identifying silence between broadband stimuli of 500 ms duration was established. A three interval forced choice method was used where on each trial subject had to identify one from three blocks which had the variable stimuli. On each trial of three blocks, two blocks consisted of a 500 ms broadband noise with no gap and the other block had a variable stimulus with the gap in it. The minimum and maximum duration of gap used was 0.1 ms and 64 ms.

SNR-50. In order to determine SNR-50, six lists of sentences were taken from the recorded version of a phonetically balanced sentence test in Kannada (Geetha, Sharath, Manjula & Pavan, 2014). Each list comprised of ten sentences each having four key words. Each sentence in a list was mixed with a speech shaped noise at a particular signal to noise ratio (SNR) that ranged from +12 to -6 dB SNR. An SNR difference of 2 dB was maintained between the sentences. In order to generate the speech shaped noise, the sentences were concatenated and spectrally analyzed to derive its long-term average speech spectrum (LTASS). The LTASS was then used to design an infinite impulse response (IIR) filter using MATLAB software (v. 7.12). Speech shaped noise was derived using white noise subjected to the designed IIR filter. The speech shaped noise was mixed to each sentence using AUXVIEWER (v

1.37) software. The two signals were mixed in such a way that the added signal gives the desired SNR. The output stimulus was then RMS normalized to maintain equal loudness. For each sentence, the duration of noise was adjusted in such a way to provide sufficient duration of noise before and after the stimulus.

The SNR at which 50% of the sentences were perceived was calculated using the Spearman–Kärber equation, which is as follows:

$$\text{50\% point} = \mathrm{I} + (0.5 \times d) - d\ (\#\ \text{correct})/\mathrm{w}$$

Where, 'I' is the initial presentation level (dB SNR), 'd' is the decrement step size (attenuation), and 'w' is the number of words per decrement.

Analysis

The data obtained from the study were subjected to appropriate statistical analyses using the SPSS software.

Chapter 4

Results

The present study compared the psychoacoustic abilities as well as speech perception in noise between normal hearing individuals and normal ear of those with unilateral hearing impairment. In order to assess psychoacoustic abilities, frequency discrimination, intensity discrimination, duration discrimination and gap detection tests were performed. Speech perception ability in noise was assessed using SNR-50. Descriptive statistics was performed in order in find the mean and standard deviation for all the psychoacoustic tests and SNR-50.

Frequency Discrimination

It can be found in Table 3 that mean frequency discrimination thresholds obtained from the normal hearing individuals were better than that of those with unilateral hearing loss. Similar trend was observed across all the frequencies. Frequency discrimination threshold was found to be smallest for 500 Hz and increased with increasing frequency in both the groups. In order to compare the performance between unilateral hearing loss and normal hearing groups MANOVA was performed. Scores obtained in different tests (psychoacoustic test and SNR-50) were the dependent variables and the groups (unilateral hearing loss and normal hearing group) were independent variables.

Table 3: Mean and Standard deviation for frequency discrimination threshold obtained from Group I and Group II

Frequency	Group I		Group II	
	Mean	Standard Deviation	Mean	Standard Deviation
500 Hz	49.68	19.05	28.54	12.49
1000 kHz	60.88	19.13	49.40	18.32
2000 kHz	75.99	20.04	61.50	17.99
4000 kHz	91.20	15.44	82.87	15.53

Group I = Individuals with unilateral hearing loss. Group II = normal hearing individuals

Results of MANOVA revealed that there was a significant difference seen between normal group and unilaterally impaired group in frequency discrimination threshold of 500 Hz [$F(1,4558.71)=17.03$, $P<0.0005$],1 kHz [$F(1,1344.47)=3.816$, $P<0.01$] and 2 kHz [$F(1,2139.424)=5.851$, $P<0.01$]. Normal hearing individuals had significantly better performance compared to those with unilateral hearing loss. However, there was no significant difference between the two groups at 4 kHz [$F(1,706.43)=3.816$, $P<0.01$]. This can be observed in Figure 1.

