# TEMPORAL PROCESSING
# IN LISTENERS WITH UNILATERAL DEAFNESS

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**ALL INDIA INSTITUTE OF SPEECH AND HEARING**

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**JUNE 2011**

## Certificate

This is to certify that this dissertation entitled **"Temporal Processing In Listeners With Unilateral Deafness"** is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student (Registration No. 09AUD019). 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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This dissertation entitled **"Temporal Processing In Listeners With Unilateral Deafness"** is the result of my own study under the guidance of Dr. Vijay Kumar Narne, Lecturer, 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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June, 2011

*Dedicated to*

*Papa,*

*Mummy, Di*

*&*

*Runjhun…*

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# CHAPTER 1

# INTRODUCTION

Important cues to the perception of speech, music, and environmental sounds are carried in the temporal fluctuations of the waveforms associated with such signals. Temporal cues are conveyed both in the long-term properties of the temporal envelope and in short-term fluctuations. In addition, temporal processing may be related to ability to understand speech in background noise when listeners take advantage of transient changes in speech-to-noise ratio to improve reception. Thus, the ability to detect and discriminate temporal properties of acoustic waveforms is very important for recognition of speech and other signals both in quiet and noise by listeners with or without hearing impairment.

Temporal analysis can be considered as resulting from two main processes: analysis of the time pattern occurring within each frequency channel and comparison of the time patterns across channels. Temporal processing has been studied using several psychoacoustic measures over the years. Gap-detection tasks test listeners' abilities to follow rapid changes in continuous sound over time by measuring the shortest interval of silence that is detectable; modulation- detection tasks measure how listeners' abilities to perceive rapid fluctuations (or modulation) in a continuous signal change as the rate of modulation is varied; and forward - masking tasks can measure how rapidly the thresholds for a brief signal recover after stimulation by a masking sound. All these measures are concerned with the limits of our ability to follow rapid changes and are collectively referred to as measures of *temporal resolution*.

Hearing impairment can produce two types of deficits that degrade the perception of auditory signals. The first type arises from a reduction in audibility due to elevated detection thresholds. The second type of deficit is defined as the loss in auditory abilities beyond those due to elevated thresholds. Such supra-threshold deficits might be manifested, for example, as poorer-than-normal frequency selectivity or temporal resolution for signals that are clearly audible (De Filippo & Snell, 1986; Lister & Roberts, 2005; Reed, Braida, & Zurek, 2009).

Many investigators have demonstrated that temporal processing is very important for understanding speech in quiet and noise. Gap detection has been used has one of tool to assess temporal resolution of the auditory system by many investigates (Reed et al, 1992). Gap-detection thresholds decrease rapidly for the first 20-30 dB SL and reach an asymptote value at levels beyond 30 dB SL. In studies that have compared the performance of age-matched hearing impaired and normal hearing listeners (De Filippo & Snell, 1986; Fitzgibbons & Wightman, 1982) or the normal and impaired ears of listeners with unilateral hearing loss (Glasberg, Moore, & Bacon, 1987; Moore & Glasberg, 1988), gap-detection thresholds are more similar for comparisons made at equal SL than at equal SPL; though there are large individual differences observed in the data of hearing impaired listeners, with many of their thresholds falling within the ranges observed for normal hearing listeners (Glasberg, Moore, & Bacon, 1987; Hall, Grose, Buus, & Hatch, 1998).

Another such measure of temporal processing is Temporal Modulation Detection wherein, temporal resolution is examined through measurements of the minimal amounts of Sinusoidal Amplitude Modulation (SAM) necessary for the listener to discriminate between a modulated and an unmodulated noise. Studies have been conducted over the years with the aim of comparison between TMTF (Temporal Modulation Transfer Function) in normal hearing and hearing impaired listeners. For signals presented at equal SPL or at equal SL, there is an indication of general similarity in performance between the two groups of listeners both in the overall shape of the TMTF and in magnitude of the modulation thresholds (Bacon & Viemeister, 1985; Bacon & Gleitman, 1992; Moore, 1992).

A sub-group of such studies have aimed at examining these processes in listeners with bilateral cochlear hearing impairment through a wide range of tasks, conditions, and listener characteristics. The researchers have in consensus found degraded temporal processing abilities when compared to normal hearing listeners at equal SPL's. While the focus of the research with respect to temporal resolution has been concentrated towards the performance in listeners with bilateral cochlear hearing impairment, little has been studied about the temporal resolution abilities in listeners with unilateral hearing impairment.

In specific, the impact of unilateral deafness on processing of acoustic signals varying in temporal and spectral complexity is of investigable interest on account of the variable stimulation each ear is receiving. Such variable auditory inputs are speculated to develop neuronal rewiring in the cortical neuron networks and consequently may alter the physiological processing route of the existing template.

Therefore, while a major bulk of the research have been conducted in studying the ear with hearing impairment, there is dearth of literature existing on the compensatory or plastic changes occurring in physiology of the normally functioning ear of listeners with unilateral deafness.

Evidence of central nervous system (CNS) plasticity, defined as an experience-related change in function or activity (Greenough, 1975), has been observed in all sensory systems and the auditory system is found to be no exception. In tonotopically organized areas of auditory cortex, regions deprived of their normal peripheral input often become responsive to intact adjacent frequencies (Robertson and Irvine, 1989; Kaltenbach, Czaja, & Kaplan,1992; Rajan, Irvine, Wise, & Heil (1993). This altered activation results in increased interhemispheric correlations which in turn can be demonstrated by (1) a change in the timing of activity between the hemispheres, and (2) a more consistent pattern of ipsilateral/ contralateral response amplitudes across individuals. Often these results are based on the amplitude and latency measures of long latency auditory evoked responses following experimentally induced monaural deafness (e.g., Reale, Brugge, & Chan, 1987; Popelar, Erre, Aran, & Cazals, 1994). Changes in central auditory pathway activation tend to be more extensive when sensory experience is modified soon after birth (e.g., Popelar, Erre, Aran, & Cazals, 1994). However, experience related changes in CNS sensory and motor pathways have been reported in the adult brain of many mammals, including humans (Donoghue, 1995).

Functional specialization of the auditory system is yet another area of exponentially growing research. This form of specialization i.e. of the left and right cerebral cortex has been documented primarily using imaging studies (fMRI), and magnetoencephalography. The general findings indicate that auditory areas of the right hemisphere are specialized for spectral processing of tonal stimuli and music. On the other hand, these areas of auditory cortex of left hemisphere are primarily responsible for processing of temporally complex and rapidly changing stimuli (Zatorre & Belin, 2001).

Nicholls (1999) observed that perceptual asymmetry is due to left hemisphere's specialization for the detection of brief temporal events based on the findings that right ear performance on gap detection task required shorter reaction time and lesser error probability. These findings were correlated and supported well with the increased beta activity in the left temporal lobe in contrast with the right temporal lobe. Robin, Tranel, & Damasio (1990), concluded from his findings based on subjects with lesions in the temporoparietal regions of left or right hemisphere that left temporal lobe lesions led to impaired perception of temporal information in a gap detection task than the group with right temporal lobe lesion.

