Temporal Processing in Listeners with Unilateral Deafness

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Abstract

In general, auditory cortex located in the left hemisphere is specialized for processing of acoustic stimuli with complex temporal and spectral structure, while the right hemisphere is primarily responsible for processing of tonal and music stimuli. This asymmetry is reflected in tasks involving processing such stimuli which are spectrally or temporally different. Also, it is not clear whether cortical reorganization may exist following loss of function in one ear particularly in the case of unilateral profound hearing loss. The present study was aimed to investigate the temporal processing abilities in two groups of right handed listeners: a group of normal hearing listeners and group of listeners with unilateral deafness. Gap detection and temporal modulation transfer function were used as measure of temporal resolution. Gap detection thresholds were determined using broadband noise, 400 and 2000 Hz pure tones individually for the right and left ears. Temporal modulation transfer function was examined using amplitude modulated broadband noise for both right and left ears. These experiments were conducted in the ear with normal hearing for the group with unilateral deafness. It was found 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 have a fair amount of similarity. No ear differences were found to be present with respect to processing of modulation detection.*

Keywords: *Temporal processing, unilateral deafness, laterality, cortical reorganization*

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 (Reed et al, 2009; Shailer & Moore, 1987 etc). Gap detection has been used has one of tools to assess temporal resolution of the auditory system by many investigators (eg: Reed et al, 2009). Gap-detection thresholds decrease rapidly for the first 20-30 dB SL and reach an asymptote value at levels beyond

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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 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 SPLs. 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 & 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., 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 et al. 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 et al. (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 and Damasio (1990) concluded from their 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 right temporal lobe lesion.

One special case of asymmetric hearing is described by one ear with essentially normal hearing (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). It leads to asymmetric hearing and 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. There are only a handful of studies which evaluated performance using both temporally complex and tonal stimuli, comparing performance of right and left ears individually in listeners with UHL (Sininger & De bode, 2008). 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. The present study is aimed 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.

Method

Participants

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

Normal Hearing (Group I): The present study was performed on 15 participants (7 males & 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 of 15 dB HL or better at octave frequencies between 0.25 kHz and 8.0 kHz (ANSI, 1969). They also had bilateral normal middle ear functioning as indicated by a type 'A' tympanogram and present acoustic reflexes . 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), as was ascertained by administering the Hand Laterality Preference Schedule (modified version) developed by Venkatesan (2010). *Unilateral deafness (Group II):* Fifteen right handed participants with unilateral deafness in the age range of 18 and 40 years with mean age of 29.8 years participated in the study. All the participants had average (500, 1000 & 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 had an 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. Four participants had left ear as their normal hearing ear while Six participants had right ear as the normal hearing ear. The demographic and audiological data of the participants is presented in the Table 1.

Stimulus

Gap detection task (GDT)

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

Broad band noise GDT: A white noise was digitally generated and band pass filtered from 20-14,000 Hz with 100 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 was minted by reducing the duration of the leading and trailing edge of the signal. The approximate duration of the leading and trailing edge was calculated, by subtracting the gap duration from 500 ms and then dividing it by two. The duration of the gap was varied from 1 ms to 20 ms with an initial step size of 5 ms which was reduced to 1 ms after two reversals.

Sinusoidal signal GDT: 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 ms. 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. The approximate duration of the leading and trailing edge was calculated, by subtracting the gap duration from 500 ms and then dividing it by two. 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.

Table 1: Demographic and audiological data for group II participants

Subject No.	Age	Gender	Normal ear	PTA (Poor ear)	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

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 that was barely audible in the background noise, but not so high as to cause an audible spectral splatter. 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, as given in equation (2), 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 of approximately 60 dB SPL. The level was varied over 10dB to avoid the intensity cues.

Procedure

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 & 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 ms 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 ms. 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.

Results and Discussion

Gap Detection Threshold

Normal hearing listeners (Group I): From the Figure1, 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 2 kHz 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, GDTs 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 and Moore (1987). These results might be attributed to the differential processing of complex versus simple temporally varying stimuli.

