EFFECT OF AGE AND HEARING LOSS ON GAP DETECTION THRESHOLD

Reg. No. A0490002

A dissertation submitted in part fulfillment for the final year
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DEDICATED TO MY Dear

PARENTS,
TEACHERS &
GOD

CERTIFICATE

This is to certify that this master's dissertation entitled *"Effect **of Age and Hearing loss on Gap Detection Threshold"*** is the bonafide work done in part fulfillment of the degree of Master of Science (Audiology) of the student with **Reg. No. A0490002.** This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this Master's Dissertation entitled **"Effect of Age and Hearing loss on Gap Detection Threshold"** is the result of my own study under the guidance of Dr. K. Rajalakshmi, Reader and HOD, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any University for any other Diploma or Degree.

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CHAPTER 1

INTRODUCTION

Speech is characterized by rapid changes in intensity & frequency over time, the accurate processing of these temporal fluctuations is likely critical for optimal perception of speech. Processing of temporal information may occur via monaural and or binaural inputs. Often, the background noise found in every day listening situations is characterized by fluctuations in intensity over time. Temporal resolution is important for resolving brief dips in the intensity of the interfering noise and therefore it is critical for understanding speech in these situations (Dubno, Horwitz, and Ablstrom, 2003; Oxenham and Bacon, 2003; Peters, Moore and Baer, 1998). The normal auditory system is remarkable in its capacity to extract & encode temporal features of a stimulus waveform. One of the factors identified in psychoacoustic experiments as contributing to poor speech perception is the reduced temporal resolving power of the auditory system. (Dreshcler and Plomp, 1985; Gingel et al 1982; Price and Simon, 1984; Schneider, 1997; Tyler et al 1982).

Temporal resolution may be defined as the ability to follow and resolve rapid fluctuations over time. Temporal resolution is measured in various ways, including detection threshold for amplitude modulation (Viemeister, 1979), forward masking and backward masking (Moore, Glassberg, Plack and Biswas, 1988), temporal order discrimination (Green, 1973). There are two other tests which are similar to gap detection are the Auditory Fusion Test – Revised (AFT-R), and the Random Gap

Detection Test (RGDT). Temporal resolution can be studied using a gap detection paradigm. Typically, in this paradigm, a listener reports the observation interval, in which a silent gap is detected, with the smallest detectable silent interval being termed as Gap Detection Threshold (GDT). Gap detection is probably the most commonly used measure of temporal resolution. Gap detection is likely as popular in method as because it provides a description of temporal resolution based on a single threshold; where as other methods require multiple threshold estimates. Another advantage is that the gap detection is easy to measure in naïve listeners, including infants. The Gap Detection Thresholds obtained from naïve listeners are close to those obtained from well trained listeners (Werner, Marean, Halpen, Spetner and Gillenwater, 1992).

Several investigators have recorded the responses of single auditory neurons to sounds containing gaps and quantified the neural responses by various means to estimate "neural gap threshold". Such neural gaps of auditory nerve fibers are reported to be very similar to the psychophysical Gap Detection Threshold in various species (Zhang, Salvi and Saunders, 1990; Klump and Glitch, 1991). Gap threshold of at least some single units in the central nervous system are also reported to be as low as gap detection (Buchfellner, Leppelsack, Klump and Hausler, 1989; Eggermont, 1995, 1999; Walton, Frisina, Ison and O'Neil, 1997). Such findings have been taken to mean that gap detection is limited primarily by peripheral mechanism, as reflected in the auditory nerve response.

It is also clear, however, that central processing is important in temporal resolution and specifically in gap detection. A lesion of the auditory cortex has been shown to produce deficits in gap detection in rats and ferrets, animals whose temporal resolution is similar to that of humans (Ison, O'Connor, Bowen and Bocirnea, 1991; Kelly and Rooney, 1996). Further, Shammon and Otto (1990) have reported that gap detection in people with auditory brain stem implant was about the same as, or perhaps a little worse than that of people with normal hearing or with cochlear implant. The gap detection is unaffected when the periphery is completely by passed, suggest that the periphery may not be the limiting factor in normal processing, but at the very least that central mechanisms are also involved. Finally, a recent model of temporal processing that includes band of modulation filter following a peripheral processing has done an excellent job for predicting psychophysical results with realistic cochlear filtering (Dau, Kollmeier and Kohlrausch, 1997).

Although it is generally acknowledged that auditory temporal processing improves substantially over the first several years of life, there is considerable disagreement about the specific developmental timetable. For example, the age of achievement of adult–like temporal acuity is reported to be between 5 to 6 years of age by some investigators (Morrongiello, Kulipg and Clifton, 1984; Jensen and Neff, 1993) 9 and 11 years of age by others (Irwin, Grose, as cited in Sandra et al 1995). Shivaprakash (2003) developed normative data for Gap detection test in children & young adults with normal hearing. The findings suggest that normal hearing individuals start performing like adults on Gap detection test by the age of 6 to 7 years.

Age & hearing loss related deficits have been demonstrated in the detection & discrimination of temporal gaps (Lister, Besing & Koehnke, 2002; Lister, Koehnke & Besing, 2000; Roberts & Lister, 2004). Such deficits may contribute to problems with speech understanding in noise experienced by listeners with presbycusis (e.g. Gordon-Salant & Fitzgibbons, 1993; Koehnke & Besing, 2001; Roberts, Koehnke & Besing, 2003; Snell, Mapes, Hickman & Frisina, 2002). Generally Gap threshold in people with cochlear hearing loss are reported to be higher (Moore & Glassberg, 1998). Results obtained in a number of studies indicate that listeners with hearing loss have larger Gap Detection Threshold than listeners with normal hearing for many different types of stimuli (Grose & Hall 1989). However, results of other studies revealed no effect of hearing loss on Gap Detection thresholds (Moore, Peters & Glassberg, 1992; Buss, Hall & Grose, 1998).

Although one study (Moore, Peters & Glassberg, 1982) concluded that reduced temporal gap resolution does not accompany aging, other studies (Fitzgibbons & Gordon- salant, 1992) have shown that age can have significant effect on auditory temporal measures, independent of effects of peripheral hearing impairment. Thus the effects of subject’s age & hearing loss on gap detection ability are not clear.

NEED FOR THE STUDY: -

Psychophysical evidence indicates that trained normal hearing observers can discriminate fluctuations in a waveform that occur in time intervals as brief as 2-3 msec. Resolution thresholds in this range come from several studies that were designed to measure auditory temporal acuity (Miller and Tyler, 1948; Hirish, 1959; Plomp, 1964; Green, 1971; 1973). Relatively little is known about temporal acuity in impaired auditory systems, or the extent to which deficits in this capacity might affect the hearing impaired observer's ability to process complex time-varying stimuli such as speech.

Oxenham (2000) proposes that the perceptual channels important for gap detection depend primarily on peripheral encoding of the marker spectra and higher level neural coding is much less important. This does not explain the findings of normal gap resolution when peripheral encoding of frequency is impaired (i.e. listeners with sensorineural hearing loss have normal gap detection and discrimination), impaired gap resolution when peripheral encoding of frequency is intact (i.e. older listeners with normal hearing have impaired gap detection and discrimination) or normal gap resolution by those whose peripheral auditory system is by passed by an Auditory Brainstem Implant (Shannon and Otto, 1990). Further exploration of this topic using groups of listeners across the age range with and without hearing loss is warranted. Hence, in the present study it is intended to study the effect of age and hearing loss on Gap Detection Test.

- To know the independent & interactive effect of age and hearing loss on gap detection test by comparing the performance of young and older adults with normal hearing and hearing impairment with a significant hearing loss (sensorineural hearing loss).
- To know the effect of configuration of audiogram on Gap Detection Threshold.
- To develop a normative data for older adults with normal hearing.

AIM OF THE STUDY: -

- To study the independent and interactive effects of age and hearing loss on temporally based non-speech measure (Gap Detection Test).
- To study the configuration of hearing loss on gap detection test.
- To develop a normative data for older adults with normal hearing.

CHAPTER 2

REVIEW OF LITERATURE

A pre-requisite for the reliable perception of speech and music is the ability of the auditory cortex to process rapid amplitude fluctuations of acoustic signals. The ability to perceive a stimulus, which are presented, in very rapid succession as different is called " TEMPORAL PROCESSING". Rapid Auditory Processing (RAP) skills are believed to underlie successful language acquisition. Likewise, deficits in rapid auditory processing of both verbal and non-verbal stimuli are characteristic of individuals with developmental language disorders such as Specific Language Impairment (SLI). Auditory processing abilities are well developed in infancy and thus such deficits should be detectable in infants. Auditory processing abilities are affected in hearing impaired and elderly subjects.

In temporal processing it is important to distinguish "Temporal resolution" and "Temporal integration (or summation)". Temporal summation refers to the ability of the auditory system to add up information over time to enhance the detection or discrimination of stimuli. Temporal resolution refers to ability to detect changes in stimuli over time. Temporal resolution normally refers to the resolution of changes in envelop, not in the fine structure. It depends on two main processes,

a) Analysis of time pattern occurring within each frequency channel and

b) Comparison of the time pattern across channels.

This research study mainly concentrates on temporal resolution, specifically the gap detection in Broad Band Noise (BBN).

Experiments on temporal auditory acuity have been done using a variety of stimuli and approaches, such as the Temporal Modulation Transfer Function (TMTF) and Gap detection (e.g., Patterson and Green, 1970; Formby and Muir, 1988; Ronkin, 1970; Green, 1971, 1973a,b, 1985; Viemster, 1979; Forrest and Green, 1987).

Auditory Fusion Test - Revised (AFT – R), Random Gap Detection Test (RGDT), and Gap Detection Test (GDT) are the measures of temporal resolution.

Auditory Fusion Test–Revised (AFT–R)

The Auditory Fusion Test-Revised (AFT-R) is designed to measure one aspect of audition discussed by ASHA consensus panel, namely temporal resolution. The method of evaluating temporal resolution in the AFT-R is through determination of the Auditory Fusion Threshold (AFThreshold).

The Auditory Fusion Threshold is measured in milliseconds (msec) and is obtained by having a listener attend to a series of puretones presented in pairs. The silent time interval the interpulse interval, (IPI) between each pair of tones increases and decreases in duration. As the silent interval changes, the listener reports whether the stimulus pairs are heard as one or two tones. The interval at which the tone pairs are perceived as two (when the IPI is increasing) is averaged with the interval at which the tone pairs are perceived as one (when the IPI is decreasing) and that average is called the Auditory Fusion Threshold (AFThreshold).

The Auditory Fusion Threshold is measured in milliseconds (msec). This stimulus protocol is sometimes called "Gap Detection." The AFT-R can be used to identify temporal processing disorders that may account for language learning problems. The AFT-R is viewed as a test of temporal integrity at the level of the cortex. Even though it is a cortical measure, the test has a low linguistic and cognitive load, e.g., the listener must simply respond by indicating whether one or two tone pulses were heard. As with the duration pattern test, the AFT- R is unaffected by peripheral hearing loss.