One special case of asymmetric hearing is described by one ear with essentially normal hearing (NH) (audiometric thresholds ≤ to 25 dB HL) and the other ear with severe-to-profound hearing loss (thresholds ≥ 70 dB HL) (Cozad, 1977). This is sometimes categorized as unilateral hearing loss (UHL). Wich leads to asymmetric hearing and that in turn causes an imbalanced auditory input to the brain.

Focus has recently turned to listeners with UHL in order to explore the plasticity and capabilities of the auditory pathways in the brain with asymmetrical auditory input.

**Need for the study**

Temporal processing abilities of auditory function have been studied widely over the years in listeners with hearing impairment. A multitude of tasks can be used to assess such processing mechanisms which are broadly defined into detection and discrimination tasks. The aforementioned studies have utilized either one of the tasks namely:

- Gap Detection or,
- Temporal Modulation Detection

with the objective of measuring temporal resolution abilities in listeners with unilateral deafness. Studies need to be conducted in order to explore the plasticity and capabilities of the auditory pathways in the brain with asymmetrical auditory input. It is a common assumption that the audiometrically normal ear of individuals with UHL perform as well as one ear of an individual with bilateral NH. However, little research has examined this assumption.

Laterality of auditory function has also been shown in perceptual experiments in typically functioning listeners. In these experiments, laterality has been manipulated by the mode of auditory stimulation that can be monotonic to the right ear or left ear, dichotic with different stimulus to each ear simultaneously. Without simultaneous evaluation of brain function, there is an implicit assumption that when auditory stimuli are presented to the right ear, performance primarily reflects processing in the left hemisphere and vice-versa, because of the crossed pathways between the ear and the auditory cortex. Kimura and co-workers used dichotic stimuli to demonstrate a slight but significant right ear advantage for consonant perception and a left ear advantage for processing of tonal stimuli (Kimura, 1961, 1964; King & Kimura, 1972). Subsequent studies validated these findings related to ear performance (Kallman, 1977; Kallman & Corballis, 1975; Sidtis, 1980; Sidtis 1982)

However, few studies have evaluated performance using both temporally complex and tonal stimuli, comparing performance of right and left ears individually (Kallman, 1977; Kimura, 1964). In addition, less importance is given on administration and designing of psychophysical experiments for comparison of performance on measures of temporal resolution across stimuli and evaluation of ear differences. Psychophysical experiments involving gap detection and temporal modulation detection will provide information regarding the nature of asymmetrical processing, salience of stimulus and task effects on laterality through both temporally complex wide band noise and tonal stimuli. Therefore, there is a need to evaluate and implement the utility of assessing temporal resolution abilities in listeners with unilateral deafness.

**Aim of the study**

- To study the asymmetry of processing if any, of tonal and complex (hemisphere-favored) stimuli in a group of listeners with unilateral deafness and normal hearing listeners.
- To examine the common assumption of similar performance in listeners with UHL and listeners with normal hearing for an amplitude modulation detection task.

**Objectives**

- To examine and compare Temporal Modulation Transfer Functions for wide band noise acting as a carrier stimuli at different modulation frequencies.
- To evaluate the relative Gap Detection Thresholds (GDT) using both temporally complex wide band noise and tonal stimuli, by ear of presentation in,

    i. Listeners with normal hearing.

    ii. The normal hearing ear of listeners with unilateral deafness.

# CHAPTER 2

# REVIEW OF LITERATURE

## 2.1 Plasticity of the central auditory system due to late onset unilateral profound hearing loss:

The central auditory system of mammals, including humans, includes afferents that project cortically on the side of the brain ipsilateral to the stimulated ear as well as afferents that cross the midline at the level of the brainstem and project to cortex on the contralateral side. The contralateral pathway contains a greater number of nerve fibers and represents a more direct route with fewer synapses to cortex than the ipsilateral pathway (Adams, 1979; Brunso-Bechtold, Thompson & Masterson, 1981; Coleman & Clerici, 1987).

Physiological studies in nonhuman mammals have shown that central auditory system activity evoked by monaural presentation is stronger and has lower activation thresholds in the contralateral than in the ipsilateral auditory pathway (Reale, Brugge, & Chan, 1987; Popelar, Erre, Aran, & Cazals, 1994; Kitzes, 1984). This asymmetrical activation of the central auditory system also occurs in humans. Thus, studies using monaural presentation have consistently shown earlier and much larger evoked electrical potential and (MEG) responses over the hemisphere contralateral to the stimulated ear (Vaughan & Ritter, 1970; Elberling, Bak, Kofoed, Lebech, & Saermark, 1981; Pantev, Lutkenhoner, Hoke, & Lenhaertz, 1986; Reite, Teale, Zimmerman, Davis, & Whalen, 1988).

Data from fMRI studies suggest an even more asymmetric pattern of monaurally elicited cortical activation (Scheffler, Bilecen, Schmid, Tschopp, & Seelig, 1998). In non-human mammals, experimentally induced profound unilateral deafness significantly alters the normally observed asymmetrical activation of the central auditory system. Unilaterally deafened animals show much larger than normal responses and lower thresholds of activation in the pathway ipsilateral to the intact ear, with little change in activity along the contralateral pathway. These changes are apparent subcortically in auditory nuclei such as the inferior colliculus (Reale, Brugge, & Chan, 1987; Kitzes, 1984, 1996), as well as at the level of auditory cortex (Reale, Brugge, & Chan, 1987).

While most studies have focused on changes following neonatally induced deafness, Popelar et al. (1994) demonstrated similar patterns of change at both subcortical and cortical levels in unilaterally deafened adult guinea pigs. Hendry and Jones (1988) have suggested that a loss of inhibitory processes might account for the increased ipsilateral pathway activity. Alternatively, the data of Kitzes (1996) suggest that, at least in neonatally deafened animals, the increased activity may reflect the emergence of additional afferent fibers in the ipsilateral pathway.

In humans, the changes in cortical activity following profound unilateral deafness are consistent with those that follow experimentally induced unilateral hearing loss in non-human mammals. Thus, MEG studies including individuals with early-and adult-onset profound unilateral deafness have shown both an increase in cortical activation ipsilateral to the intact ear and evidence of additional activation in other cortical areas (Vasama et al., 1994; Vasama & Makela, 1995; Fujuki et al., 1998). These endings are corroborated by brain imaging data from Scheffler, Bilecen, Schmid, Tschopp, and Seelig, (1998) who used fMRI to compare patterns of cortical activation produced by monaural stimulation in normal-hearing and unilaterally deaf adults.