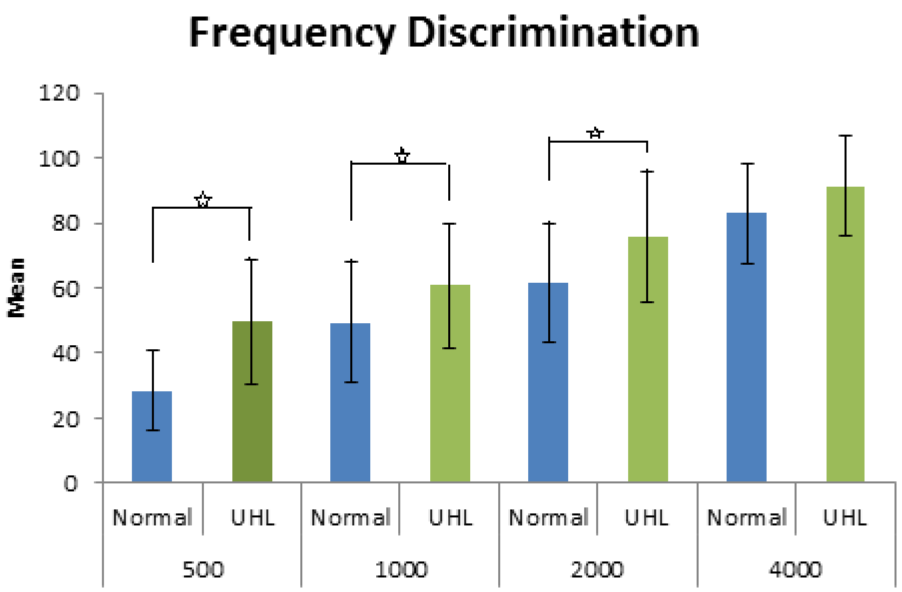

Figure 1.*Mean scores and significance of difference (*p<0.05) between Unilateral hearing loss and Normal hearing group for frequency discrimination thresholds across different frequencies. The error bars indicate 1 SD of error.*

Intensity Discrimination

Descriptive statistics as shown in Table 4 revealed that mean threshold for intensity discrimination in the normal hearing group was better than that of the impaired group. Intensity discrimination threshold was lowest at 500 Hz and slightly increased with increasing frequency for both normal and impaired population.

Table 4: Mean and standard deviation intensity discrimination threshold obtained from Group I and Group II

Frequency	Group I		Group II	
	Mean	Standard Deviation	Mean	Standard Deviation
500	5.38	2.54	2.95	0.7
1000	6.23	1.20	5.57	1.97
2000	8.80	1.76	7.39	1.72
4000	8.19	1.88	7.50	2.13

Group I = Individuals with unilateral hearing loss. Group II = normal hearing individuals

The results of MANOVA showed significant difference in intensity discrimination thresholds between normal and impaired population at 500 Hz [F(1,60.10) =16.20, P<0.005] and 2 kHz [F(1,20.03) =6.57, P<0.001].However, there was no significance difference between the two groups at 1 kHz [F(1,4.98)=1.241, P>0.01] and 4 kHz [F(1,4.98) =1.24, P>0.01]. This can be observed in Figure 2.

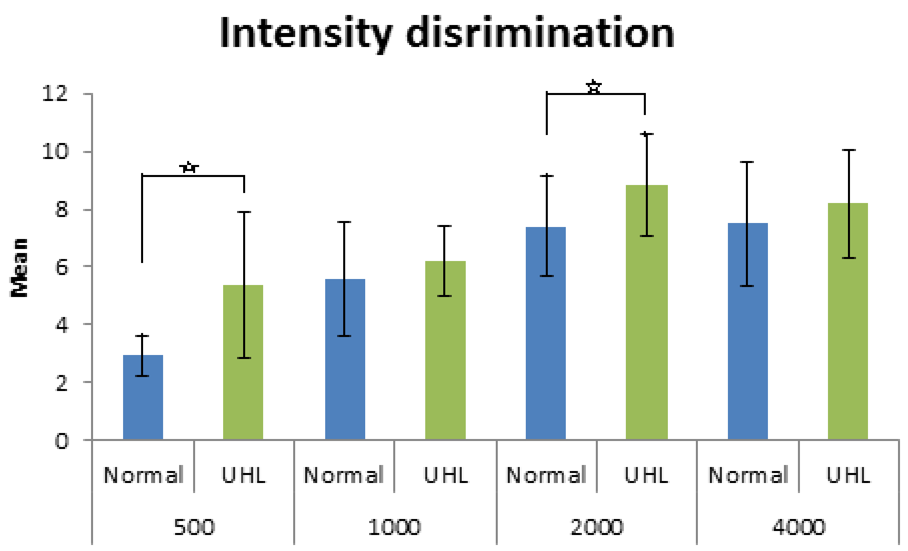

Figure 2.*Mean scores and significance of difference (*p<0.05) between Unilateral hearing loss and Normal hearing group for intensity discrimination thresholds across different frequencies. The error bars indicate 1 SD of error.*