Background research on the Auditory Fusion Test-Revised was conducted in the 1980’s by McCroskey and his colleagues at Wichita State University. At that time the procedure was known as the Wichita Auditory Fusion Test (WAFT). McCroskey and Kidder (1980) investigated the temporal integrity of the auditory system using an Auditory Fusion Threshold technique. One hundred-thirty-five children aged seven to nine years were studied. They were grouped in equal numbers of children who were normally achieving, reading disordered, and learning disabled. The children were administered the original version of the Wichita Auditory Fusion Test (WAFT). Auditory Fusion Thresholds (AFThresholds) were computed by averaging the ascending-descending fusion points for two-tone bursts at five frequencies and three intensities. There was a significant difference in the AFThresholds between the children who were considered normal and the other two groups. Interestingly, there was no significant difference in AFThresholds between children who were reading disordered and those who were learning disabled. This and many other studies by McCroskey underlined the importance of temporal processing regarding language and learning problems, and the need to identify temporal processing disorders.

Isaacs, et al., (1982) studied children from 9 to 18 years. Isaacs separated subjects into two groups. The first group had language or learning disabilities and the second group was composed of normally achieving children. Subjects in the two groups were matched for mental age and adolescent development. Auditory Fusion Thresholds were significantly different between groups, with language/learning-disabled children having larger AFThresholds than control subjects.

Overview of AFT-R subtests

Following publication of the ASHA Task Force on Central Auditory Processing (ASHA, 1996) with emphasis on testing of temporal processing, McCroskey and Keith revised the WAFT in the following manner:

The original test was recorded on audiotapes that had lost their precision and quality. Therefore the original test was re-recorded onto CD. The test stimuli were precisely recorded using digital recording techniques as originally described in the WAFT test manual. The resulting test is therefore a high quality, low signal–to-noise recording with precise test stimuli.

The test is described as follows:

Subtest 1, Practice and preliminary screening. The screening subtest begins with a brief 500 Hz calibration tone and is followed by eighteen 500 Hz tone pairs that ascend from a 0 msec to a 300 msec interpulse interval (IPI).

Subtest 2, Standard Test. Subtest 2 contains interpulse intervals that range from 0 through 40 msec. The specific order encompasses ascending and descending interpulse intervals; for example, the test sequence at a given frequency begins with 0 msec IPI and proceeds to a maximum of 40 msec IPI, which is repeated, and then the intervals decrease to 0 msec.

Subtest 2 begins and ends with the 500 Hz stimulus pairs. Repetition of the 500 Hz stimuli serves at least two purposes. If the initial instruction and the practice afforded by the Screening Test have not stabilized the responses of the listener, the first administration of the 500 Hz stimuli can serve as additional practice. In that case results from the first administration of the 500 Hz stimuli would be disregarded and only the data from the second administration would be used in computing the Auditory Fusion Threshold. The repetition also serves as a measure of whether the listener has changed strategies during the course of the test and serves as a measure of reliability.

Subtest 3, Expanded test. This subtest is included for individuals who did not detect the IPI until a 60 msec or greater interval occurred on the Screening AFT-R (subtest 1). This version of the test begins at the point where the regular test ends, at 40 msec. The test includes only three frequencies but retains 18 stimuli per frequency. The IPI ascends from 40 msec to 300 msec and then descends to 30 msec. Individuals who require this test to establish an AFThreshold have (by definition) demonstrated abnormally poor temporal processing abilities. The test simply identifies whether there are frequency differences that could also contribute to auditory reception, speech, language, or reading disorders.

The Random Gap Detection Test (RGDT)

The Random Gap Detection Test (RGDT) is modification of the Auditory Fusion Test–Revised with the following improvements. The Auditory Gap Detection Threshold of tones and white noise (clicks) is obtained by having the subject identify when signal pairs are separated in time from 0 to 40 msec. The major improvement in the signal presentation during the RGDT is that the gap interval is randomly assigned, and therefore unpredictable to the subject. The test includes stimuli at four frequencies (500, 1000, 2000, and 4000Hz) and white noise clicks of 50 msec duration.

A practice session is presented with tone pairs at 1000Hz. The test takes approximately 10 minutes to administer, including instructions and practice.

Interpretation is made by averaging the Gap Detection Threshold for all tonal stimuli and comparing the results to normative data that is currently available on subjects from 5 – 12 years of age.

The Random Gap Detection Test (RGDT) – Expanded Test

The Random Gap Detection Test (RGDT)–Expanded Test is intended for individuals whose gap detection threshold exceeds 40 msec. This test begins at time intervals longer than those measured by standard RGDT, and includes time intervals between 50 and 300 msec. The test is administered in the same manner as the standard RGDT. Individuals who require this test to establish a Gap Detection Threshold have already demonstrated abnormal temporal processing abilities. The single purpose is to determine the time interval in which their gap detection threshold exists. These data can be used to measure improvement in temporal processing abilities that may occur with maturation or following remediation.

Gap Detection Test (GDT)

One of the psychophysical methods for measuring auditory temporal processing is the gap detection paradigm. Gap detection is reasonably well-established method, which measures the ability of the listener to detect brief temporal gap separating two successive stimuli. Gap Detection is probably the most commonly used measure of temporal resolution, i.e. ability to follow rapid changes over time. The Gap Detection Threshold is the duration of the just detectable interruption in a sound. Gap Detection is likely as popular in method as it is because it provides a description of temporal resolution based on a single threshold; where as other methods require multiple threshold estimates. Another advantage is that the gap detection is easy to measure in naïve listener, including infants. The Gap Detection Thresholds obtained from naïve listeners are close to those obtained from well-trained listeners (Werner, Marean, Halpen, Spetner & Gillenwater, 1992).

Temporal resolution can be measured using tasks of silent gap detection in which markers bounding the gap are of similar (frequency–fixed) or different (frequency– disparate) spectral characteristics and or presented to one ear (monotic), to both ears simultaneously (diotic), or to different ears (dichotic: e.g., Lister et al 2002; Roberts and Lister, 2004).

Regardless of the stimuli or presentation method used, a common task is to report perception of a silent gap. The smallest gap that the listener perceives is recorded as a Gap Detection Threshold (GDT). Silent gap can be measured using both within–channel and across–channel paradigms. Within–channel gap detection is measured using monotic or diotic markers of similar frequency characteristics.

Two methods for measuring across–channel gap detection have been used;

a) Dichotic presentation of markers of similar frequency characteristics (e.g., Formby, Gerber, Sherlock, and Magder, 1998).

b) Monotic or diotic presentation of markers that differ in frequency characteristics (e.g., Lister et al 2002). The former may be termed "across–ear" and latter "across–frequency".

The performance of young listeners with normal hearing sensitivity differs across various GDT paradigms, specifically, GDTs measured dichotically are poorer than those measured monotonically or diotically for the same participants and stimuli (e.g., Formby et al 1998; Phillips, Taylor, Hall, Carr and Mossop, 1997). GDT measured using frequency-disparate markers are poorer than those obtained using fixed frequency markers (e.g., Grose, Hall, Buus and Hatch, 2001; Lister et al., 2002). GDTs for markers that differ in both dimensions (i.e., are both frequency–disparate and presented dichotically) may (Phillips et al 1997; Taylor, Hall, Boehnke and Phillips, 1999) or may not (Formby et al 1998) be poorer than GDTs for markers that differ in either dimension alone.

These effects may be explained using the perceptual channel theory of temporal resolution (e.g., Formby et al 1998; Grose et al 2001; Oxenham, 2000), as discussed in the particle (Roberts and Lister, 2004).

Factors Affecting Gap Detection Threshold (GDT)

There are several factors that affect the gap detection. These include

1) Type of stimuli:

A. Bandpass noise

B. Wideband noise

C. Stimuli with sinusoidal markers

2) Noise burst duration

3) Location and uncertainty of gap

4) Gap onset and offset

5) Subject related factors

a) Age

b) Hearing loss

c) Language disabilities

d) Oto - Acoustic Emissions (O.A.E)

1) Type of stimuli: -

Resolution of the silent gap is highly dependent on the characteristics of the signals (markers) that bound the gap. The experimental stimuli are generally constructed from broadband noise, narrow band noise, or puretones.

A) Gap detection in bandpass noise

The use of narrow band noise permits the specification of stimulus frequency, but it has been suggested that gap thresholds for noise bands are partly limited by fluctuations in the noise (Shailer & Moore, 1983; Glassberg, Moore & Bacon, 1987). Dips in the noise envelope may be confused with the gap to be detected. Consequently, Gap Detection Thresholds will be influenced by the ability to discriminate difference between local amplitude fluctuations and an actual gap in a narrow band noise (Glassberg et al 1987; Moore & Glassberg, 1988).

Gap detection for noise band markers decreased with increasing center frequency when the relative bandwidth of the noise was held constant. The discrepancies between the results for noise markers and sinusoidal markers are most easily explained in terms of the inherent fluctuations in the noise markers, dips in the noise are confusable with the gap. When both the noise bandwidth and auditory bandwidth are large, the fluctuations in the noise at the output of auditory filters are rapid and not very confusable with the gap. When the noise bandwidth is small, or when the noise is centered at a low frequency where the auditory filter bandwidth is small, the fluctuations at the output of the filter are slower, and more confusable with the gap.

Most studies showing increasing gap thresholds with increased center frequency have used noises whose bandwidth increased with increasing center frequency, making it difficult to separate the effects of bandwidth with center frequency. When the bandwidth is held constant, the pattern of result depends on the bandwidth used. When the bandwidth is large (greater than the auditory filter bandwidth at the highest center frequency used), gap thresholds for normal subjects decreased with increasing center frequency, but at lower rate than when relative bandwidth is held constant (Shailer and Moore, 1985).

For narrow bandwidth, gap thresholds for both normal and impaired subjects hardly change with center frequency (Shailer and Moore, 1985). This is consistent with the idea that fluctuation in the noise plays a significant role. Fluctuations in the noise may be particularly important for hearing impaired subjects owing to the presence of loudness recruitment. The fluctuations in loudness associated with intensity fluctuations in the noise are greater than normal for these subjects, making dips in the noise sound more like gaps. These subjects reported that the noise sounded

“ broken up”, apparently the dips in the noise were heard as silent intervals owing to their extreme loudness recruitment. This is consistent with the idea that fluctuations in the noise play an important role.

B) Gap Detection in Wideband noise: -

The detection of gap in broad noise has been studied using a variety of physiological and psychological techniques, which have provided similar measures of temporal acuity. These studies range from single unit recording of auditory nerve fibers in the chinchillas (Zhang, Salvi and Saunders, 1990), inferior colliculus neurons in the mouse (Walton, Frisina, Ison and O’ Neill, 1977), and primary auditory cortex neurons in the cat (Eggermont, 2000), to behavioral techniques such as pre-pulse inhibition in the rat (Ison and leitner; as cited in Allen et al 2002), as well as psychophysical perceptual measures in humans (e.g., Plomp, 1964; Green and Forrest, 1989; Snell, 1997; Florentine, Buus and Geng,1999). In addition to these, gap detection has also assumed significance owing to the importance of temporal acuity for human speech perception (Tyler, Summer, Wood and Fernandes, 1982; Busby and Clark, 1999; Snell and Frisina, 2000). But it obscures the specific frequencies used in detecting gap (Florentine and Buus, 1982,1984; Fitzgibbons, Glassberg & Wightman, 1982; Shailer and Moore, 1983; Glassberg, Moore & Bacon, 1987). Broadband noise stimuli are popular since they can be varied in duration or interrupted for precise specification of Δt, without causing significant change in the stimulus energy spectrum.