The unilaterally deaf adults had much more symmetrical cortical activation of auditory areas. Scheffler et al.'s results included data from a mixed group containing individuals with early- and late-onset unilateral deafness. These data would suggest that changes in central auditory activation patterns occur even with late-onset deafness. However, the extent to which such changes occur exclusively in individuals with late-onset profound deafness is not known.

### 2.2 Temporal resolution in normal hearing listeners

A wide range of studies varying in factors such as stimulus types, response modalities, stimulus paradigms have been conducted in the past with the primary aim of comparison of temporal resolution abilities in listeners with normal hearing and hearing impairment. Temporal resolution of the normal auditory system has been investigated by employing various approaches over the years, and among them, temporal modulation transfer studies (Viemester, 1979), forward-masking studies (Nelson & Freyman, 1987; Plomp 1964), and gap-detection studies (Fitzgibbons, 1983; Shailer & Moore, 1987) have formed majority of the experimental tasks.

*a) Gap detection*

Florentine and Buus (1984) studied the detection of gaps in broadband noise in listeners with normal hearing and concluded that gap-detection thresholds decreased from 25 msec at 25 dBSPL to an asymptotic value of roughly 3 msec in the range of 50 – 90 dBSPL. Another study by Fitzgibbons & Wightman, (1982) examined gap detection thresholds in listeners with normal hearing and it was found that these thresholds decrease as the centre frequency of the narrow band noise increased. Also, gap-detection thresholds decreased as the level of presentation increased. Similar findings were reported by De Filippo and Snell, (1986) and Eddins, Grose and Hall (1989). Moore, Peters, and Glasberg (1992) examined Gap-detection thresholds for sinusoidal markers as a function of signal level in normal hearing listeners and they reported a decrease in gap-detection thresholds with an increase in both stimulus frequency and level.

b. *Temporal Modulation Transfer Functions*

Another measure of temporal processing is through the assessment of the ability to detect temporal modulation in the complex acoustic signal. One such psychoacoustical task is by obtaining Temporal Modulation Transfer Functions (TMTF) for a Sinusoidal amplitude modulated signal. In amplitude modulation detection tasks, the modulation depth necessary to just notice the modulation of a sinusoidally amplitude modulated wide band noise (known as the "carrier") is measured for numerous modulation frequencies. The temporal modulation transfer function (TMTF), a graph of amplitude modulation detection of as a function of frequency, allows a quantitative description of the temporal resolution ability of an individual (Viemeister, 1979). The modulation depth, or index, *m*, ranges between 0 and 1, where 0 refers to the noise carrier with no modulation and 1 refers to 100% modulation applied to the noise carrier.

Bacon and Veimeister, (1985) obtained TMTF for normal hearing listeners (at equal SPL and equal SL). The findings revealed that the sensitivity to amplitude modulation was constant with modulation thresholds of roughly -25 dB for modulaiton rates in the range of 2-10 Hz. These thresholds increase by 3 dB at 50 Hz and continued to increase at a rate of 4-5 dB/ octave in the range of 50-1024 Hz. Similar findings were reported by Bacon and Gleitman, (1992) and Formby, (1987). In a study by Moore & Glasberg (2001) TMTF was measured using sinusoidal carriers at a level of either 80 or 30 dBSPL for normal hearing listeners and it was observed that the modulation thresholds improved at 80 dBSPL for modulation frequency above 80 Hz.

In summary, the ability to detect temporal modulations deteriorates as the modulation rates are increased and modulation thresholds improve as the presentation level increases beyond 80 dBSPL. Temporal resolution studies using TMTFs have revealed a fairly consistent shape, often described by a low-pass characteristic with a 3 dB cutoff frequency of approximately 50 Hz (Viemeister, 1979; Bacon & Viemeister, 1985; Formby, 1985; Bacon & Gleitman, 1992). Above the cutoff frequency of 50 Hz, detection of modulation appears to become progressively poorer at a rate of about 4 dB per octave (Viemeister, 1979; Bacon & Gleitman, 1992; Bacon & Viemeister, 1985; Formby, 1985).

**2.2 Asymmetry of temporal processing in normal hearing listeners**

Few studies have investigated ear effect by employing different stimuli to assess gap-detection abilities in normal hearing as well as hearing impaired listeners.

Sininger and De Bode, 2008 examined ear differences in gap-detection thresholds for broadband versus sinusoidal stimuli. Based on the results, listeners with normal hearing demonstrated an overall right ear advantage for noise stimuli with mean GDT of 1.49 msec in the right ear over 3.67 msec in left ear. A left ear advantage was found for the sinusoidal stimuli, particularly at 4000 Hz with mean GDT of 1.51 msec in the left ear over 2.60 msec in right ear. These findings are in consensus with those of Nicholls et al., (1999) and Brown and Nicholls, (1997).

However, subsets of such studies have reported contradictory findings. Among these, study by Oxenham (2000) could not conclude on presence ear differences for GDT measured using wide-band noise markers, but it was speculated that a small sample and lack of control of handedness might have influenced the lack of laterality. Efron et al. (1985) also found no clear laterality in gap-detection functions in normal hearing listeners using a broad band stimulus. Therefore, studies examining ear effect on gap resolution due to laterality have in general not reached consensus and several confounding variables could be speculated to influence the results.

In normal hearing listeners, although contralateral connections are primary, each ear also has afferent projections to the ipsilateral auditory cortex and it is possible for a single ear to detect and process both temporally complex and tonal stimuli. Therefore, one might speculate a reorganization of central projections from the remaining/ functional ear showing stronger ipsilateral cortical activation (Reale, Brugge, & Chan, 1987; Popelar, Erre, Aran, and Cazals, 1994). Such a strengthening of the ipsilateral auditory pathway would facilitate processing of both noise and tonal stimuli in listeners with unilateral hearing loss.

Therefore, it is a common assumption that the audiometrically normal ear of individuals with UHL perform as well as one ear of an individual with bilateral NH. However, little research has examined this assumption.

**2.4 Psychoacoustic Abilities of Listeners with Unilateral Hearing Loss**

The implications of the above described plastic changes in the auditory system following unilateral hearing loss towards auditory behavioral abilities can only be speculated. Under natural listening conditions, the unilaterally deaf perform much worse than normal-hearing subjects on tests of speech recognition in the presence of competing background noise (Bess et al., 1986; Colletti et al., 1988). When compared to normal-hearing subjects who are tested binaurally, the unilaterally deaf also perform much worse on tests of sound localization (Jongkees & van der Veer, 1957; Slattery & Middlebrooks, 1994). However, when both groups were tested under monaural listening conditions, some of the congenitally unilaterally deaf adults studied by Slattery and Middlebrooks (1994) localized sound better than the normal hearing subjects.

This suggests that for at least some congenitally unilaterally deaf adults, compensatory processes exist that dynamically respond to a change in sensory input. Whether such compensatory processes also operate in adults with late-onset unilateral deafness is not known. Further studies are planned to determine whether the experience-related neurophysiological changes associated with late-onset profound unilateral deafness correlate with possible changes in behavioral abilities.