From the Figure 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 and 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.

Listeners with Unilateral Deafness (Group II): The mean and standard deviation values for GDT in Group II are depicted in Figure 2. The values, on observation, appear to be slightly different across stimuli and between 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), and Nicholls et al. (1999), who showed a clear right ear advantage for temporally

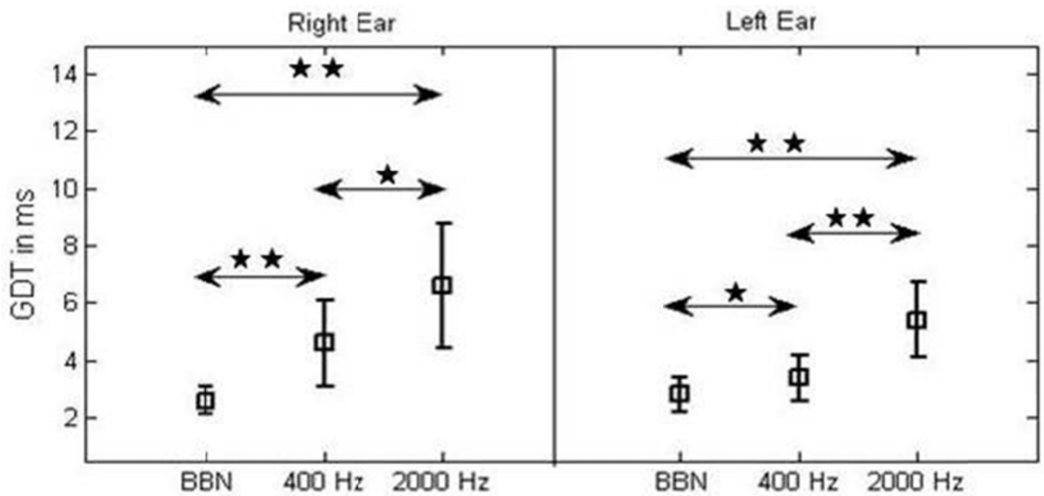

Figure 1: Mean and SD of GDT across different stimuli group I for left ear and right ear.

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

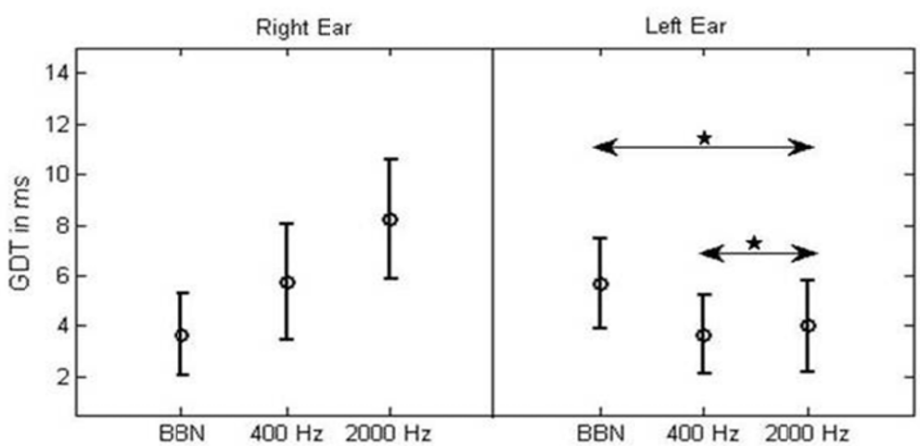

Figure 2: Mean and SD of GDT across stimuli for Group I in right ear and left ear.

★ *Significance at $p < 0.05$.*

complex stimuli over simple stimuli. The GDT values represented in Figure 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 between 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. Sininger and De Bode (2008) 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). 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.