Humans detect gaps in broadband noise (BBN) according to effective gap duration without much additional cues from abrupt envelope changes (Allen, James Virage and Ison, 2002). This advantage can be obtained from BBN gap detection. For sinusoids and BBN, silent gaps of 5 msec or less can be detected. This minimum, detectable gap duration has been interpreted as revealing “sluggishness” in the auditory system’s response to very rapid changes in sound level.

In other class of gap detection experiment, the sound before and after the gap, known as “markers”, differ along a certain physical dimension, so minimum gap threshold for simple rectangular BBN is typically between 2 and 3 msec (Plomp, 1964; Irwin and Purday, 1982; Forrest and Green, 1987) and the psychometric function for gap detection is very steep, with a range of approximately 2 msec between 0% and 100% detectability, which as suggested by Green and Forrest, 1989, would assure a high precision (or a low within subject variability) in measurement of the Gap Detection Threshold.

However, the steepness does not guarantee good agreement among studies. Indeed considerable controversy exists in the gap detection.

Computational models of gap detection have generally assumed that gap detection occurs on the bases of short term fluctuations within single-channel detectors (Buunen and Van Valken Berg, 1979; Buus and Florentine 1985; Forrest and Green, 1987). The typical threshold for detection of a gap in wideband noise burst is 2 – 3 msec (Green, 1985 as cited in He et al., 1999). Plomp (1964) suggested that temporal resolution is limited by the decay of sensation production by the first part of the stimulus, which would fill in the gap.

The advantage of using broadband noise as a signal is that any spectral splatter resulting from the abrupt cessation of sound during the gap will be masked. Its major disadvantage is that it is not possible to specify the frequency region, the listener is using for detection.

Several studies indicated that the gap detection in broadband noise is primarily based on the high frequency components of the noise (Fitzgibbons, 1983; Shailer and Moore, 1983; Buus and Florentine, 1985; Formby and Muir, 1988).

C) Gap detection in sinusoidal markers: -

Most studies of temporal gap detection have been done with noise burst stimuli having similar properties before and after the silent gap. Only a few studies of temporal gap detection have used sinusoidal stimuli. Temporal Gap Detection Threshold measured with sinusoidal stimuli (as a function of the frequency separation between the sinusoidal markers) appears to offer the opportunity to evaluate both temporal acuity and frequency selectivity. The uses of signals constructed from sinusoidal signal preclude the frequency specification problem of broadband noise and amplitude fluctuation of Narrow Band noise.

Shailer and Moore (1987) studied the detection of temporal gaps in sinusoids. They used three conditions differed in the phase at which the sinusoid was turned on at the end of the gap; for the standard phase condition the sinusoid started at positive–going zero–crossing; for the reversed phase condition the sinusoid started at negative–going zero- crossing; and for the preserved phase condition, the sinusoid started at the phase it would have had if it had continued without interruption.

For the preserved phase condition, performance improves monotonically with increasing gap duration. However, for the other two conditions psychometric functions are distinctinctly non–monotonic. For the standard–phase condition, the gap is difficult to detect when its value is an integer multiple of the period (P) of the signal i.e. 2.5 msec and 5 msec. Conversely, the gap is easy to detect when its value is (n+0.5), where n= 0 or 1. The psychometric function for the reversed phase condition shows poor performance when gap duration is (n+0.5) P, where n = 0 or 1 and good performance, when gap duration is nP.

Shailer and Moore (1987) explained these results in terms of ringing in the auditory filter. Their argument is that responses of a simulated auditory filter with a center frequency of 400Hz to a series stimuli from the standard phase condition, with gap durations ranging from 1.2 to 3.7 msec, when the sinusoid is turned off at the start of the gap, the filter continues to respond for a certain time. If the gap duration is 2.5 msec, corresponding to one whole period of the sinusoid, the sinusoid following the gap is in phase with the ringing response. In this case the output of the filter shows only a small dip and we would expect gap detection to be difficult. For gap duration of 1.2 msec or 3.7 msec, the sinusoid following the gap is out of phase with the ringing response. Now the output of the filter passes through Zero before returning to its steady state value. The resulting dip in the filter output is larger and is much easier to detect. This explains why psychometric function is non monotonic for the standard phase condition. Similar arguments explain the non-monotonicities for the preserved phase condition.

For the preserved phase condition, the sinusoid following the gap is always in phase with the ringing response of the auditory filter. Thus, the dip in the auditory filter increases monotonically with increasing gap duration and the psychometric function is monotic.

Shailer and Moore (1987) found that the gap threshold was roughly constant at about 5-msec for center frequency of 400, 1000 and 2000Hz. Moore et al (1993a) measured gap thresholds for center frequency of 100, 200, 400, 800, 1000, and 2000Hz, using a condition similar to the preserved phase condition of Shailer and Moore. The gap thresholds were almost constant at 6 to 8 msec over the frequency range 400 to 2000Hz, but increased somewhat at 200Hz and increased markedly, to about 18 msec, at 100Hz. Individual variability also increased at 100Hz.

Over all, while the auditory filter seems to play a role in determining the form of the results for the standard-and reversed phase conditions, gap threshold estimated from the preserved phase condition do not show a strong effect of center frequency except at very low frequency (200Hz and below). It appears that ringing in the auditory filter only limits gap detection for sine waves at very low center frequencies.

The gap detection experiment with sinusoidal marker was reported by Williams and Perrott (1972) for a condition where the silent gap was positioned temporally between pairs of sinusoids of different frequencies. They measured gap detection for sinusoidal markers as a function of marker duration and frequency separation. It was reported that for sinusoidal markers of 100 and 300 msec duration, silent gap became more difficult to detect in the frequency separation between two markers, which were spaced equidistantly above and below 1000Hz, was increased from 8 to 480Hz. For shorter marker duration (3, 10, and 30 msec), the gap detection thresholds were essentially independent on frequency separation.

Puretone signal has the advantage that the gap detection threshold will not be affected by fluctuations in the noise. As Glassberg et al (1987) have pointed out, listeners have to discriminate the occurrence of the gap from the local fluctuations in the amplitude envelope that occur with band limited noise. Because there are no changes in the amplitude envelope of a puretone, a gap in a puretone should be easier to detect than a gap in a band limited noise. The use of signals constructed from puretones precludes the frequency specification problems of Broadband noise and the amplitude fluctuations of narrowband noise.

Detection of silent temporal gaps is characterized by two prominent features, when measured as a function of frequency separation between two sinusoids that mark the onset and offset of a silent gap. First, over a range of about a half octave to an octave separation, Temporal Gap Detection (TGD) thresholds measured for monaural presentation routinely increase as the frequency of the post gap marker (F2) is increased relative to a lower frequency pre gap marker (F1) (Neff et al 1982; Formby and Forrest, 1991; Formby et al 1996). Second, TGD thresholds tend to become asymptotic for greater sinusoidal marker frequency separations (Formby et al 1996). This characteristic TGD pattern probably reflects two different processes. The first process almost reflects a TGD cue i.e. based on the output of a single auditory filter or channel (Williams and Perrott, 1972; Formby and Forrest, 1991; Formby et al 1996; Phillips et al 1997). The nature of second process is less certain, but may reflect across–frequency between channel processing of the silent gap stimulus in two or more independent frequency channels (Viemeister and Phillips, 1993; Phillips et al 1997).

Formby, Gerber, Magder and Sherlock (1998) concluded that;

1) For small marker frequency separations (i.e. F2/F1 ratios less than or equal to 1.15), MONOTIC TGD thresholds were several folds smaller than DICHOTIC TGD thresholds.

2) MONOTIC TGD thresholds deteriorated with increasing marker frequency separation for F2/F1 ratios less than or equal to 1.24, where as DICHOTIC TGD thresholds were relatively invariant with increasing marker frequency separation.

3) For marker frequency separations greater than or equal to half an octave (i.e. F2/F1 ratios greater than or equal to 1.15) the MONOTIC TGD threshold function for each condition of F1 (250, 500, 1000, 2000 or 4000Hz) became asymptotic and converged with the corresponding DICHOTIC TGD threshold function.

4) These findings support the hypothesis that across frequency, between–channel processes can explain asymptotic TGD thresholds measured by MONOTIC stimulus presentation at marker frequency separations greater than about half an octave for F2 marker frequencies greater than the standard F1 marker frequency.

Regardless of the type of signals–puretones, broadband noise or Narrowband noise – those that are continuous are likely to produce substantial adaptation prior to the introduction of the gap (Harris and Dallos, 1979; Westerman and Smith, 1984). To the extent that gap detection based on an onset responses to the reintroduction of the stimulus, greater adaptation will be associated with lesser sensitivity to the gap. Consequently, differences in adaptation (and recovery from adaptation) across test procedures and age groups may confound the measurement of gap detection thresholds.

The effect of a difference in a marker frequency has generally been attributed to the frequency selectivity established in the auditory periphery and has also been modeled in the study (Forrest and Formby, 1996). When the two marker frequencies are the same or very similar, the markers stimulate the same region of the cochlear partition, which in turn leads to responses from the same population of auditory nerve fibers. Thus any perceived interruption (fluctuation, onset or offset) in the stimulus is a reliable cue for detecting the gap. When the two markers have different frequencies, they are separated in the cochlea such that they maximally stimulate different places along the cochlear partition, which in turn leads to different population of auditory nerve fibers responding to each frequency. In this case, the offset of the first tone and the onset of the second are always perceived, whether the gap is present or not. Thus the perceived onset or offset is no longer a reliable cue and the gap can only be detected by timing comparison across different neural channels (e.g., Hanekom and Shannon, 1998). These two cases are often referred to as "within-channel " and between-channel gap detection responses.

This explanation relies on the fact that stimulus frequency is a neurally and perceptually relevant dimension; if the auditory system was not frequency selective, then no discontinuity between two markers would be perceived, regardless of frequency difference.

Similarly, gap detection might be used to probe other, higher level, organizational principles in the auditory system. Two dimensions that are known to have neural representations established at a level higher than the cochlea are spatial location (Moore, 1991; Brainard, 1994) and periodicity (Langner, 1992). Phillips et al (1998) reported an influence of spatiatal perceptual channels on gap detection.

2) Effect of noise burst duration: -

In many auditory perception tasks, performances decrease with increased stimulus duration (Moore, 1973; Viemeister, 1979; Hall and Fernandes, 1983), thus suggesting a common underlying temporal integration process. However, reports of the effect of noise burst duration on gap detection are inconsistent.

Muchnik (as cited in the He et al 1985) showed that Gap Detection Thresholds of young normally hearing subjects increased as noise burst duration decreased from 85 to 10 msec.

Ning–Jittle, Horwitz, Dubno, and Mills (1999) reported that when the gap was located at the center of the noise burst, the noise–burst duration had a significant effect on the gap threshold, but the effect was not age related. For both young and aged subjects, gap threshold decreased with increasing stimulus duration.