Duration Discrimination

It can be found in Table 5 that that mean score of duration discrimination threshold was less for normal hearing group compared to impaired population. This shows that impaired population need longer duration stimuli to differentiate between them.

Table 5: Mean and standard deviation of duration discrimination threshold obtained from Group I and Group II

Duration Discrimination	Group I		Group II	
	Mean	Standard Deviation	Mean	Standard Deviation
250	52.5	16.81	38.3	6.29

Group I = Individuals with unilateral hearing loss. Group II = normal hearing individuals

The results of MANOVA revealed that there was significant difference in duration discrimination threshold between the two groups [F(1,2054.96)=12.05, P<0.01]. Normal hearing individuals had significantly better performance compared to those with unilateral hearing loss. This can be observed in Figure 3.

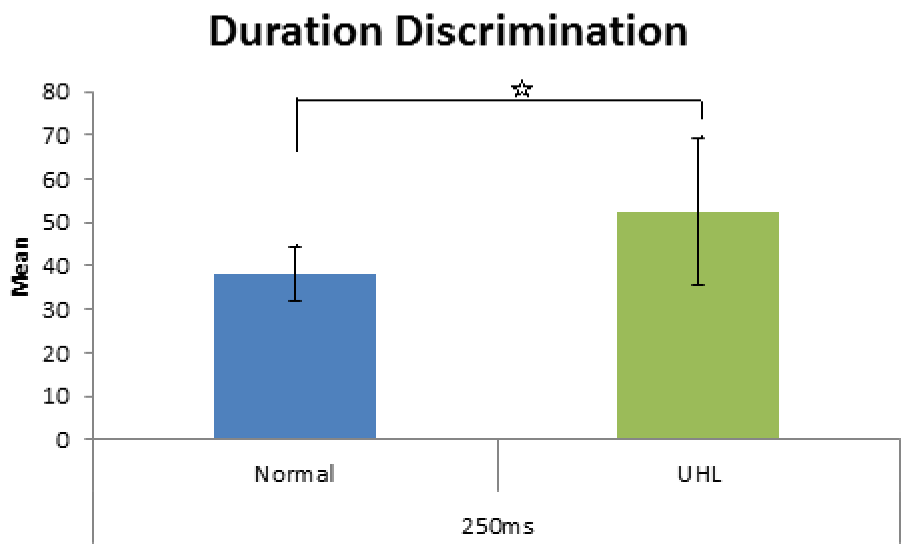

Figure 3.*Mean scores and significance of difference (*p<0.05) between Unilateral hearing loss and Normal hearing group for duration discrimination thresholds. The error bars indicate 1 SD of error.*

Gap Detection

Mean and SD for gap detection thresholds obtained from Group I and Group II are given in table 6. It was found that participants in Group I needed longer gap duration to identify the gap compared to that of Group II.

Table 6: Mean and standard deviation of gap detection threshold obtained from Group I and Group II

Gap detection	Group I		Group II	
	Mean	Standard Deviation	Mean	Standard Deviation
	3.2	0.65	2.71	0.51

Group I = Individuals with unilateral hearing loss. Group II = normal hearing individuals

It was found through MANOVA that gap detection threshold of normal group and impaired group were significantly different [F(1,2.789)=7.89, P<0.005]. Normal hearing individuals had significantly better performance compared to those with unilateral hearing loss. This can be observed in Figure 4.