Normal hearing listeners versus listeners with unilateral deafness: Between 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. No significant difference was found between the right ears of Group 1 and Group 2 ($p > 0.05$) for any of the stimuli. A significant difference was found between the left ears of Group 1 and Group 2 ($p < 0.05$) only for the broadband noise condition. The results for the same are summarized in Table 2 and Table 3.

In listeners with unilateral deafness (Group II), right ear only GDTs showed a trend of poorer temporal resolution as the stimulus changed from broadband to sinusoidal. Additionally, left ear only GDTs 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.

Table 2: Mean and standard deviation GDT values across Group I and Group II (right ear only)

Group (RE)	GDT (BBN)		GDT (400 Hz)		GDT (2KHz)	
	Mean(ms)	S.D.	Mean(ms)	S.D.	Mean(ms)	SD
Group I (N=15)	2.62	0.58	4.60	1.58	6.62	2.25
Group II (N=6)	3.66	1.63	5.72	2.30	8.28	2.35

Table 3: Mean and standard deviation GDT values across Group I and Group II (left ear only)

Group (LE)	GDT (BBN)		GDT (400 Hz)		GDT (2KHz)	
	Mean(ms)	S.D.	Mean(ms)	S.D.	Mean(ms)	S.D.
Group I(N=15)	2.82	0.68	3.42	0.88	5.40	1.31
Group II (N=4)	5.66	1.78	3.66	1.56	4.00	1.82

Temporal Modulation Detection

Figure 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. 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 3 & 4) 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, Wable, Moroni, Derobert, Frachet, & Belin, 2000; Eddins, Hall, & Grose, 1992).

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 between 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 TMTF revealed no significant difference between the groups while the bandwidth of the function obtained was found to be statistically significant ($p > 0.05$) between the two groups only for left ear presentation.

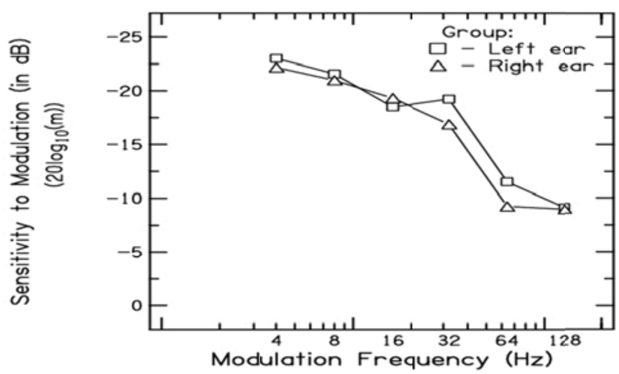

Figure 3: TMTF for listeners with normal hearing (Group I) in both ears.

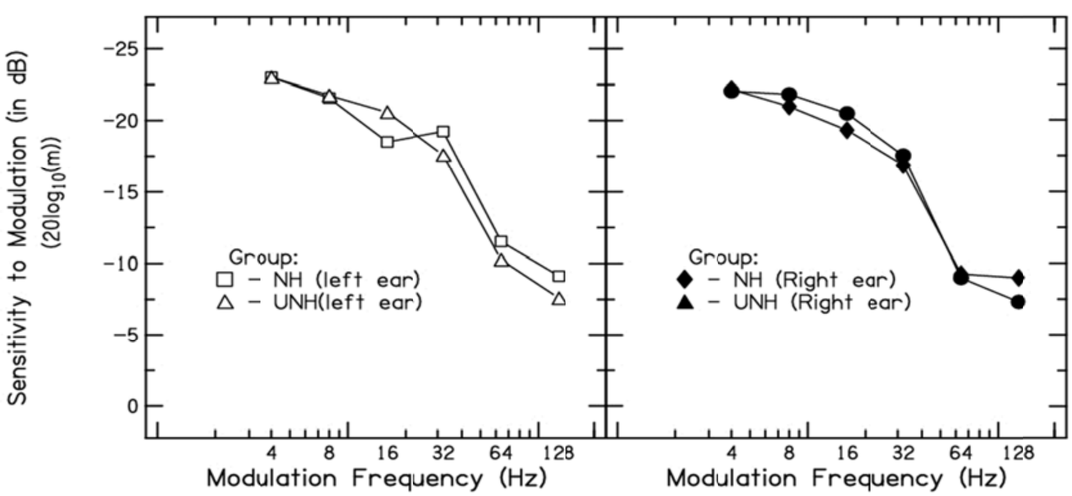

Figure 4: TMTF for Group I and Group II participants (between ear comparisons).