3) Effect of location and uncertainty of gap on speech perception: -

A few studies examined the effect of temporal location of the gap within a noise burst and the effect of randomness of the gap location.

Forrest and Green (1987) measured gap thresholds with the gap fixed at 10, 30, 50, 70 or 90 msec after onset of a 100 msec burst. They found that the location had essentially no effect on gap threshold except for the location of 30 msec, where the detection threshold was slightly lower. However, an early study (Penner, 1977) showed that when the second noise burst duration was kept constant (2 msec), the detectability of gap between two noise bursts was decreased by increasing the duration of the first noise burst. In this paradigm, changing the duration of the noise burst actually changed the relative location of the gap. Thus the effect of varying location of temporal gap within a noise burst remains unclear.

Gap stimuli used in psycho–acoustic studies are acoustically analogous to voice–onset-time for consonants in speech. However, unlike conventional gap detection paradigms, where the gaps are typically fixed at the center of a stimulus burst, the acoustic gap in a continuous speech stream occur pseudo random at different locations. These differences in paradigm might explain the poor correlation between speech perception and gap detection noted in some studies, especially for aged subjects (Strouse, Ashmed, Ohde and Granthm, 1998).

The general placement of the psychometric function does not appear to be affected by the randomness of the gap location. For all subjects, there was an overlap in the functions measured in the fixed and random condition (Green and Forrest, 1989). The condition related difference was smaller than the between subject variability, indicating high reliability of individual subjects performance. Below 50% point (i.e. at the shorter gap duration), differences between the two functions were minimal which resulted in small differences in threshold. The most obvious difference was the reduced detectability at longer gap duration in some subjects, which resulted in shallower slopes of the function for the random as compared to the fixed condition.

Green and Forrest (1989) observed that gap threshold with random gap location were 1.3 to 1.5 times higher than those with a fixed gap location. Performance on gap detection threshold varies for various gap locations e.g., 5%, 50% or 95% of total burst duration.

When the gap was at the center of the noise burst (50% and middle panels), gap detection was independent of the uncertainty of gap location for both young and aged subjects. Furthermore, there was only a small difference in performance between two groups in either condition. When the gap was located away from the center position to the two extreme ends locations (5% and 95%), performance declined.

In the fixed condition (when the gap location is fixed trail to trail, at either 5%, 50% or 95% of total duration of narrow band), the functions for the 5% and 95% gap locations shifted towards larger gap duration, compared to the 50% location. Also at the fixed 95% location elderly subjects were unable to perform this task. Thus, for aged subjects only, gap thresholds were significantly lower at the middle location than at the end location, and were significantly lower at the 5% location than at the 95% location.

In summary, the significant main effect of age was due to the significantly higher gap threshold of the aged subjects when the gap was at the end locations and was presented randomly. Comparing only the 50% location with the 27.5% and 72.5% locations, the analysis revealed that the difference in slope was not significant for either young or aged subjects. When the gap was located sufficiently away from both ends of the burst (e.g., 27.5% and 72.5%) perception was robust, regardless of the uncertainty about the gap location.

4) Effect of signal onset and offset: -

Effect of onset and offset are basically independent of noise burst duration. Effect of signal onset and offset on gap threshold is seen more in aged subjects than in young subjects. If the gap is located near the onset and offset, it results in poor detection (Fitzgibbons and Wightman, 1982; Irwin, Hinchcliff and Klump, 1981; Florentine and Buus, 1984).

5) Subject related factors: -

a**)** **Effect of subject's age: -**

The studies that have examined the gap threshold in infants and children have all reported age differences.

Werner, Marean, Halpin, Spetner,and Gillenwater (1992) found that the gap thresholds in 3, 6, and 12 months old infants were approximately 60 msec in contrast to gap thresholds of approximately 5 msec in adults. There was a little difference among infants at different ages, although variability was high among 12 month old and some of these had gap thresholds that were close to adult values.

Trehub, Schneider, and Henderson (1995) measured the gap detection threshold for 6.5 months, 12 months, 5 years and 21 years of age. They found the gap-detection threshold at 11, 5.6, and 5.2 msec for infants, children and adults, respectively. It is likely that smaller–adult–infant differences in their study compared to those reported in previous research stem from their use of Gaussian–enveloped tone pips and the consequent minimization of adaptation effects.

The result of Irwin (1985) and Wightman (as cited in Formby and Forrest, 1991) disagree on the age at which gap threshold mature. Irwin found that gap threshold was not mature, until 10 to 12 years, whereas, Wightman obtained adult–like gap threshold among 5 to 7 years old.

Schneider (as cited in Schneider, Fuller, Kowalchuk & Lamb 1994) reported that gap thresholds of elderly subjects were more variable and about twice as large as those from young subjects in all conditions studied i.e. older subjects have poor temporal resolution. It remains unclear, whether the decreased temporal acuity reported for the older subjects reflects age related changes alone or interaction between age and hearing loss. Older listeners with and without hearing loss often experience difficulty-understanding speech (WGSUA, 1988).

Studies on the effect of age on temporal resolution are motivated in part by the search for auditory factors that contribute to difficulties in speech understanding experienced by elderly individuals (CHABA, 1988; as cited in the He et al 199). Many studies (Van Rooij and Plomp, 1990; Dubno, Dirks and Morgan, 1984) have reported that reduced audibility of speech signal can account for a large portion of the difference between young and aged subjects. This conclusion is applicable to speech recognition with no temporal waveform distortion. Confounding factor in measuring temporal resolution for elderly subjects may be hearing loss, which is commonly associated with age. Numerous studies have reported degraded gap detection ability associated with sensorineural hearing loss (Fitzgibbons and Wightman, 1982; Irwin 1981; Florentine and Buus, 1984). However, there is a relatively large body of evidence showing age related differences in the perception of temporally distorted speech.

In a series of studies (Gordon–Salant and Fitzgibbons, 1993), a robust aging effect was observed in recognition of speech stimuli modified by several temporal factors such as speech rate, time compression and reverberation. These observations suggested that impaired temporal resolution might contribute to diminished speech perception of the aged subject, though straight forward relation between speech perception and temporal resolution that has been established (Tyler et al 1982; Glassberg and Moore, 1988; Strous et al 1988).

Lutman (1991) found that gap detection deteriorated with hearing loss but not with age for three groups of subjects aged 50–59, 60–69 and 70–79 years. However, using a related paradigm, Fitzgibbons and Gordon–Salant (1995) measured difference limen for gaps from both young and aged subjects with or without hearing loss and reported that elderly listener performed more poorly than young listeners and that hearing loss had no systematic effect on gap detection. Thus, the effects of subject's age on gap detection ability are not clear.

Snell (1997) studied the age–related effects on temporal resolution by precisely matching young and old subjects with normal hearing and measuring gap thresholds in a variety of listening conditions. Younger subjects were between 17 and 40 years of age, older subjects between 64 and 77 years. Signals were noise bursts, which varied in upper – cut off frequency, overall frequency and sinusoidal–amplitude–modulation depth. Signals were presented in quiet, noise floor and with a gated–high–frequency masker in noise floor. Mean gap thresholds ranged between 2.1 and 10.1 msec and were larger for the older subjects in all 24 conditions. In some conditions, introduction of a noise floor increased the gap thresholds of the younger. He concluded, that mean differences between groups reflect shifts in the distributions of gap thresholds of the older subjects towards poorer temporal resolution

Moore et al (1992) measured thresholds for detection of temporal gaps in sinusoidal signals as a function of frequency in elderly hearing impaired subjects and elderly subjects with near normal hearing (audiometric thresholds less than equal to 25dBHL from 205 to 2000Hz). Results were compared to previous data collected from young normal hearing subjects (Moore et al 1993), revealing that elderly with near normal hearing had higher gap detection thresholds than young subjects. Moore et al (1992) attributed this result to the inclusion in the elderly group of some individuals who had large gap detection thresholds. Nevertheless, when they compared gap thresholds in elderly subjects with near normal hearing to those with hearing impairment, they found no difference between the two groups. Schneider et al (1994) reached a similar conclusion.

Snell (1997) measured Gap Detection Thresholds for noise burst stimuli in young and elderly listeners with puretone thresholds less than or equal to 20dBHL from 250–4000Hz. Again, gap thresholds were significantly larger in elderly subjects. Thus the studies agree in that all found some elderly individuals who exhibited losses in temporal resolution that were unrelated to degree of hearing loss. Therefore it is reasonable to consider factors other than peripheral hearing loss that could account for age related differences in monaural temporal resolution.

Strouse, Ashmead, Ohde and Grantham (1998) measured monaural temporal processing by gap detection threshold and binaural sensitivity by inter aural time difference (ITD) thresholds for 12 young (Mean age = 26.1 years) and 12 elderly (mean age = 70.9) adults with normal hearing (puretone thresholds less than or equal to 20dBHL from 250–6000Hz). Gap and ITD thresholds were obtained at three sound levels (4, 8, or 16 dB above individual threshold). Subjects were also tested on two measures of speech perception, a masking level difference (MLD) task, and a syllable identification or discrimination task that included phonemes varying in voice onset time (VOT).

Elderly listeners displayed poorer monaural temporal analysis (higher GDT) and poorer binaural processing (higher ITD thresholds) at all sound levels. There were significant interactions between age and sound level, indicating that the age difference was larger at lower stimulus levels.

Gap detection performance was found to correlate significantly with performance on the ITD task for young, but not for elderly adult listener; elderly listeners on both speech measures; however, there was no significant correlation between psycho acoustic and speech measures on temporal processing. Findings suggest that age–

related factors other than peripheral hearing loss contribute to temporal processing deficits of elderly listeners. .

Studies suggest that reduced within channel and across channel temporal resolution in older listeners may occur independent of peripheral hearing sensitivity (Fitzgibbons and Gordon–Salant, 1994; Lister, Besing and Koehnke, 2000). This effect is attributed to age related changes within central auditory system and to slowed auditory processing (e.g., Fitzgibbons and Gordon–Salant, 1994,1999; Salthouse, 1985). Although the findings of Phillips et al (1997) and Formby et al (1998) were support the existence of centrally located perceptual channels, some evidence exists for a peripheral attribution to deficits of temporal resolution (Fitzgibbons & Wightman, 1982; Glassberg, Moore and Bacon 1987).

Lister, Besing and Koehnke (2002) hypothesized that perceptual channels that appear to narrow with age are not limited by peripheral auditory filter widths but are influenced by both peripheral and central encoding mechanism that become less acute with age.

Clear age related changes in within channel and frequency disparate gap detection have been documented that appears to be unrelated to the hearing sensitivity of the participants (e.g., Fitzgibbons and Gordon–Salant, 1994, 1995; He, Horwitz, Dubno, and Mills, 1999; Lister et al 2002; Schneider, Pichora–Fuller, Kowalchuk, and Lamb, 1994).