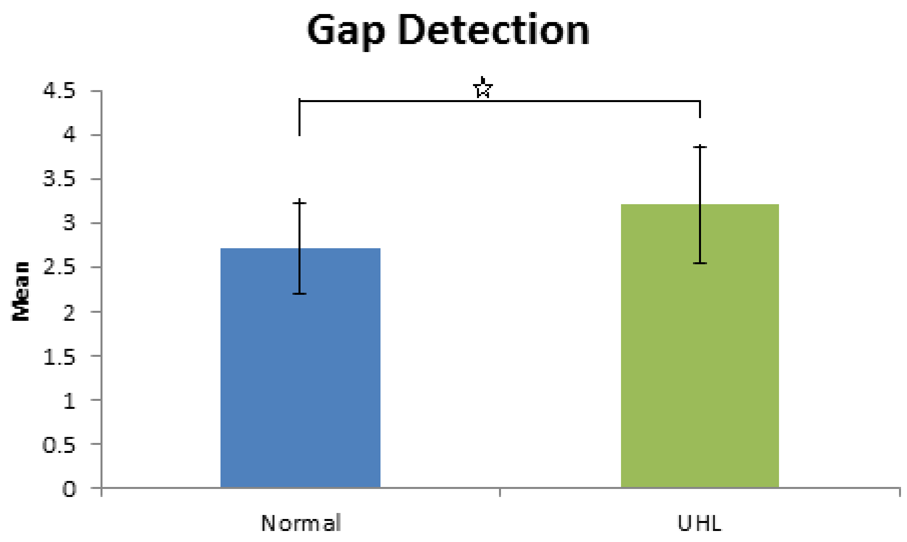

Figure 4.*Mean scores and significance of difference (*p<0.05) between Unilateral hearing loss and Normal hearing group for gap detection thresholds. The error bars indicate 1 SD of error.*

SNR-50

Mean and SD for SNR-50 from Group I and Group II are given in table 7. Mean scores of SNR-50 was found to be worse for impaired group compared to normal group. This shows that unilaterally impaired individuals needed slightly higher SNR compared to normal individual to perceive speech clearly. However, this difference between normal and impaired group was not statistically significant [F (1, 1.77) =1.37, P>0.1]. This can be observed in Figure 5.

Table 7: Mean and standard deviation of SNR-50 obtained from Group I and Group II

SNR-50	Group I		Group II	
	Mean	Standard Deviation	Mean	Standard Deviation
	-3	-4.97	-4.5	-5.39

Group I = Individuals with unilateral hearing loss. Group II = normal hearing individuals

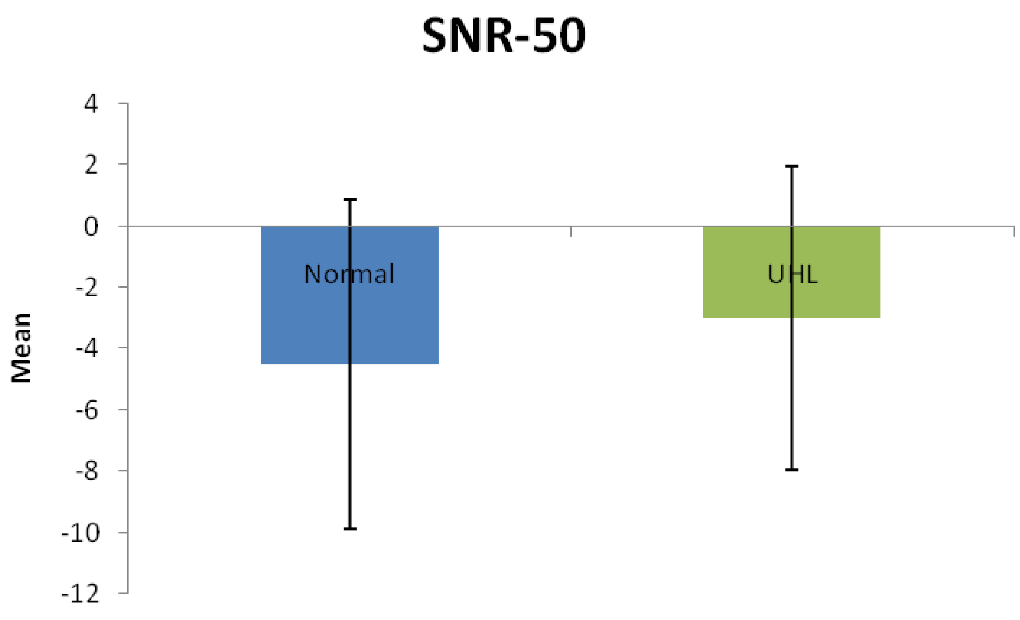

Figure 5.*Mean scores and SD obtained from Unilateral hearing loss and Normal hearing group for SNR-50. The error bars indicate 1 SD of error.*

Pearson's product moment correlation was carried out to analyse the relation between scores obtained in psychoacoustic tasks and speech perception in noise. Results revealed no statistical correlation between them in both Group I and Group II (Table 8).