To date, Sininger and De Bode (2008) have published the only psychoacoustic study of temporal processing in the good ear of listeners with UHL. Using a gap detection threshold paradigm, no significant differences in temporal resolution abilities were found between subjects with NH bilaterally and those with UHL. In addition, when comparing those with congenital UHL to the corresponding ear of NH listeners, no differences were found between the two groups. A recent study by Firszt et al. (2010), utilizing the Random Spectrogram Sound (RSS) stimuli as described by Schonwiesner, Rubsamen, & von Cramon, (2005) found that listeners with UHL showed poor performance than listeners with bilateral NH (when restricted to listening monaurally) on tasks varying in temporal complexity.

Studies exploring temporal resolution in individuals with hearing loss have uncovered deficits in sensitivity to amplitude modulation. The degree of deficit observed appears to be dependent on the configuration of the hearing loss (Bacon & Viemeister, 1985; Formby, 1987). TMTFs of listeners with high frequency sensorineural hearing loss show poorer overall modulation detection thresholds when utilizing either broadband noise carriers (Bacon & Viemeister, 1985) or tonal carriers (Moore & Glasberg, 2001). Temporal resolution studies in subjects with unilateral hearing loss using TMTF in the functional ear are scarce. One of such few studies by Moore, Shailer & Schooneveldt (1992), state that temporal resolution in listeners with unilateral deafness as measured by TMTF's, are similar to normal hearing listeners, and they may not be adversely affected by cochlear hearing loss.

Both methods are important in determining temporal resolution abilities, although amplitude modulation detection is often preferred due its ability to examine the effects of intensity resolution and temporal resolution independently (Strickland & Viemeister, 1997).  In summary, the process of temporal resolution plays such an integral part of everyday listening and aids in the extraction of important auditory information, thereby, it is fitting to extend investigations of temporal processing abilities to listeners with UHL.

# CHAPTER 3

# METHOD

## Participants

Participants in the present study were divided in to two groups. Group I include normal hearing listeners. Group II include participants with unilateral deafness.

*a) Normal Hearing (Group I)*

The present study was performed on 15 participants (7 males and 8 females) in the age range of 18 and 30 years with mean age of 23.7 years. All participants had hearing sensitivity in normal limits in both ears, that is pure-tone thresholds 15 dB HL or better at octave frequencies between 0.25 kHz and 8.0 kHz (ANSI, 1969), and bilateral normal middle ear functioning as indicated by a type ‘A’ tympanogram (Jerger, 1970) with acoustic reflex present. None of them had a history of ear infections, noise exposure or ototoxicity. All the participants were right handed listeners (to form a homogenous group), it was ascertained by administering the Laterality Preference handed Schedule (modified version) developed by Venkatesan (2010).

*b) Unilateral deafness (Group II)*

15 right handed participants with unilateral deafness in the age range of 18 and 40 years with mean age of 29.8 years. All the participants had average (500, 1000 and 2000 Hz) hearing loss of 70 dB HL or greater in the poor ear for duration of

6 months to 5 years with mean duration of 3.35 years. The better ear of these participants average pure-tone thresholds of 20 dB HL or lesser at octave frequencies between 0.25 kHz and 8.0 kHz (ANSI, 1969), with normal middle ear functioning as indicated by a type 'A' tympanogram with acoustic reflex present. None of the participants had a history of ear infections, noise exposure or ototoxicity in the better ear. 4 participants had left ear as their normal hearing ear while 6 participants had right ear as the normal hearing ear. The demographic and audiological data of the participants was presented in the table 3.1.

Table 3.1: *Demographic and audiological data for group II participants*

| Subject no. | Age | Gender | Normal Hearing Ear | PTA for poor ear (dBHL) | Duration (years) |
|---|---|---|---|---|---|
| S1 | 25 | Male | Right | >90 | 4 |
| S2 | 30 | Male | Right | 85 | 0.5 |
| S3 | 32 | Male | Right | 85 | 3 |
| S4 | 40 | Female | Right | 75 | 5 |
| S5 | 25 | Male | Right | >90 | 5 |
| S6 | 26 | Male | Right | 90 | 2 |
| S7 | 32 | Male | Left | >90 | 4 |
| S8 | 33 | Male | Left | 75 | 3.5 |
| S9 | 28 | Male | Left | 80 | 4.5 |
| S10 | 27 | Male | Left | 85 | 2 |

**Stimulus**

*a) Gap detection task*

Gap detection was performed for three different stimuli, namely broad band noise (BBN), 4000 Hz and 400 Hz sinusoidal stimuli.

1. Broad Band noise

A white noise is digitally generated band pass filtered from 20-14,000 Hz with100 dB/octave. Duration of the stimulus was 500 ms with cosine squared ramp of 20 ms. The gap was generated by introducing the silence at the midpoint of signal. The overall duration of signal is minted by reducing duration of the signal leading and trailing edge. Signal duration of the leading and trailing edge is calculated, by subtracting the gap duration from 500 ms and divided by two; this gave the approximate durations of the leading and trailing signal. The duration was gap is varied from 1 msec to 20msec with step size of 5 ms initially and was reduced to 1 msec after two reversals.

2. Sinusoidal signal

Sinusoidal signal of frequency 400 Hz and 4000 Hz were digitally generated at 44.1 kHz sampling rate. Duration of the stimulus was 500 ms with cosine squared ramp of 20 msec. The gap was generated by introducing the silence at the center of signal. The overall duration of signal is minted by reducing duration of the signal leading and trailing edge. Signal duration of the leading and trailing edge is calculated, by subtracting the gap duration from 500 ms and divided by two; this gave the approximate durations of the leading and trailing signal. The duration of the portion of the signal preceding the gap was then rounded to the nearest whole cycle, so that it both started and ended with a positive going and zero crossing. To preserve the phase the signal started at the end of the gap with the phase that it would have had if the signal would have continued. The portion of the signal following the gap was terminated at the positive-going zero crossing that would give an overall duration as close as possible to 500 ms.

These stimuli were presented at a level where they are bare audible in the background noise, but not so high that spectral splatter is audible. To avoid the spectral splatter, signal was mixed with band stop noise in such way that side lobe (splatter) was well below 15 dB from the main lobe and also well within the pass band of the noise.