It is demonstrated that the deterioration in gap perception that occurs with increase in marker frequency disparity is more pronounced for older listeners than young listeners, regardless of hearing sensitivity (Fitzgibbons and Gordon–Salant, 1994; Lister et al 2000, 2002).

b) Gap detection in hearing impaired listeners: -

The normal auditory system is remarkable in its capacity to extract and encode temporal features of a stimulus waveform. Psychophysical evidence indicates that trained normal hearing observers can discriminate fluctuations in a waveform that occur in time intervals as brief as 2 to 3 msec. Resolution thresholds in this range come from several studies that were designed to measure auditory temporal acuity (Miller and Tyler, 1948; Plomp, 1964; Green, 1973).

Relatively little is known about temporal acuity in impaired auditory systems, or the extent to which deficits in this capacity might affect ability of hearing impaired observers to process complex time varying stimuli such as speech. Since it is generally assumed that the sensation persists around the physical extent of the stimuli, the threshold gap is presumed to be a measure of the time required for sensation to decay some just noticeable degree during the time interval.

Many listeners with sensorineural hearing loss have difficulty detecting a brief pause, gap, in a continuous noise (Boothroyd, 1973; Cudahy, 1977; Fitzgibbons and

Wightman, 1982; Giraudi–Perry, Salvi and Henderson, 1982; Irwin, Hirnchcliff and Kemp, 1981; Irwin and Purday, 1982; Tyler, Summerfield, wood and Fernandes, 1982).

One explanation for this finding is that some of the information required to perform the task is below the impaired listeners absolute threshold (Boothroyd, 1973). Experiments on gap detection in octave band of noise have shown that temporal resolution is much better at high than at low frequencies (Buus, Florentine, 1982; Florentine and Buus, 1983; Fitzgibbons and Wightman, 1982). This indicates that the high frequencies are responsible for the detection of gap in a broadband noise and that impaired listeners may have enlarged gap thresholds because they simply cannot hear the high frequency part of the white noise. In fact, limiting the temporal gap to frequency below 2 KHz increases the Minimum Detectable Gap (MDGs) in normal listeners to values similar to those observed in listeners with high frequency hearing impairments (Florentine and Buus, 1982). These findings point to the role of audiometric configuration in gap detection. In addition to important parts of the signal being inaudible, it is also possible that hearing impaired persons truly have reduced temporal resolution.

Study of temporal resolution in ears with sensorineural impairment has not been pursued extensively. Cudahy and Elliott (as cited in He et al 1999) inferred from data that some listeners with sensorineural impairment have reduced temporal resolving capacity.

Cudahy (as cited in He et al 1999) also reported cases of elevated gap threshold in subjects with high frequency hearing loss. Large inter-subject variability in the performance of hearing impaired listeners is cited in many of these reports. The gap threshold of the hearing impaired subjects are significantly greater than those of normal hearing subjects. This condition holds whether the comparison to normal resolution made for signals of equivalent SPL or equivalent SL and at each octave band frequency the gap thresholds of all subjects decreased systematically as the octave band frequency increased. The magnitude of threshold shift between the signal condition is greatest for the hearing impaired subjects, but did not prove to be significantly different from that of normal hearing subjects if the comparison is made for condition equivalent SL. This data indicate that temporal resolving capacity is not independent of stimulus spectral characteristics and also with frequent observation the temporal capacity is independent of signal level, once exceeded some minimum value.

Temporal resolution in hearing impaired subjects is clearly poorer than normal. The deficit with condition equaled for SL must be attributed to processing distortion imposed by cochlear damage. In terms of current thinking about gap detection, this finding might indicate increased persistence of sensation in the cochlear impaired listeners. This of course does not specify an underlying mechanism and presumes also that the criterion just noticeable decay in sensation is the same for normal hearing and cochlear impaired subjects exhibit effectively narrower peripheral filtering mechanism.

Two main effects can be observed regarding temporal processing in hearing impaired listeners.

1) It appears that for normal listeners, the signal level has an important influence on temporal resolution. This necessarily implies the existence of an inverse relationship between degree of hearing loss and the optimum temporal resolution that can be expected with stimulation held constant in terms of SPL; of course the characteristics of such a relationship may vary with stimulus frequency band.

2) The influence of signal frequency content on subject's performance suggests that the configuration of hearing loss may be a determining factor of temporal resolution in other hearing impaired listeners. That is the maturity of cochlear impaired listeners shows greater sensitivity losses at the higher audiometric test frequencies. These same frequency regions may prove to be dominant for temporal resolution. This is an outcome which, if confirmed would impact a relative disadvantage (re: optimal normal acuity) in temporal processing to these listeners.

Several groups of workers have reported that at the threshold for the detection of temporal gaps in noise stimuli are usually larger for subjects with cochlear hearing impairments than for normally hearing subjects. This is true both for broadband noise stimuli (Irwin, Hinchicliff and Klump, 1981; Florentine and Buus, 1984) and for bandpass noise stimuli presented in a broadband or band stop background (Fitzgibbons and Wightman, 1982; Tyler et al 1982; Buus and Florentine, 1985). However, in making comparison between normal and impaired hearing, two important factors have to be taken in to account. The first is the effective frequency range available to the subject. There is a considerable evidence that for normal hearing subjects, threshold for the detection of gaps in band limited noise decreases with increasing center frequency and increasing band width (Fitzgibbons and Wightman, 1982; Shailer and Moore, 1983,1985).

Fitzgibbons, 1983; Shailer and Moore, 1983 and Buus and Florentine, 1985 argued that for normal subjects, gap detection for noise bands at low center frequencies is partly limited by "ringing" in the auditory filter. This could account for the increase in gap threshold with increasing center frequency. If this is so, it is expected that subjects with cochlear impairments would be better than normal at gap detection, since their auditory filters are usually broader than normal and would therefore be expected to ring for shorter time.

Auditory filter of subjects were broader in their impaired ear than in their normal ear (Glassberg and Moore, 1988). The fact that gap detection is not better for impaired ears suggests that some factor other than ringing in the auditory filter limits performance for impaired ears. One possible explanation for the decrease in gap thresholds with increases in center frequency is that the inherent fluctuation in the noise becomes less confusable with gap as the noise bandwidth passing through the auditory filter increases. The second possibility is that, inspite of relatively flat audiograms of the subjects the functioning of their cochlea was more disrupted towards the apical end than towards the basal end.

For broadband stimuli, it appears that subjects primarily use information from the highest frequency region available (Shailer and Moore, 1983,1985). For subjects with high frequency hearing loss, the performance might be poorer simply because the higher frequency component in the stimuli are inaudible (Bacon and Viemeister, as cited in Brain, Glassberg and Moore, 1986). This would decrease both the effective bandwidth and the effective upper cut–off frequency.

When making comparison between normal and impaired hearing listeners based on the level at which subjects are tested, gap threshold decreases with increasing level both for normal and for impaired subjects (Shailer and Moore, 1983; Florentine and Buus, 1983, 1984; Buus and Florentine, 1985). It remains unclear whether impaired and normal subjects should be compared at equal SL, at equal SPL or some other level such as equal loudness.

Some factors that influence the Gap Detection Threshold have been identified. First, studies with band passed noise reveal that gap detection thresholds depend more on the bandwidth of the stimulus, than its center frequency (Eddins, Hall & Grose, 1992). This perhaps reflects the greater information transmitted to the central nervous system (Grose, 1991; Hall, Frose and Joy, 1996). There is an agreement that, under optimal conditions, i.e. using wide band or high frequency signals; minimal detectable gaps are in order of a few milliseconds (Plomp, 1964; Fitzgibbons and Wightman, 1982; Fitzgibbons, 1983; Florentine and Buus, 1984). Second, there is some evidence that the gap detection performance supported by apical regions of the cochlea is relatively poor. This is likely because of the greater stimulus uncertainty, (i.e. inherent fluctuations in the low frequency stimulus envelope that might be confused with an intended gap in the stimulus), longer integration time, or slower decision processes within low frequency central perceptual channels and in extremely low frequency (less than 200Hz). Perhaps because the narrower filters of the low frequency; cochlea has longer response times ("ringing") (Moore and Glassberg, 1988).

In gap detection paradigm, the temporal task is actually discontinuity detection within a perceptual channel. Information about the stimulus perturbation offset of the sound that defines the leading edge of the gap and onset of the sound defining the trailing edge of the gap and it can presumably be carried by any all of the afferent nerve fibers, and their central projections, innervating the cochlea at the locus or loci representing the stimulus content. It is the "within channel" features of the processing which renders a neural correlate of gap detection visible in recordings from single cochlear nerve cells. Much behaviorally important temporal discrimination, however, are not strictly of this kind. In many instances, the gap to be detected is delimited by spectrally different markers. This requires a relative timing operation to be performed on a activity between different perceptual channels. In the case of discriminating the voice–onset–time in stop consonants, for example, the task is to judge the relative timing of the consonantal burst and subsequent vowel.

Conceptualized with a gap detection paradigm, the task of the listener in such instances superficially remains the same (“ which stimulus combination contains the gap?”). But the mechanisms that mediate the perceptual response in the two paradigms are likely to be different. The cochlear nerve array as a whole may contain information about the relative timing of the elements (Carnacy and Geisler, as cited in Snell, 1997) but does not contain any machinery capable of executing the relative timing operation, since there are no lateral neural connections between cochlear output fibers. Only if there is significant spectral overlap between the stimulus defining the gap can a single neural channel carry information about the timing of the silent period. To some extent, these situations exist in speech signals (Sinex & Mc. Donald, 1988; Sinex and Narayan, 1994). In the extreme case of the stimulus elements, having no spectral over lag, however, the relative timing operation must presumably performed centrally.

In this regard, there is behavioral evidence that the introduction of a spectral disparity between relatively low frequency stimuli defining the leading and trailing edges of the gap, in the gap detection stimulus, results in significantly impoverished gap detection performance (Neff, Jesteadt & Brown, 1982; Formby and Forrest, 1991). These findings are consistent with the view that there may be something fundamentally different about the perceptual process involved in within the channel and between the channel gap detection.

Schneider, Pichora–Fuller, Kowalchuk and Lamb (1994) investigated threshold for detecting a gap between two Gaussian–envelopes (S.D. = 0.5 ms), 2 KHz tones were determined in young and older listeners. The gap detection thresholds of old adults were more variable and about twice as large as those obtained from young adults. Moreover, gap detection thresholds were not correlated with audiometric thresholds in either group. The larger gap detection thresholds of old subjects indicate that they may have larger temporal windows than young subjects. The lack of correlation between audiometric and gap detection thresholds indicates that this loss of temporal acuity is not revealed to the degree of sensorineural hearing loss.

The minimum detectable gap duration, MDG, in a low–pass (cut–off at 7 KHz) noise measured monaurally as a function of sound pressure level in six listeners with normal hearing, seven listeners with hearing impairments of primarily cochlear origin, and eight with impairments simulated by masking. The impaired listeners MDG s at 80 and 90 dB vary from about 3.5 msec (equal to normal MDG) to about 8 msec and show little correlation with their average hearing loss. At lower levels, the MDG is enlarged for all impaired listeners owing to the decreased sensation level of the noise. However, at high levels, some impaired listeners performed worse than their simulated loss counterparts, indicating that temporal resolution per se may be reduced in some, but not all, impaired listeners (Florentine and Buus, 1984).