Table 8: *Results of the Pearson's correlation between different psychoacoustic tasks and SNR-50 in Group I and Group II.*

	Group I	Group II
	r (p value)	r (p value)
FDT500	0.094 (0.679)	0.211(0.387)
FDT1000	0.213(0.341)	0.121(0.620)
FDT2000	0.183(0.414)	0.290(0.228)
FDT4000	0.201(0.369)	0.452(0.052)
IDT500	0.272(0.221)	0.461(0.047)
IDT1000	0.077(0.732)	0.576(0.010)
IDT2000	0.055(0.809)	0.213(0.381)
IDT4000	0.516(0.014)	0.211(0.386)
DPT	0.152(0.501)	0.121(0.623)
GDT	0.213(0.340)	0.303(0.208)

Note: FDT= Frequency discrimination threshold, IDT=Intensity discrimination threshold, DPT=Duration pattern threshold and GDT=Gap detection threshold

From the above results it is clear that all psychoacoustic test and SNR-50 showed a better performance in normal hearing subjects than unilateral hearing subjects. Frequency discrimination was significantly different between two groups at 500 Hz, 1 kHz and 2 kHz. There was no significant difference at 4 kHz. Intensity discrimination increased with increase in frequency in both the groups. Intensity discrimination was significantly different at 500 Hz and 2 kHz. Normal hearing individual needed smaller gap to discriminate compared to unilateral hearing group. Gap detection also showed a significant difference between two groups where unilateral individual needed longer gap to detect compared to unilateral hearing impaired. Unilateral hearing individual needed higher SNR compared to normal hearing individual. However there was no significant difference between two groups in SNR-50.

Chapter 5

Discussion

The present study compared frequency discrimination, intensity discrimination, duration discrimination and gap detection abilities of normal hearing individuals and normal ear of those with unilateral hearing impairment. Additionally, speech perception in noise was also compared. There were 22 individuals with unilateral hearing loss and 22 with normal hearing participated in the study.

Frequency Discrimination

Results of the present study revealed that frequency discrimination thresholds of individuals with unilateral hearing loss were significantly poor compared to normal hearing individuals. However, frequency discrimination thresholds increased with increase in frequency in both the groups. Wier et al. (1997) hypothesised that this may be due to place mechanism. They have attempted to relate the limits of frequency discrimination to estimates of the critical band or critical ratio. Critical-band models have the common assumption that frequency selectivity relies on peripheral spectral analysis, and thus, they represent a subset of place models which in turn is responsible for increase in frequency discrimination threshold with increased frequency.

However, significant difference in frequency discrimination between these two groups showed difference in their perceptual abilities. This result might be because patients with unilateral SNHL may have a more pervasive disease process that results in abnormalities of both ears (Marcus et.al, 2014). They observed objectively measured abnormalities of the inner ear in the contralateral audiometrically normal ears of subjects with unilateral SNHL. They observed that the cochlear basal turn lumen width was significantly greater in magnitude and central lucency of the lateral semicircular canal bony island was significantly lower in density for audiometrically normal ears of subject with unilateral sensorineural hearing loss compared to normal hearing subjects.

Intensity Discrimination

It was found that intensity discrimination thresholds of individuals with unilateral hearing loss were significantly poor compared to normal hearing individuals. However, intensity discrimination thresholds increased with increase in frequency in both the groups. Further, there was significant difference in intensity discrimination between 500 Hz and 2 k Hz. Present results are in contradiction with Maslin, Taylor, Plack and Munro (2015) reported significantly smaller intensity discrimination threshold in individuals with unilateral hearing loss compared to controls. Authors reported an increased cortical activity to sounds heard in the intact ear of subjects with unilateral hearing loss. These results provide evidence of the perceptual consequences of plasticity in human following unilateral deafness.