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 for similar reasons as described in context to GDT.

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 show a fair amount of similarity. No ear differences were found to be present with respect to processing of modulation detection.

Conclusions

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 kinds of deprivation effects were noticed in terms of poorer performance for BBN when right ear is damaged and for tonal stimuli when left ear is damaged. However, results should be interpreted with caution due to the reduced sample size considered for the study.

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References

ANSI (1969) ANSI S1.1. Standard reference threshold sound-pressure levels for audiometers. New York, NY: American National Standards Institute

Bacon, S. & Gleitman, R. (1992). Modulation detection in subjects with relatively flat hearing losses. *Journal of Speech and Hearing Research, 35*, 642-653.

Bacon, S., & Viemeister, N. (1985). Temporal modulation transfer functions in normal hearing and hearing-impaired listeners. *Audiology, 24*, 117-134.

Cozad, R. (1977). Speechreading skill and communication difficulty of children and young adults with unilateral hearing loss. *Journal of Auditory Research*, *17* (1), 25-29.

De Filippo, C. L., & Snell, K. B. (1986). Detection of a temporal gap in low-frequency narrow-band signals by normal- hearing and hearing-impaired listeners. *Journal of the Acoustical Society of America, 80*, 1354-1358.

Donoghue, J. P. (1995). Plasticity of adult sensorimotor representations. *Neurobiology, 5*, 749-754.

Eddins, D., Hall, J., & Grose, J. (1992). The detection of temporal gaps as a function of frequency region and absolute bandwidth. *Journal of the Acoustical Society of America, 91, 1069-1077.*

Efron, R., Yund, E. W., Nichols, D., & Crandell, P. H. (1985). An ear asymmetry for gap detection following anterior temporal lobectomy. *Neuropsychologia, 23*, 43-50.

Fitzgibbons, P., & Wightman, F. (1982). Gap detection in normal and hearing-impaired listeners. *Journal of the Acoustical Society of America, 72*, 761–765.

Formby, C. (1985). Differential sensitivity to tonal frequency and to the rate of amplitude modulation of broadband noise by normally hearing listeners. *Journal of the Acoustical Society of America, 78*(1), 70-77.

Forrest, T. & Green, D. (1987). Detection of partially filled gaps in noise and the temporal modulation transfer function. *Journal of the Acoustical Society of America, 82*(6), 1933-1943.

Glasberg, B., Moore, B. C. J., & Bacon, S. (1987). Gap detection and masking in hearing-impaired and normalhearing subjects. *Journal of the Acoustical Society of America, 81*, 1546–1556.

Greenough, W. T. 1975. Experiential modification of the developing brain. *American Science. 63*, 37-46.

Hall, J. W., Grose, J. H., Buss, E., & Hatch, D. (1998). Temporal analysis and stimulus fluctuation in listeners with normal and impaired hearing. *Journal of Speech, Language, and Hearing Research, 41*, 340-354.

Kaltenbach, J. A., Czaja, J. M., & Kaplan, C. R. (1992). Changes in the tonotopic map of the dorsal cochlear nucleus following induction of cochlear lesions by exposure to intense sound. *Hearing Research. 59*, 213-223.

Lister, J. J. & Roberts, A. R. (2005). Effects of age and hearing loss on gap detection and the precedence effect: Narrow-band stimuli. *Journal of Speech, Language, and Hearing Research*. 48, 482–493.