Lister et al (2000) measured the overall gap thresholds for older listeners with sensorineural hearing loss (four subjects aged 62–71 years) and without hearing loss (three subjects aged 42–51 years); then young listeners with hearing loss (two subjects aged 21–26 years) and with out hearing loss (three subjects aged 22–26 years). The gap detection thresholds for older listeners increased more dramatically with marker frequency disparity than those of young listeners whose gap thresholds remained stable for small frequency disparity regardless of hearing loss. They suggested that the effect of marker frequency composition on temporal discrimination was greater for older listeners with and without hearing loss that for younger listeners with or without hearing loss.

Glassberg, Moore and Bacon (1987) did two experiments. In first experiment, gap thresholds were measured for 9 unilateral and 8 bilateral impaired subjects, using band limited noise stimuli centered at 0.5, 1.0, and 2.0 KHz. Gap thresholds were usually larger for the impaired ears, even when the comparisons were made at equal Sensation Levels (SLs). Gap thresholds tended to increase with increasing absolute threshold, but the scatter of gap threshold was large for a given degree of hearing loss. In experiment two, threshold was measured as a function of the delay between the onset of 250 msec masker and the onset of a 10 msec signal in both simultaneous and forward masking conditions. The signal frequency was equal to the center frequency of band limited noise masker, which was 0.5, 1.0, and 2.0 KHz. Five subjects with unilateral cochlear impairments; two subjects with bilateral impairments and two normal subjects were tested. The rate of recovery from forward masking particularly the initial rate, was usually slower for the impaired ears, even when the maskers were presented at equal SLs. Large gap thresholds tended to be associated with slow rates of recovery from forward masking.

Fitzgibbons and Wightman (1982) measured the gap detection threshold in five normal hearing and five cochlear impaired listeners. The signals were octave band noises (400Hz–800Hz, 800Hz–1600Hz, and 2000Hz–4000Hz) presented in a background of continuous, broadband-notched noise that was applied to eliminate unwanted spectral cues. Temporal resolution in all listeners showed systematic improvement with an increase in octave–band center frequency. Resolution in the hearing impaired subjects was significantly poorer than normal regardless of whether the comparisons were made at equal sound pressure level or at equal sensation level. However, studies showing a normal gap resolution by listeners with sensorineural hearing loss (Grose et al and Lister et al 2000) and impaired gap resolution by listeners with normal hearing (Fitzgibbons and Gordon–Salant, 1994; Lister et al 2002) seem to suggest that hearing sensitivity alone does not determine temporal resolution.

c) Language disability and gap detection: -

The ability to process two or more rapidly presented, successive, auditory stimuli are believed to underlie successful language acquisition. Likewise, deficits in rapid auditory processing of both verbal and non-verbal stimuli are characteristic of individuals with developmental language disorders such as Specific Language Impairment. Auditory processing abilities are well developed in infancy and thus such deficits should be detectable in infants.

Individuals with developmental language disabilities, including developmental dyslexia and specific language impairment (SLI), exhibit impairments in processing rapidly presented auditory stimuli. It has been hypothesized that these deficits are associated with concurrent deficit in speech perception and, in turn, impaired language development.

Developmental language disabilities, such as developmental dyslexia (specific reading disability) and specific language impairment (SLI), are characterized by significant limitation in reading and or language development and ability without the presence of an overt underlying condition such as low overall IQ or impaired hearing. Moreover, individuals with developmental language disabilities typically exhibit deficits in speech perception and, more specifically, processing of phonemes incorporating rapid change (e.g., stop consonants). Interestingly, this processing impairment has been observed for non–linguistic stimuli as well. For example, Tallal and Piercy (as cited in Zeng, Oba, Grade, Sininger and Starr, 1999) demonstrated that normal children were able to discriminate two 75 msec tones separated by an inter stimulus interval (ISI) as short as 8 msec, while the individuals with SLI required an ISI exceeding 300 msec to perform the same discrimination at the same level of accuracy. Similar rate specific auditory processing deficits have been observed in dyslexics behavior and neurophysiology, using both speech and non speech stimuli. These accumulated findings overwhelmingly support the view that individuals with developmental language disabilities have fundamental dysfunction in the ability to process brief auditory stimuli followed by other acoustic information (i.e., rapid auditory processing). Indeed, in a review of studies on SLI, Leonard (as cited in Zeng et al 1999) writes: “Among the most enduring findings in the literature on SLI is the finding that children with SLI perform quite poorly on tasks requiring the processing of brief stimuli sand the processing of stimuli that are presented in rapid succession.”

These findings have been assimilated into theoretical framework advanced by Tallal and colleagues (as cited in Zeng et al 1999). This model predicts that an impaired ability to process and discriminate rapidly changing auditory information will lead to severe impairments in speech perception, particularly for phonemic signals that incorporate rapid change (i.e., formant transitions). This causal association is supported by evidence that non-lingual auditory processing thresholds in infants and toddlers predict significantly to later language outcome. Such a bottom–up model of speech and language development also predicts that speech perception deficits will exert cascading developmental effects on phonological representation and phonological–orthographic association (i.e., reading acquisition), a notion supported by evidence that more than 80% of SLI children go on to develop reading impairments. This model forms one framework within which we can characterize the association between focal cortical malformations as seen in language-disabled populations, using an animal model. Interestingly, individuals with developmental language disabilities do not show equivalent deficits on all rapid auditory processing tasks. For instance, no group difference in gap detection threshold was found for adults with developmental dyslexia as compared to control adults. Conversely, infant gap detection thresholds do predict significantly to later language performance in toddlers, and gap detection thresholds appear to be significantly higher for SLI and reading disabled children as compared to control children. Since gap detection tasks are generally accepted as a means to assess temporal auditory acuity, these conflicting results suggest that temporally dependent auditory deficits associated with developmental dyslexia and SLI may interact with the stimulus characteristics of specific task, as well as task difficulty or demand (which in turn may be age dependent). Clearly, further characterization of task and stimulus parameters which elicit processing deficits might help in pinpointing the neurobiological basis for these deficits, as well as providing neurobiological insight into the top level behavioral profile comprising language disability.

d) Oto acoustic emissions: -

.Smurzynski and Probst measured gap detection for two groups of normal hearing adults. Group 1 consisted of subjects who exhibited both strong spontaneous otoacoustic emissions (S.O.A.E) and click–evoked otoacoustic emissions (C.E.O.A.Es). Group 2 included individuals with no S.O.A.Es and weak C.E.O.A.Es. Noise stimuli with a bandwidth of either 0.1 to 12 or 0.1 to 4 KHZ were presented through an insert earphone. An adaptive 2 IFC procedure was used to determine the hearing threshold of the stimuli for each ear tested. Next, an adaptive 2 IFC gap detection task was performed for the stimuli presented at either 10 or 20 dB SL. The levels of 30 and 50 dB SL were also tested for the broader stimulus. They found that gap detection thresholds decreased with broadening the stimulus spectrum in agreement with other studies. They found that at the stimulus levels of 10 or 20 dB SL, the ears in Group 1, exhibited higher mean gap detection thresholds than those in Group 2, for both bandwidths. This suggests that strong OAE activity creates an internal noise that masks the gap in a signal presented near the hearing threshold. The results at the stimulus levels of 30 and 50 dB SL did not show any difference between the two groups and were consistent with the data in the literature. These results suggest that for higher stimulus levels, strong OAE activity is suppressed by the test signal. The gap detection threshold is shorter than the time needed to recover from suppression and thus there is no difference in the gap detection in subjects with highly contrastive OAE profiles.

Gap Detection in Cochlear Implant Users

In cochlear implant users, Chatterjee et al (1998) observed that “within–channel” gap detection thresholds increase when the stimuli marking the gap were of unequal amplitude or unequal pulse rate. They concluded that the perceptual discontinuity caused by dissimilar markers complicated the gap detection task, and suggested that under these conditions gap detection thresholds may be a function both of limitations caused by peripheral mechanisms and a central perceptual distance detector. Their results also emphasize the importance of loudness balancing the stimuli marking the gap.

Shannon (1989) measured gap detection thresholds in cochlear implant users as a function of stimulus level, for both closely spaced (bipolar) and widely spaced (monopolar) electrode configurations, using sinusoids and pulsatile stimuli. He found that gap detection thresholds were a strong function of stimulus level, with the shortest gap thresholds in the order of 1.5 to 3.1 msec regardless of the separation between the active and reference electrodes. He concluded that the temporal resolution for implant subjects was as good as or better than for normal hearing listeners. However, all measures were made with the stimuli marking the gap on a single electrode pair, i.e., no cross–channel gap detection was done.

Hanekom and Shannon (1998) measured the gap detection threshold in three users of Nucleus cochlear implant. Gap detection thresholds were measured as a function of the distance between the two electrode pairs and as a function of the spacing between the two electrodes of a bipolar pair (i.e., using different modes of stimulation).

Their results indicated that measuring gap detection thresholds was a function of the physical separation of the electrode pairs used for the two stimuli that bound the gap. Lower gap thresholds were observed when the two electrode pairs were closely spaced, and gap thresholds increased as the separation increased, resulting in a "psychophysical tuning curve" as a function of electrode separation. The sharpness of tuning varied across subjects, and for the three subjects in their study, the tuning was generally sharper for the subjects with better speech recognition. Their data also indicate that increasing the separation between active reference electrodes has limited effect on spatial selectivity (or tuning) as measured perceptually. From their study they concluded that;

1) Gap thresholds increase from a minimum when the two stimuli are presented on the same electrode pair to a maximum when the two stimuli are presented on widely separated electrode pairs. This change may be due to a changeover from a peripheral, within–channel gap detection process for widely spaced electrode pairs.

2) When the two marker bursts are presented to the same electrode, gap detection thresholds are similar across subjects at 1 to 4 msec. Gap thresholds for widely separated electrodes vary considerably among subjects and may be related to speech recognition performance, with better implant users having lower gap thresholds in this condition.

3) The area of neural activation by each electrode (as inferred from the width of the tip region of the gap detection tuning curves as a function of electrode pair separation) varies across subjects and across electrodes. For the three subjects in the study, the better implant users exhibit sharper tuning, i.e., a smaller area of neural activation around each stimulation pair.

4) Using stimulation modes with larger separation between active and reference electrodes has limited effect on spatial selectivity. AR (apical reference) stimulation mode, although presumably having larger current spread, has better neural selectivity than BP (bipolar) mode for some subjects. This implies that there is no fixed optimal

stimulation mode, but that the optimal stimulation mode may vary across subjects and from one end of the electrode array to the other.

Electro Physiological Tests and Gap Detection

Compared with the large number of psycho acoustic investigation on gap detection paradigm, only few electro physiological studies have been carried out. The following are some of the electro physiological tests, which were used to study the temporal resolution.

1) Mismatch negativity (MMN): -

Probst (2002) investigated the effects of aging on temporal resolution, the electrophysiological and psychoacoustic detection thresholds for a very short silent gap with in a puretone were determined and the relation between the two test results were examined. Behavioral gap detection thresholds were determined in ten young and ten elderly normally hearing subjects using an adaptive test procedure. To elicit Mismatch Negativity (MMN), deviant stimuli with gap durations varying from 6 to 24 msec in 3 msec steps were presented in separate test blocks. They found no significant differences in the psychoacoustic gap detection thresholds between young and elderly subjects. In contrast, longer gaps were needed to elicit MMN in elderly subjects. They also had significantly reduced MMN peak amplitudes, increased MMN peak latencies, a significantly smaller P2 amplitude and longer P2 latency in their responses to the standard stimulus when compared to the same measures in young subjects. They concluded that processing of basic temporal stimulus features in elderly subjects is considerably more reduced pre attentive level (as indicated by MMN), than when attention is directed to the task (as indicated by the psychoacoustic results).