*b). Stimuli for detection of temporal modulation task*

Two stimuli, unmodulated white noise and sinusoidally amplitude modulated white noise, of 500 ms duration with ramp of 20 ms were used. The stimuli were generated using a 16-bit digital to analogue converter with a sampling frequency of 44100 Hz and were low pass filtered with a cut off frequency of 20,000 Hz. The modulated signal was derived by multiplying the white noise by a dc-shifted sine wave. The depth of the modulation was controlled by varying the amplitude of the modulating sine wave. Equation (1) gives the expression describing the sinusoidally amplitude modulated stimuli.

$$s(t) = c[1 + m\sin(2\pi f_m t)]n(t) - - - - - (1)$$

$$c = \left[1 + \frac{m^2}{2}\right]^{-0.5} - - - - - (2)$$

where m is the modulation depth (0<m<1), *fm* is the modulation frequency in Hz (2, 4, 8, 16, 32, 64, 128, 256, 512), and n (t) is the waveform of the white noise. The term c is a multiplicative compensation term (Viemeister, 1979) set such that the overall power was same for modulated and unmodulated stimuli. The level of presentation was randomized over a range of 10 dB with mean level of presentation was (Approximately 60 dB SPL). The level was varied over 10dB to avoid the intensity cues.

***c). Test environment***

Psychophysical testing using the above mentioned stimuli was carried out in a sound treated double room situation. The ambient noise levels were set as per the specification of ANSI (1994).

***d). Equipment***

1. The audiological testing was carried out using a calibrated Madsen Orbiter- 922 audiometer. The stimuli from the audiometer will be routed through TDH- 39 supra aural headphones mounted in MX-41 cushion and B-71 Radio Ear bone vibrator. The immittance evaluation was carried out using a calibrated GSI – Tympstar immittance meter.

2. Temporal resolution tasks was carried out utilizing a PC connected to the audiometer using a customized program for Gap Detection and Temporal Modulation Transfer Function on an APEX 3 platform.

***e). Procedure***

Hearing evaluation was performed for all participants. Ear specific pure-tone air and bone conduction thresholds were measured at octave frequencies between 250 to 8000Hz and 4000Hz respectively. Tympanometry for 226 Hz probe tone was carried out accompanied by reflexometry across 500 to 4000 Hz. For UHL participants, the stimuli were presented in the “intact” ear while the “poorer” non-test ear was left open.

***Psycho-acoustic procedure***

Threshold estimation was made based on a 3 AFC procedure with a 2-down 1-up tracking method, estimating the 70.7% correct point on psychometric function In this procedure target signal (amplitude and frequency modulation) was reduced after 2 correct responses, and target signal was increased after 1 in-correct response. In the above two tasks stimuli were presented at a 40 dB SL (ref to PTA). The stimuli were played from a computer and routed through an audiometer (Madsen OB-922). The listeners received the signal from the headphones (TDH-39).

**Gap detection**

In the gap detection experiment, the participant’s task was to identify the interval containing the silent interval. No feedback was given. The step size was initially 5 ms and was reduced to 1 msec after two reversals. The mean of the level at the last eight reversals in a block of 14 was taken as threshold. The worst threshold that could be measured was 20 msec. In this procedure GDTs were measured using a two down, one up paradigm. Stimulus order and ear of presentation were randomized.

**Amplitude modulation detection**

In the TMTF experiment, the participant’s task was to identify the interval containing the amplitude modulation. No feedback was given. The step size and modulation thresholds were based on the modulation depth in decibels ($20\times\log_{10}(m)$). The step size was initially 4 dB and was reduced to 2 dB after two reversals.

The mean of the level at the last eight reversals in a block of 14 was taken as threshold. The worst threshold that could be measured was 0 dB, and it corresponded to a modulation depth of one (100% modulated noise). While estimating the TMTF threshold, it was noticed that many listeners could not detect even 100% at some modulation frequencies. The procedure was terminated at that level and the data of those frequencies were not considered for further analysis.

The data obtained through the administration of the two tasks involved in the present study was tabulated and subjected to statistical analysis.

# CHAPTER 4

# RESULTS AND DISCUSSION

The present study aimed at studying the temporal resolution abilities in listeners with normal hearing and unilateral deafness. Group I consisted of 15 normal hearing listeners while group II consisted of 10 listeners with unilateral deafness (6 unilaterally deaf in the right ear and 4 unilaterally deaf in the left ear). To investigate the aim of the present study temporal resolution was measured using Gap detection and modulation detection. The collected data was tabulated and subjected to statistical analysis using SPSS software version 17.

The following analysis was conducted:

I. Within group comparison:

- Group I: for comparison across ears and stimuli for 15 normal hearing listeners, a paired sample t-test was used.
- Group II: for comparison across right unilaterally deaf (N=6) and left unilaterally deaf (N=4) listeners Wilcoxon signed rank test was used.

II. Across Group comparison:

- This was carried out using Mann-Whitney U test for comparison with respect to stimulus and ear across the two groups.

## Experiment I: Gap Detection Threshold

***A.*** *Normal hearing listeners (Group I)*

From the figure 4.1, one can read that the mean values for GDT shows an increasing trend as the stimulus changed from broadband noise to 2 KHz sinusoidal stimulus. This trend was noticed irrespective of the ear to which the stimuli were presented. To assess whether this mean difference reaches significance, a paired sample t-test was carried out. The results revealed a significant effect of stimulus on Gap detection thresholds within Group I. This implies that the Gap detection thresholds obtained using three stimuli used in this study namely; broadband noise, 400 Hz sinusoid and 2KHz sinusoid were different. The t-value and level of significance is also presented in figure1.

On the basis of the above findings, it can be contemplated that gap resolution performance of normal hearing listeners in the current study were in general agreement with other studies (Snell, Ison & Frisina, 1994; Forrest & Green 1987; Shailer & Moore, 1987) wherein, GDT's were lower for BBN and higher for tonal stimuli. For the tonal stimuli GDT obtained in the present study were similar to those obtained by Shailer & Moore, (1987). These results might be attributed to the differential processing of complex versus simple temporally varying stimuli.

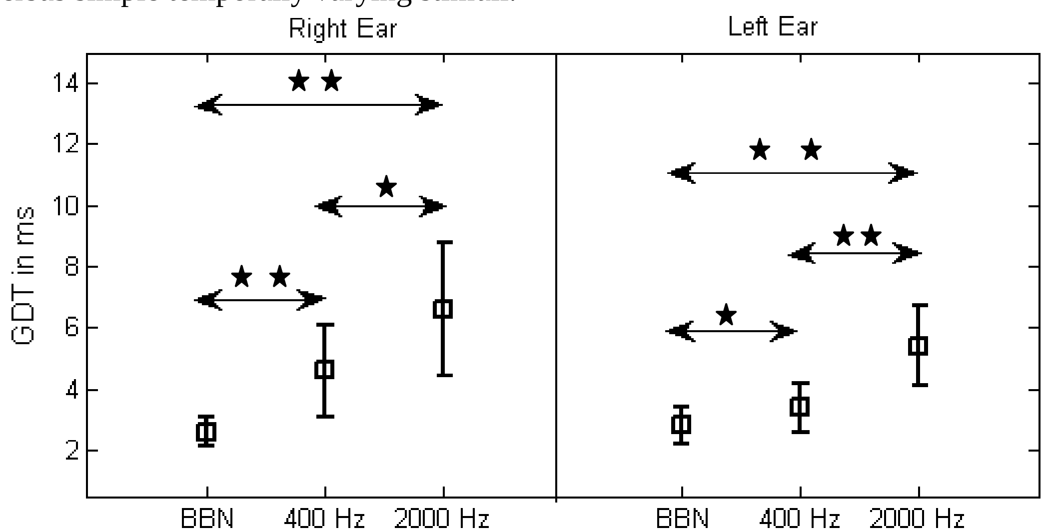



*Figure 4.1*: Mean and SD of GDT across different stimuli group I for left ear and right ear.