Lorenzi**, C.**, Wable, J., Moroni, C., Derobert, C., Frachet, B., & Belin, C. (2000). Auditory temporal envelope processing in a patient with left-hemisphere damage. *Neurocase, 6*(3), 231-244.

Lorenzi, C., Sibellas, J., Garnier, S., & Gallego, S. (2002). Second order temporal modulation transfer functions (TMTFs) in normal hearing, hearing impaired, and cochlear implant listeners. *Journal of the Acoustical Society of America*, *111*, 2469-2469

Nicholls, M. E., Schier, M., Stough, C. K., & Box, A. (1999). Psychophysical and electrophysiological support for a left hemispehere temporal processing advantage. *Neuropsychiatry Neuropsychology and Behavioral Neurology, 12*, 11-16.

Oxenham, A. J. (2000). Influence of spatial and temporal coding on auditory gap detection. *Journal of the Acoustical Society of America,107,* 2215-2223.

Popelar, J., Erre, J.P., Aran, J.M., & Cazals, Y., (1994). Plastic changes in the ipsi-contralateral differences of auditory cortex and inferior colliculus evoked potentials after injury to one ear in the adult guinea pig. *Hearing Research. 72,* 125-134.

Rajan, R., Irvine, D. R., Wise, L. Z., & Heil, P. (1993). Effect of unilateral partial cochlear lesions in adult cats on the representation of lesioned and unlesioned cochleas in primary auditory cortex. *Journal of Comparative Neurology*, *338*, 17-49.

Reale, R. A., Brugge, J. F., & Chan, J. C. (1987). Maps of auditory cortex in cats reared after unilateral cochlear ablation in the neonatal period. *Brain Research, 431,* 281-290.

Reed, C. M., Braida, L. D., & Zurek, P. M. (2009). Review of literature on temporal resolution in listeners with cochlear hearing impairment: a critical assessment of the role of suprathreshold deficits. *Trends in Amplification, 13*(1), 4-43.

Robertson, D., & Irvine, D. R. (1989). Plasticity of frequency organization in auditory cortex of guinea pigs with partial unilateral deafness. *Journal of Comparative Neurology, 282*, 456-471.

Robin, D. A., Tranel, D., & Damasio, H. (1990). Auditory perception of temporal and spectral events in patients with focal left and right cerebral lesions. *Brain and Language, 39*, 539-555.

Shailer, J. & Moore, B. C. J. (1987). Detection of temporal gaps in sinusoids: effects of phase and frequency. *Journal of the Acoustical Society of America, 81,* 1110-1118.

Sininger, Y., & De Bode, S. (2008). Asymmetry of temporal processing in listeners with normal hearing and unilaterally deaf subjects. *Ear & Hearing, 29*, 228-238.

Snell, K., Ison, J., & Frisina, D. (1994). The effects of signal frequency and absolute bandwidth on gap detection in noise. *Journal of the Acoustical Society of America, 96*, 1458-1464.

Sulakhe, N., Elis, L. J., & Lejbak, L. (2003). Hemispheric asymmetries for gap detection depend on noise type. *Brain and Cognition, 53*, 372-375.

Venkatesan, S. (2010). Laterality Preference Checklist (modified). Cited in *Neurophysiological Functional Assessment Battery (NFA-B).* New Delhi: Psychogen.

Viemeister, N. (1979). Temporal modulation transfer functions based upon modulation thresholds. *Journal of the Acoustical Society of America, 66*(5), 1364-1380.

Zatorre, R. J. & Belin, P. (2001). Spectral and temporal processing in human auditory cortex. *Cerebral Cortex, 11*, 946-956.

Zeng, F. G., Nie, K., Stickney, G. S., King, Y. Y., Vingphoe, M., Bhargave, A., et al., (2005). Speech recognition with amplitude and frequency modulation. *Proceedings of The National Academy Of Sciences*, USA, *02*, 2293-2298.