It was found in the current study that DLI increased with increase in frequency. Analogously, Florentine, Buus, and Mason (1987) reported that DL for intensity was poorer at higher frequencies than the low and mid frequencies. In contradiction Jesteadt, Weir and Green (1977) measured DLI in three participants with normal hearing sensitivity at 5, 10, 20, 40 and 80 dB SL for frequencies of 400, 600, 800, 1000, 2000, 4000 and 8000 Hz. They did not find any frequency effect on DL at any given SLs. The difference in the results of studies can be attributed to the difference in methodology.

Duration Discrimination

It was found in the current study that duration discrimination thresholds of individuals with unilateral hearing loss were significantly poor compared to normal hearing individuals. This results could be due to pervasive disease process in patients with unilateral SNHL that resulted in abnormalities of both ears (Marcus et.al, 2014). They also reported objectively measured abnormalities of the inner ear contralateral to audiometrically normal ears of subjects with unilateral SNHL. They observed that the cochlear basal turn lumen width was significantly greater in magnitude and central lucency of the lateral semicircular canal bony island was significantly lower in density for audiometrically normal ears of subject with unilateral sensorineural hearing loss compared to normal hearing subjects.

Gap Detection

It was found in the current study that gap detection thresholds of individuals with unilateral hearing loss were significantly poor compared to normal hearing individuals. The significant different in gap detection between two groups might also be due to reduced frequency selectivity in unilateral hearing individual compared to normal hearing individual. This again could be attributed to objectively measured abnormalities of the inner ear contralateral to audiometrically normal ears of subjects with unilateral SNHL ears (Marcus et.al, 2014). Glasberg and Moore (1989) reported the difference in GDT between individuals with unilateral hearing loss and normal hearing sensitivity might be due to reduced temporal resolution in unilateral hearing impaired subject This study also performed GDT using sinusoidal signal where they found results contradicting the noise GDT. It was seen with sinusoidal gap detection, unilateral hearing subjects had better detection score than normal hearing individuals because of ringing in auditory filter which is not heard in unilateral hearing loss due to their broader auditory filter. Through these studies we can draw a conclusion saying the GDT between unilateral hearing individual and normal hearing subjects varies depending on the signal used.

SNR- 50

In the current study there was no significant difference in speech perception in noise between normal hearing individuals and those with unilateral hearing loss. It is well known fact that when both extrinsic and intrinsic redundancies are present, understanding of speech becomes easy (Miller, Heise & Lichten, 1951). As speech is very redundant, highly degrading speech signal will not alter the perception of normal listener due to good intrinsic redundancy. (Wilson & Strouse, 1999). Depending on whether one is listening to word in isolation, in sentence or in a conversation the redundancy of the signal varies (Festen & Plomp, 1990). Generally, longer sentences are easily understood than shorter when speech is presented in presence of noise. But in comparison, sentences are the easiest signal as they deliver the listener with acoustic information, semantic and contextual cues and linguistic content. Hence, these signals provide greater redundancy. In comparison to all, monosyllabic words are found to be the most difficult signal to comprehend in presence of (Wilson & Strouse, 1999)but nonsense syllables are the most confusing one to perceive in the adverse condition (Carhart, 1995). In the present study we used sentences having abundant extrinsic cues that made perception easy for both the groups. Additionally, monaural presentation that reduced the extrinsic redundancy in both the groups made perception similar.

Relation between Psychoacoustic Abilities and SNR-50

In the present study there were no correlation found between psychoacoustic abilities and SNR-50. In contradiction to our results Glasberg and Moore (1989) found that there was correlation between psychoacoustic tests and speech test. They reported that SRT in quiet is in correlation with absolute threshold and SRT in noise is in correlation with the supra-threshold discrimination abilities. Multiple regression done in there study showed that SRT in noise can be best predicted by combination of frequency discrimination of complex tones, intensity discrimination of pulsed tone and age. They also mentioned that gap detection threshold for noise can predict difficulty in understanding speech in presence of noise. The results in these two studies might be contradicting due to different stimulus used for psychoacoustic tests.