★★ Significance at $p < 0.01$ ★ Significance at $p < 0.05$

From the Figure 4.1 one can note that, mean GDT values were similar between right ear and left ear for BBN, but they were slightly higher for right ear when compared to left ear for 400 Hz and 2 KHz. A paired sample t-test was used for this comparison and the results revealed no significant difference in GDT for broadband noise between the ears while the GDT values for 400 Hz and 2 KHz sinusoids were significantly different for right ($t = 2.98$, $p < 0.05$) and left ears ($t = 2.69$, $p < 0.05$). Similar to the present study Sininger and De Bode (2008) also reported a left ear advantage for tonal stimuli in GDT task. This clearly indicates better ability of the left ear (right hemisphere) to process temporally simple stimuli like sinusoids i.e. a processing advantage for such stimuli is shifted to the right hemisphere. However, Sininger and De Bode (2008) and Sulakhe, Elis & Lejbak (2003) have reported a right ear advantage for BBN condition, in contrast to the present study wherein, no ear advantage was revealed.

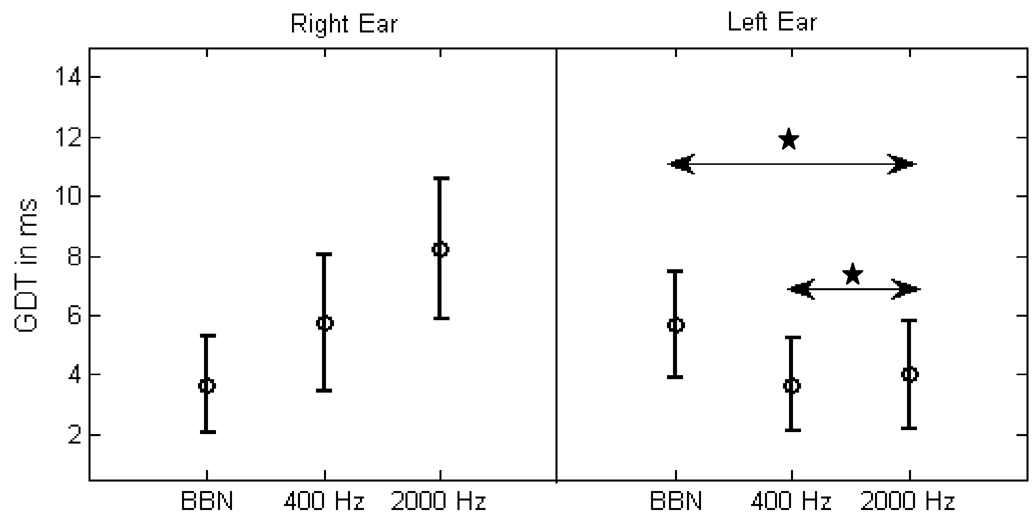
The lack of laterality for GDT in broad band stimulus has been reported by other studies which therefore, supports the findings of the present study (Efron et al., 1985; Oxenham 2000). Hence, absence of ear differences with respect to the gap resolution performance for broadband stimuli do not completely support a lateralized processing of auditory signal i.e. in the present study temporal processing of complex signal between ears is not significantly different.

However, based on the results obtained, the temporally simple stimuli like sinusoids are best analyzed by the left ear and right hemisphere contributing to partial lateralization for processing of such stimuli. It has been shown in the literature that pure-tone stimuli have deterministic temporal properties that facilitate spectral analysis and this distinguishes left ear processing. Therefore, the presence of a right or left ear advantage is driven by the type of stimulus employed.

**B.** *Listeners with Unilateral Deafness (Group II)*

The mean and standard deviation values for GDT in Group II are depicted in Figure 4.2. The values on observation appear to be slightly different across stimuli and across ears. Wilcoxon signed rank test was carried out to investigate the effect of stimulus on GDT values for each subgroup i.e. right ear only (N=6) and left ear only (N=4) individually. The results revealed no effect of stimuli on GDT values in left ear only condition (i.e. temporal complexity of the stimulus does not affect the temporal resolution ability when stimuli are presented to the normally functioning left ear of the unilaterally deaf listeners). On the contrary, for right ear only condition, the results revealed a significant difference in GDT values across stimulus namely: GDT for broadband noise and 2 KHz sinusoidal stimulus as well as GDT for 400 Hz and 2 KHz sinusoidal stimulus ($p < 0.05$).

The above findings imply a significant effect of temporal complexity of the stimulus on gap resolution when the stimuli are presented to typically functioning right ear of the unilaterally deaf listeners. These findings are consistent with those reported by Sininger and De Bode, (2008), Brown and Nicholls (1997) and Nicholls et al. (1999) who showed a clear right ear advantage for temporally complex stimuli over simple stimuli.




★ Significance at $p < 0.05$

*Figure 4.2*: Mean and SD of GDT across stimuli for Group I in right ear and left ear.

The GDT values represented in figure 4.2 show a reverse trend for left ear only condition as compared to right ear only condition i.e. the gap detection thresholds become better as the stimulus changes from broadband to sinusoidal stimulus. To investigate the significance of difference across the ears Mann-Whitney U test was used to compare gap resolution thresholds across left ear only and right ear only condition for group II. The results revealed significant difference in GDT values only for the 2 KHz sinusoidal stimulus. This is to imply that the 2 ears of unilaterally deaf listeners differ in processing of sinusoidal stimulus but not with respect to broadband stimulus. Also, it can be concluded that there is poorer gap resolution for broadband noise by the typically functioning left ear of unilaterally deaf listeners in comparison to the right ear.

These differences can be attributed to the role of dominant hemisphere in gap resolution based on the temporal complexity of the stimulus. Assuming a physiologically normal left dominant hemisphere in all subjects with right sided unilateral deafness, the processing of broadband stimulus would be minimally affected while the same may not hold good for the subjects with left sided unilateral deafness. Owing to the above reason, a poorer temporal resolution for complex stimuli like broadband noise can be speculated.

Based on the average duration of unilateral deafness in the participants (3.35 years), it can be assumed that the plastic changes speculated to be occurring in such a condition, is not adequate enough to allow for complete compensation of processing of stimuli of varying complexity. However, similar findings were reported by Sininger & De Bode (2008) wherein they also noticed similar kind of differences for the processing of temporally complex and simple stimuli for the participants who were unilaterally deaf with congenital or early childhood onset (< 5 years) and they attributed this to no significant reorganization of the central auditory system. Therefore, a persistence of ear advantage is still noticed in these listeners with unilateral deafness despite the asymmetric stimulation of the two ears over a particular duration of time. Hence, the laterality of processing of temporally complex stimuli is not altered by the occurrence of unilateral deafness in the present study.