2) Middle Latency Response (MLR): -

The resolution of the temporal processing in the Primary Auditory Cortex (PAC) was studied in human listeners by using temporal gaps of 3, 6, 10 and 30 msec inserted in the 100 msec noise bursts. Middle latency auditory evoked fields (MAEP's) were recorded and evaluated by spatio-temporal source analysis.

The dependency of the neurophysiological activation at about 37 msec (P37 msec) on the temporal portion of the gap was investigated by inserting silent periods 5, 20, and 50 msec after noise burst onset (Rupp, Gutschalk, Uppenkamp and Scherg, 2004). The morphology of the waveforms evoked by the gap showed that the MAEFs were largely determined by the ON- response to the noise burst following the gap.

The comparison of the source wave forms revealed two major effects;

1) The amplitudes of the MAEFs increased with longer gap duration and

2) The amplitude increased with the length of the leading noise burst.

When the gap inserted after 50 msec, a significant deflection of the collapsed left and right hemisphere data was observed for all gap durations. The P37 msec amplitude failed to reach significance for the shortest gap duration of 3 msec when the gap occurred after 20 and 5msec. These neuromagnetically derived minimum detectable gap responses closely resembled psychoacoustic responses closely resembled psychoacoustic thresholds obtained from the same subjects. (Leading noise burst 50 msec: 2.4 msec; 20 msec: 3.2 msec and 5 msec: 5.3 msec). The correspondence between psychoacoustic thresholds and the cortical activation indicates that the recording of MAEFs provides an objective and non-invasive tool to assess cortical temporal acuity.

3) Auditory Brainstem Response (ABR): -

Gap detection is commonly used measure of temporal resolution, although the mechanisms underlying gap detection are not well understood. To extent that gap detection depends on process within or peripheral to, the auditory brainstem response (ABR) would be similar to the psychophysical gap detection threshold.

Werner, Folson, Manel & Syapin (2001) conducted three experiments to examine the relation between ABR gap threshold and gap detection. Thresholds for gaps in a broadband noise were measured in young adults with normal hearing, using both psychophysical techniques and electro physiological techniques that use the ABR. The mean gap thresholds obtained with the two methods were very similar, although ABR thresholds tended to be lower than psychophysical gap thresholds. There was a modest correlation between psychophysical and ABR thresholds across participants. ABR and psychophysical threshold for noise was masked by temporally continuous, high pass, or spectrally notched noise was measured in adults with normal hearing. Restricting the frequency range with masking led to poorer gap thresholds on both measures. High pass maskers affected the ABR and psychophysical gap thresholds similarly.

Notched noise masked ABR and psychophysical gap thresholds were very similar except that low frequency, notched noise masked ABR gap thresholds was much poorer at low levels. The ABR gap threshold was more sensitive to changes in signal–to–noise masker ratio than was the psychophysical gap detection threshold.

ABR and psychophysical thresholds for gaps in broadband noise were measured in listeners with sensorineural hearing loss and in infants. On average, both ABR gap thresholds and psychophysical gap detection thresholds of listeners with hearing loss were worse than those of listeners with normal hearing, although individual differences were observed.

Psychophysical gap detection thresholds of 3-months and 6–months old infants were an order of magnitude worse than those of adults with normal hearing. These results suggest that ABR gap thresholds and psychophysical gap detection depend on at least some of the same mechanisms within the auditory system.

Psychophysical and Physiological evidence on Gap Detection Test

Psychophysical evidence from research on animals may prove useful in explaining some of the trends observed in human performance. For example, it seems reasonable to expect that gap resolution is related to phasic response of sensory units along the basilar membrane. Resolution deficits in the impaired cochlea might simply reflect a loss of redundancy in the temporal coding of information via a phasic–response mechanisms. Giraudi et al (1980) reported that gap resolution in mammals (chinchilla) roughly 3 msec for a broadband signal, is essentially same as that found in human observers. Plomp (1964) suggested that temporal resolution is limited by the decay of sensation produced by first part of the stimulus, which would fill in the gap

In a study (Zhang et al 1990) measuring neural correlates of gap detection in eighth–nerve fibers from chinchilla, the decay in neural response was found to be inversely related the characteristic frequency (CF) of the unit about one msec for high–CF–units and 5 msec for fibers with CF less than 1000Hz. According to Zhang et al (1990) the neural representation of gap detection was characterized by a modulation of firing rate in the peristimulus–time (PST) histogram with an abrupt drop followed by a sharp increase. The modulation was a function of gap length. As the gap length increased, the firing rate during the gap systematically decreased, and when the gap was 10 msec long the firing rate decreased to below the spontaneous rate of the unit. Also the firing rate at the onset of the second part of the noise burst increased with increasing gap length. Thus, in some respects, the neural representations of gap detection resemble psychometric functions obtained in psychophysical measurements (Green, and Forrest, 1989; Moore and Glassberg, 1988). A distinctive measure of the psychometric function for gap detection is its steep slope, which, as suggested by Moore et al (1992), would assure high precision (or low subject variability) in measurement of the Gap Detection Threshold. However, the steep slope does not guarantee good agreement among subjects.

Physiological studies were carried out by Feng, Lin, Sun (1994) out in the frog (Rana pipiens pipiens) eighth nerve to determine: (i) whether the modulation rate or the silent gap was the salient feature that set the upper limit of time-locking to pulsed amplitude-modulated (PAM) stimuli, (ii) the gap detection capacity of individual eighth nerve fibers. Time-locked responses of 79 eighth nerve fibers to PAM stimuli (at the fiber's characteristic frequency) showed that the synchronization coefficient was a low-pass function of the modulation rate. In response to PAM stimuli having different pulse durations, a fiber gave rise to non-overlapping modulation transfer functions. The upper cut-off frequency of time locking was higher when tone-pulses in PAM stimuli had shorter duration. The fact that the cut-off frequency was different for the different PAM series suggested that the AM rate was neither the sole, nor the main, determinant for the decay in time-locking at high AM rates. Gap detection capacity was determined for 69 eighth nerve fibers by assessing fiber's spiking activities to paired tone-pulses during an OFF-window and an ON-window. It was found that the minimum detectable gap of eighth nerve fibers ranged from 0.5 to 10 ms with an average of 1.23 to 2.16 ms depending on the duration of paired tone pulses. For each fiber, the minimum detectable gap was longer when the duration of tone pulses comprising the twin-pulse stimuli was more than four times longer. When the synchronization coefficient was plotted against the silent gap between tones pulses in the PAM stimuli, the gap response functions of a fiber as derived from multiple PAM series were equivalent to gap response functions deriving from twin-pulse series suggesting that it was the silent gap which primarily determined the upper limit of time-locking to PAM stimuli.

Buchfellner, Leppelsack, Klump and Häusler (1988) investigated Gap-detection thresholds of single units were determined from auditory forebrain neurons of the awake starling. Nine different response types were statistically defined from the discharge pattern to a 400 ms broadband noise stimulus. The gap stimuli consisted of two broadband noise bursts, which were separated by a gap ranging from 0.4 to 204.8 ms duration. The median minimum detectable gap for 121 out of 145 units that had a significant threshold 204.8ms was 12.8 ms; 20% of the neurons showed thresholds between 0.4 and 3.2 ms. The neurons of the nine response types differed significantly in their minimum-detectable gaps; neurons with phasic-tonic and phasic excitation exhibited the best (i.e. shortest) minimum-detectable gaps. The neurons of the three different recording areas (field L, NCM and HV) were significantly different in their minimum detectable gaps; field L neurons showed the best temporal resolution for gaps in broadband noise. Gap Detection Thresholds are compared with psychophysical thresholds determined with the same stimuli and the relevance of forebrain units for temporal resolution is discussed.

CHAPTER 3

METHOD

Subjects: 40 subjects were participated in the study. The subjects were divided into three groups.

Group: 1 composed of 15 older adults (> 55 years) with normal hearing (puretone thresholds ≤ 25 dB HL in frequency range of 250 – 2 000Hz).

Group: 2 composed of 10 young (18-40years) adults with mild to moderate sensorineural hearing loss.

Group: 3 composed of 15 older adults (>55 years) with mild to moderate sensorineural hearing loss.

Subject Selection Criteria

Group: 1 Older subjects with normal hearing: -

In this group, the subjects were selected based on the following criteria.

a) No significant history of otological or neurological disorders.

b) Hearing thresholds of subjects were ≤ 25 dB HL in the frequency range of 250 to 2000 Hz.

c) On immittance screening, they had 'A' type tympanogram & reflexes present.

d) A checklist used to rule out subjects with APD's.

e) All subjects had average/above average intellectual functioning.

Group 2 & Group 3: Young adults & older subjects with hearing loss: -

a) All subjects had mild to moderate sensorineural hearing loss.

b) All subjects had 'A' type tympanogram with reflexes present/elevated.

c) Subjects had sloping / flat configuration of audiogram.

d) They should not have any language disabilities (which can be ascertained by screening)

Instrumentation: -

1) A calibrated two channel diagnostic audiometer (Orbiter – 922) used for subject selection & for the presentation of the stimulus.

2) An immittance audiometer (GSI –33) used for evaluation of middle ear function

3) Tape recorder (Philips AZ 2160cv) with CD on gap detection test connected to a two channel diagnostic audiometer for presenting the stimulus.

Test environment: -

The test was carried out in an air-conditioned sound treated double room with ambient noise levels within permissible limits. (Re: ANSI 1991, as cited in Wilber, 1994).

Stimuli/ test material: -

Gap detection test CD developed by Shivaprakash (2003).

Procedure:

The subjects were instructed as “ please listen to the set of three noise bursts, one of the three noise bursts contain a gap of varying duration.

Subject had to indicate verbally that which of the three noise bursts in the set had the gap. For practice listen to the sets now & tell which of the three noise bursts had the gap.The stimuli set presented monaurally at 40dB SL (with reference to pure tone average) or at comfortable level, through the audiometer to each subject. The 56 stimuli (including 6 catch trials) of the gap detection routed to each ear separately for each subject in each group.

Before the actual test sets, four practice sets were given to train the subjects. The gap duration in the four practice sets were 20, 16, 12, 10 msec.

The subject had to detect the gap, which was embedded in one of the three noise bursts. Each time the subject detected the gap correctly, the size of the gap reduced to trace the smallest gap that subject could detect using bracketing technique.

The minimum gap that was detected by the subject was taken as gap detection threshold. The gap detection thresholds were obtained for each subject in each group.

The smallest gap was then tabulated for each ear of each subject, in different groups. The appropriate statistical analysis was carried out to see the effect of age, hearing loss, and configuration of hearing loss and to develop normative data for older adults.