Chapter 6

Summary and Conclusion

Current study aimed at investigating psychoacoustic abilities of the good ear of individuals with unilateral hearing loss in comparison with monaural psychoacoustic function of normal hearing individuals. The study compared psychoacoustic tasks such as frequency discrimination, intensity discrimination, duration discrimination, gap detection and speech perception in noise.

Main objectives of the study were to compare performance of good ear of individuals with unilateral hearing loss with those having bilateral normal hearing on

- Frequency discrimination at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz
- Intensity discrimination at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz
- Duration discrimination at 1000 Hz for 250 ms
- Gap detection test
- SNR-50

A total of 44 individuals were considered for the study in which 22 were having unilateral hearing loss and 22 were bilateral normal hearing individuals. The participants were between the age range of 12-40 years. All the participants were native speakers of Kannada language. Routine audiological evaluation was done for all the individuals. None of the participants had indication of retrocochlear pathology or any middle ear infection. . The study was carried out in an acoustically treated air-conditioned room with permissible noise level as per ANSI S3.1, (1999). Stimulus for frequency discrimination, intensity discrimination, duration discrimination and gap detection were prepared and presented through MATLAB 7.10 software. A maximum likelihood procedure (mlp) in the MATLAB software was used for presenting the stimuli. Each stimulus was presented through a headphone at 40 dB SL (re:SRT). While testing normal listeners, to avoid participation of the non-test ear, headphone on one of the ear was disabled. In order to eliminate the hemispheric-laterality to certain auditory stimuli, testing was carried out in 8 right and 14 left ear.

SNR-50 was determined using sentences taken from the recorded version of phonetically balanced sentence test in Kannada (Geetha, Sharath, Manjula & Pavan, 2014). Each sentence in a list was mixed with a speech shaped noise at a particular signal to noise ratio (SNR) that ranged from +12 to -6 dB SNR. The SNR at which 50% of the sentences were perceived was calculated using the Spearman–Kärber equation.

Results of the present study revealed that frequency discrimination threshold increased with increase in frequency in both the groups which might be due to inefficient phase locking mechanism at higher frequencies as hypothesized by Wier et al. (1997). Further, a significant difference in frequency discrimination and duration discrimination thresholds were found between the two groups. Individuals with unilateral hearing loss obtained higher thresholds on these tasks compared to normal listeners. This can be attributed to changes in the auditory system function in the normal ear of those with unilateral hearing loss. It is reported that the cochlear basal turn lumen width was significantly greater in magnitude and central lucency of the lateral semi-circular canal bony island was significantly lower in density for audiometrically normal ears of subject with unilateral sensorineural hearing loss compared to normal hearing subjects (Marcus et.al, 2013).

It was found intensity discrimination threshold increased with increase in frequency in both the groups. Significant difference between the two groups was found at 2 kHz and 500 Hz. Individuals with unilateral hearing loss obtained higher intensity discrimination thresholds compared to normal listeners. Contradicting to this, Jesteadt et al. (1977) and Maslin et al. (2015) found that individuals with unilateral hearing loss had better discrimination scores compared to normal hearing individuals. This difference is attributed to difference in methodology in these two studies.

It was found that those with unilateral hearing loss needed longer gap to detect a gap in a stimulus compared to normal hearing individuals. This showed reduced temporal resolution in individuals with unilateral loss. It was also noted that individuals with unilateral hearing loss needed higher SNR compared to normal hearing individuals. However, this was not significant. In the present study, we used sentences having abundant extrinsic cues that made perception easy for both the groups. Additionally, monaural presentation that reduced the extrinsic redundancy in both the groups made perception similar.

There was no correlation between psychoacoustic tests and SNR-50 in individuals with unilateral hearing loss. This is in contradiction to the study done by Glasberg and Moore (1989) which showed a correlation between psychoacoustic tests and SRT in noise. The contradicting findings in these studies could be due to different stimulus used for psychoacoustic tests.

To conclude individuals with unilateral hearing loss showed poorer performance in all the psychoacoustic task compared to normal hearing individuals. There was no significant difference seen for SNR-50 between the two groups. No correlation was found between psychoacoustic abilities and SNR-50 in both the groups. There was no effect of duration of hearing loss on psychoacoustic abilities.

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