***C.*** *Normal hearing listeners versus listeners with unilateral deafness*

Across group comparison was made with respect to GDT values for different stimuli for left and right ears individually. Mann-Whitney test was used to derive a comparison across the groups.

- Group I (right ear) versus group II (right ear only): The results revealed no significant difference between the groups ($p > 0.05$) for the right ear across all the stimuli.
- Group I (left ear) versus group II (left ear only): A significant difference was obtained between the groups with respect to the GDT values for broadband noise

stimulus when presented to left ear. The results for the same are summarized in table 4.2 and table 4.3.

Table 4.2: *Mean and standard deviation GDT values across Group I and Group II (right ear only*)

| **Group** | **GDT (BBN)** | | **GDT (400 Hz)** | | **GDT (2KHz)** | |
|---|---|---|---|---|---|---|
| | **Mean** | **S.D.** | **Mean** | **S.D.** | **Mean** | **S.D.** |
| Group I (N=15) Left ear | 2.82 | 0.68 | 3.42 | 0.88 | 5.40 | 1.31 |
| Group II (N=4) Left ear only | 5.66 | 1.78 | 3.66 | 1.56 | 4.00 | 1.82 |

Table 4.3: *Mean and standard deviation GDT values across Group I and Group II (left ear only)*

| **Group** | **GDT (BBN)** | | **GDT (400 Hz)** | | **GDT (2KHz)** | |
|---|---|---|---|---|---|---|
| | **Mean** | **S.D.** | **Mean** | **S.D.** | **Mean** | **S.D.** |
| Group I (N=15) Right ear | 2.62 | 0.58 | 4.60 | 1.58 | 6.62 | 2.25 |
| Group II (N=6) Right ear only | 3.66 | 1.63 | 5.72 | 2.30 | 8.28 | 2.35 |

In listeners with unilateral deafness (Group II) right ear only GDT’s showed a trend of poorer temporal resolution as the stimulus changed from broadband to sinusoidal. Additionally, left ear only GDT’s depicted best gap resolution abilities for sinusoidal stimuli in comparison to broadband stimulus. Therefore, for listeners with unilateral deafness, when the functioning ear is the right ear, gap resolution is best for noise stimuli and when left ear is the functioning ear, gap resolution is better for tonal stimuli than noise.

These findings clearly indicate that no central compensation for the loss of hearing in one ear has taken place. Comparison across the two groups for gap resolution did not reveal a significant difference except for the GDT values for broadband noise when presented to left ear indicating that processing of simple stimuli is similar in both the groups. In other words, individual ears of listeners with unilateral deafness have the same temporal processing abilities for simple stimuli as the corresponding ear of binaurally normal hearing individuals. On the other hand, performance was found to be poor for complex signal and this probably suggests that no cortical reorganization or no compensation has been taken for complex stimuli. However, an appropriate conclusion cannot be made in this regard due to a very small sample size, different nature of eitiologies associated with the hearing loss and scarce literature available in this regard.

**Experiment II: Temporal Modulation Detection**

Figure 4.3 shows modulation detection thresholds in dB as a function of modulation frequency for both the ears in normal hearing subjects. One can read from the data that the mean values of both the ears were similar across all the frequencies between the ears. An attempt to see the significance of difference in modulation thresholds between the ears was not made as the mean values for the same were found to be similar.

The shape of TMTFs for both the groups (figure 4.4 and 4.5) are consistent with those found in previous studies for normal hearing listeners. The overall shape of the curve appears to contain a low pass characteristic with a cutoff frequency consistent with those found in previous experiments utilizing noise carriers (Bacon & Gleitman, 1992; Bacon &Viemeister, 1985; Formby, 1985; Viemeister, 1979). The bandwidth and peak sensitivity for TMTF were derived from the equation described by Zeng et al. (2005). These parameters noticed in the present study were approximately similar to those reported for the broadband noise by earlier investigators (Lorenzi, 2002; Eddin, 1994).

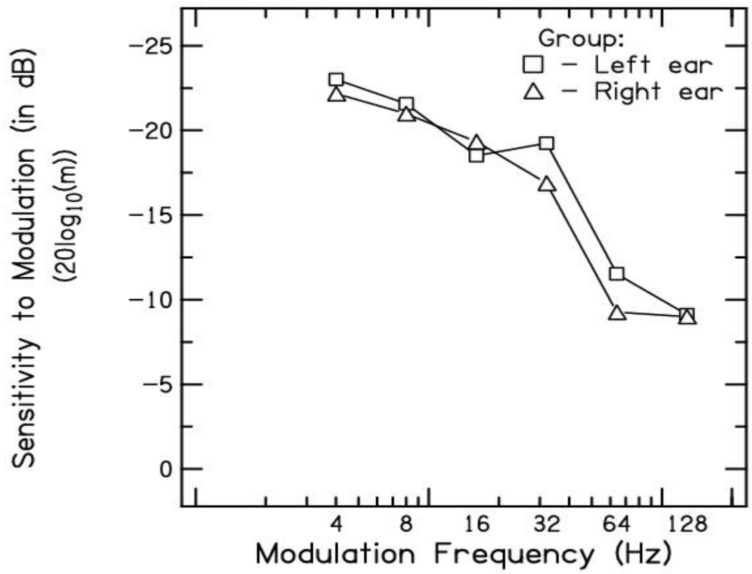



*Figure 4.2*: TMTF for listeners with normal hearing (Group I) in both ears

**A.** *Normal hearing listeners versus listeners with unilateral deafness*

Between group comparison of amplitude modulation thresholds revealed no significant difference for any modulation frequencies in the range of 4 Hz –64Hz on paired t-test between the ears ($p > 0.05$). The modulation thresholds at 128 Hz showed significant difference across the two groups ($p < 0.05$) only when the ear of presentation was right ear. Additionally, paired t-test comparison for peak sensitivity of the Temporal Modulation Transfer Function revealed no significant difference across the groups while the bandwidth of the function obtained was found to be statistically significant ($p > 0.05$) across the two groups only for left ear presentation.

According to Lorenzi et al., (2000), bandwidth is a parameter which is an approximate measure of temporal resolution. This implies that temporal processing is impaired when temporally complex stimulus is presented to left ear of the listeners with unilateral deafness in comparison to right. Above findings also imply no significant effect of temporal complexity of the stimulus on gap resolution when the stimuli are presented to typically functioning right ear of the unilaterally deaf listeners ear for similar reasons as described in context to GDT

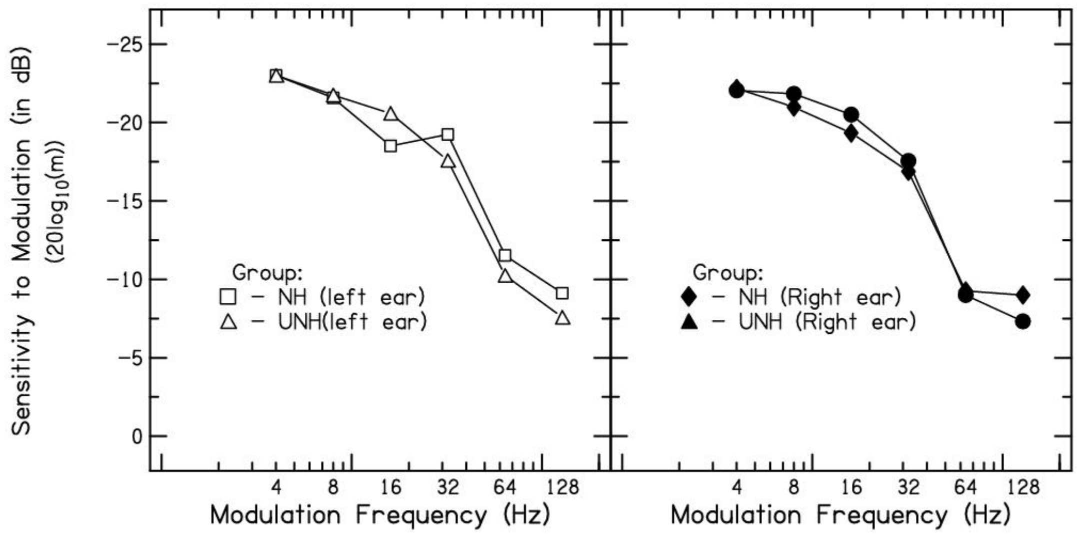



*Figure 4.3*: TMTF for Group I and Group II participants (between ear comparisons)

In summary, based on the results, it can be concluded that the gap detection abilities of listeners with unilateral deafness show the presence of ear effect in context of temporally complex and simple stimuli. Therefore, a significant effect of asymmetric stimulation has not been revealed in the present study due to absence of any kind of compensation with respect to gap resolution. Invariably, the temporal modulation transfer functions obtained from the two groups of subjects also how a fair amount of similarity. No ear differences were found to be present with respect to processing of modulation detection.

# CHAPTER 5

## SUMMARY AND CONCLUSIONS

The present study was aimed at assessing the temporal processing abilities of typically functioning ear of listeners with unilateral deafness and whether there are any indications of differences from a group of normal hearing listeners. To achieve the above mentioned aim, 2 groups of listeners participated in the study: Group I consisting of 15 normal hearing listeners and group II consisting of 10 listeners (age range= 18 -35 years) with unilateral deafness (6 listeners with normal hearing right ear and 4 listeners with normal hearing left ear in the age range of 18-45 years). All participants were right handed to ensure a homogenous group for established laterality. Psychophysical evaluation was carried out in both the groups based on the following measures 1). Gap resolution for broadband and sinusoidal stimuli (400Hz and 2KHz) and 2). Temporal Modulation Transfer Function (TMTF).

Data obtained from the participants from the two groups was tabulated and subjected to appropriate statistical analysis and the results of analysis revealed:

- In listeners with normal hearing (Group I) the Gap-detection thresholds did not differ across the ear for broadband stimuli. But there was difference for the sinusoidal stimuli.
- In listeners with unilateral deafness (Group II), when right ear was better ear (left damaged) performance for BBN was within normal limits while the thresholds for the tonal stimuli were affected. On contrary when left ear was the better ear (right damaged) GDT for tonal stimuli were within normal limits while the thresholds for BBN was elevated compared to normals.

- The TMTF for listeners with UHL is not significantly different than that from the NH subject group. However, when the righted was damaged the bandwidth for TMTF was narrower than normal listeners indicating poorer temporal processing.

Conclusion:

In general, results of the study show that compensation or reorganization had not yet taken place in the subjects taken for the study. On the other hand, some kind of deprivation effects were noticed in terms of poorer performance for BBN when righted is damaged and for tonal stimuli when left ear is damaged. However, results should interpreted with caution since less number of subjects were taken for study.

**Implications of the study:**

- The present study provides an insight into the processing of temporally complex stimulus through specialized function of the hemispheres.
- Psychoacoustical experiments or tasks as used in the current study can be employed to provide an indirect measure of laterality functions in unilateral hearing loss population.
- Such experiments can provide an indirect measure or indicator of occurrence of plastic changes, if any, following hearing impairment.

**Future directions for research:**

- Psychoacoustical experiments using various stimulus paradigms for e.g: by varying the presentation levels, or by employing more complex stimuli such as speech for evaluating temporal resolution in such a population.
- A similar study with larger sample size and better homogeneity with respect to established etiology in the experimental group can be undertaken.
- Another set of tests involving discrimination measures, non-simultaneous maskin paradigms can be employed for complete assessment of temporal resolution abilities.

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## Appendix I

## Laterality Preference Schedule, Modified

### I. With which hand would you:

| S. NO. | ACTIVITY | RIGHT | LEFT | NO PREFERENCE |
|---|---|---|---|---|
| 1. | Wipe a table with a cloth | | | |
| 2. | Hold a glass when drinking | | | |
| 3. | Put a coin in a box | | | |
| 4. | Raise when called out | | | |
| 5. | Write | | | |
| 6. | Brush teeth | | | |
| 7. | Eat | | | |
| 8. | Comb/brush your hair | | | |
| 9. | Open a drawer or dresser | | | |
| 10. | Point to objects | | | |
| 11. | Pick an object kept on the table | | | |
| 12. | Switch on the light | | | |
| 13. | Have the greatest strength | | | |
| 14. | Hold a pair of scissors for cutting | | | |
| 15. | Use first while putting on shirt | | | |
| 16. | Erase a pencil mark with eraser | | | |
| 17. | Hurl a ball | | | |
| 18. | Hold on umbrella while walking | | | |

## II. With which foot would you:

| | | | | |
|---|---|---|---|---|
| 19. | Kick a ball | | | |
| 20. | Hop | | | |
| 21. | Put on your footwear first | | | |
| 22. | Stand the longest | | | |
| 23. | Extend first when asked to stand and walk | | | |
| 24. | Have the greatest strength | | | |

## III. With which eye would you:

| | | | | |
|---|---|---|---|---|
| 25. | Look through a small hole | | | |
| 26. | Aim while hitting a ball | | | |
| 27. | See through a hole | | | |
| 28. | Spontaneously see when asked to close one eye | | | |

## IV. With which ear would you:

| | | | | |
|---|---|---|---|---|
| 29. | Listen to telephone | | | |
| 30. | Listen to faint sound from distance | | | |