CHAPTER 4

RESULTS

Data on Gap Detection Threshold (GDT) were collected for three different groups in order to develop norms for older adults and to know the effect of age, hearing loss, and configuration of hearing loss on Gap Detection Threshold (GDT). The data was tabulated for statistical analysis. The SPSS–10 (Statistical Package for Social Sciences) for windows was used to analyze the following.

1) Effect of Age
    a) Comparison between young adults* and older adults with normal hearing on GDT.
    b) Comparison between young adults and older adults with hearing loss on GDT.
2) Effect of Hearing loss
    a) Comparison between older adults with and with out hearing loss on GDT.
    b) Comparison between young adults with* and without hearing loss on GDT.
3) Effect of configuration of hearing loss

a) Comparison between flat Vs sloping configurations in young adults with hearing loss on GDT.

b) Comparison between flat Vs sloping configurations in older adults with hearing loss on GDT.

4) Comparison of right and left ear

a) Comparison between right and left ear in young adults with hearing loss on GDT.

b) Comparison between right and left ear in older adults with hearing loss on GDT.

c) Comparison between right and left ear in older adults normal hearing on GDT.

[* Normative data for young adults without hearing loss was taken from the Shivaprakash, S (2003). Gap Detection Test – Development of Norms].

EFFECT OF AGE

a) Comparison between young adults and older adults with normal hearing

Table –1: Mean & Standard deviation values for right and left ears in older adults (> 55 years) on the Gap detection threshold.

EAR	MEAN	SD
RIGHT	5.67	0.62
LEFT	5.93	0.7

Table 2: - Mean and Standard deviation values for right and left ears in young adults with Normal hearing on Gap Detection Threshold (Shiva praksah 2003)

EAR	MEAN	SD
RIGHT	3.6	0.51
LEFT	3.0	0.66

Table1 shows Mean & Standard deviation values for right and left ears in older adults (>55 years) on the Gap detection threshold in present study.

Table 2 shows Mean & Standard deviation values for right and left ears in young adults (18 to 35.11 years) with normal hearing on the Gap detection threshold, which is taken from previous study by Shiva Prakash 2003.

To see the effect of age on gap detection threshold, the one sample test t- test was performed separately for both the ears between the mean of young adults with normal hearing (previous study) and the older adults with normal hearing (present study). The results reveal that:

For Right Ear: -

The one sample t- test for right ear revealed a value of t (14) = 12.965, P< 0.001. Hence there is a significant difference between the mean of normal young adults (given from previous study) and the older adults with near normal hearing (present study) on Gap detection threshold at 0.001 level.

For Left Ear: -

The one sample t- test for left ear revealed a value of t (14) = 16.144, P< 0.001. Hence there is a significant difference between the mean of normal young adults (given from previous study) and the older adults with normal hearing (present study) on Gap detection threshold at 0.001 level.

b) Comparison between young adults and older adults with hearing loss

Table –3: Mean & Standard deviation values for right and left ears in older adults (> 55 years) with sensorineural hearing loss on the Gap detection threshold.

EAR	MEAN	SD
RIGHT	6.67	2.06
LEFT	6.45	1.04

Table – 4: Mean & Standard deviation values for right and left ears in young adults with Sensorineural hearing loss on Gap Detection Threshold.

EAR	MEAN	SD
RIGHT	4.78	1.48
LEFT	5.25	1.04

Table 3 shows Mean & Standard deviation values for right and left ears in older adults (> 55 years) with sensorineural hearing loss on the Gap detection threshold.

Table 4 shows Mean & Standard deviation values for right and left ears in young adults (18 to 40 years) with sensorineural hearing loss on the Gap detection threshold in the present study.

To see the effect of age on gap detection threshold, the independent sample t-test was performed separately for both the ears between young adults and the older adults with hearing loss. The results reveal that

For Right Ear: -

The independent sample t- test on right ear revealed a value of $t(16) = 2.232$, $P < 0.05$. Hence there is a significant difference between the young adults and the older adults with sensorineural hearing loss on Gap detection threshold for right ear at 0.05 level.

For Left Ear: -

The independent sample t- test on left ear revealed a value of t (17) = 2.504, $P < 0.05$. Hence there is a significant difference between the young adults and the older adults with sensorineural hearing loss on Gap detection threshold for left ear at 0.05 level.

Hence there is a significant difference between young adults and older adults with and without hearing loss on gap detection threshold for both the ears.

Effect of Hearing Loss

a) Comparison between older adults with and with out hearing loss

Table1 shows Mean & Standard deviation values for right and left ears in older adults with normal hearing (>55 years) on the Gap detection threshold.

Table 3 shows Mean & Standard deviation values for right and left ears in older adults (>55 years) with sensorineural hearing loss on the Gap detection threshold.

To see the effect of hearing loss in older adults, the independent sample t – test was performed separately for both the ears between older subjects with normal hearing and with sensorineural hearing loss. The results revealed that:

For Right Ear: -

The independent sample t- test on right ear revealed a value of t (22) = 1.774, 0.05< P< 0.1. Hence there is no significant difference at 0.05 level between older adults with normal hearing and with hearing loss. But a significant difference is seen at 0.1 level between older adults with normal hearing and with sensorineural hearing loss.

For Left Ear: -

The independent sample t- test on left ear revealed a value of t (24) = 1.531, P>0.05. Hence there is no significant difference at 0.05 level between older adults with normal hearing and with hearing loss.

b) Comparison between young adults with and without hearing loss

Table 2 shows Mean & Standard deviation values for right and left ears in young adults (18 to 35.11 years) with normal hearing on the Gap detection threshold, which is taken from previous study by Shiva Prakash 2003.

Table 4 shows Mean & Standard deviation values for right and left ears in young adults (18 to 40 years) with sensorineural hearing loss on the Gap detection threshold in the present study.

To see the effect of hearing loss on gap detection threshold in young adults, the one sample test t- test was performed separately for both the ears between young adults with normal hearing (previous study) and with sensorineural hearing loss. The results reveal that:

For Right Ear: -

The one sample t- test on right ear revealed a value of $t(8) = 2.385$, $P < 0.05$. Hence there is a significant difference between the mean of normal young adults (given from previous study) and young adults with sensorineural hearing loss (in present study) on Gap detection threshold at 0.05 level.

For Left Ear: -

The one sample t- test on left ear revealed a value of $t(7) = 6.148$, $P < 0.001$. Hence there is a significant difference between the mean of normal young adults (given from previous study) and young adults with sensorineural hearing loss (in present study) on Gap detection threshold at 0.05 level.

Hence there is a significant difference between young adults with normal hearing (given from previous study) and young adults with hearing loss (in present study) on gap detection threshold for both the ears.

There is no significant difference between old adults with and without hearing loss on gap detection threshold for both the ears at 0.05 level, but there is a significant between old adults with and without hearing loss on gap detection threshold for right ear at 0.01 level.

Figure 1 shows the comparison of young adults and older subjects in terms of hearing loss on gap detection threshold for right ear.

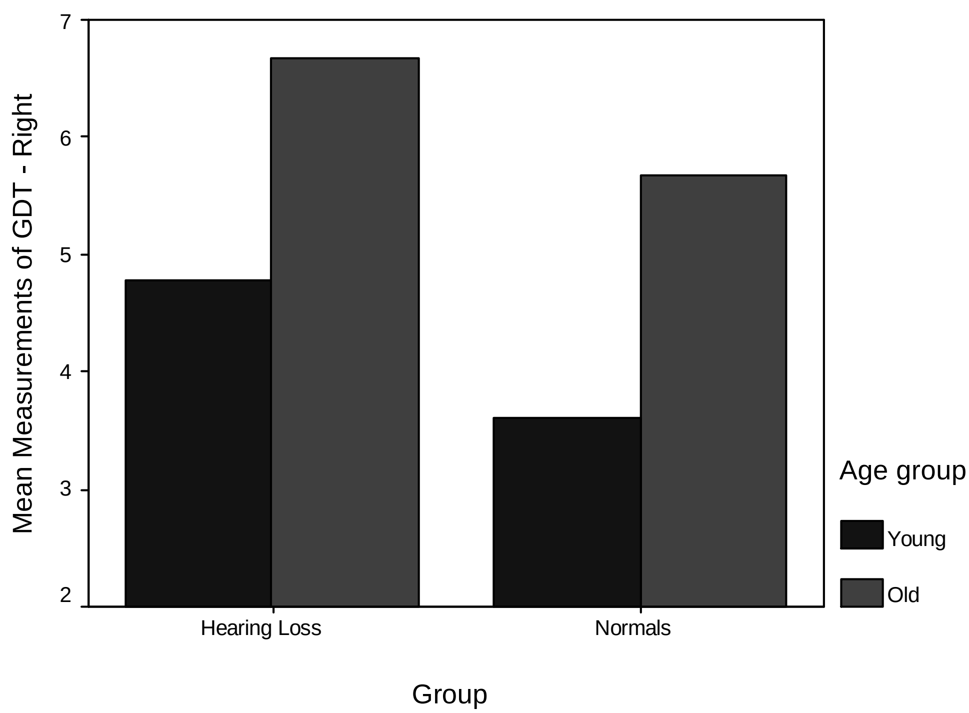
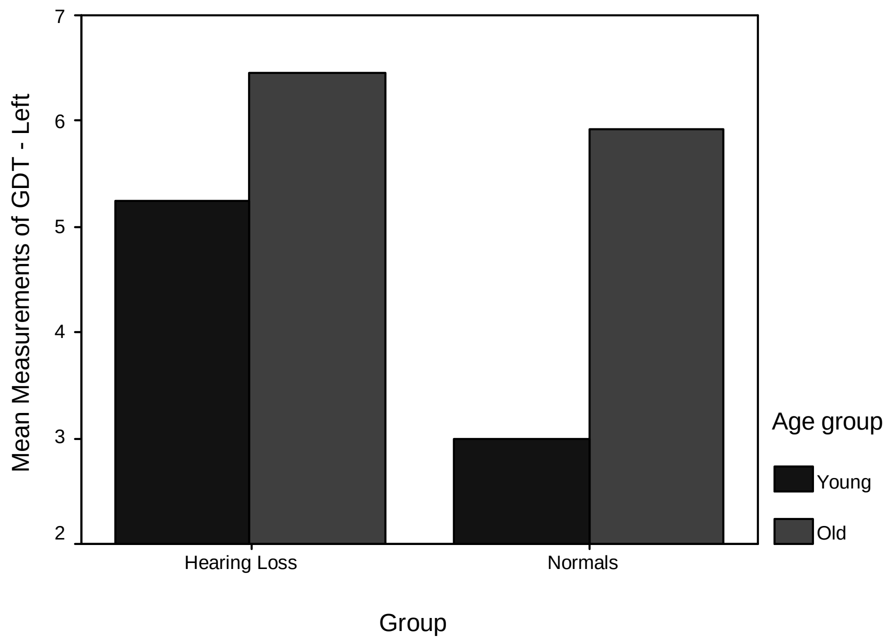


Figure 2 shows the comparison of young adults and older adults in terms of hearing loss on gap detection threshold for left ear.



Effect of Configuration of Hearing Loss

The significant difference was found between young and older subjects with hearing loss. The effect of configuration of hearing loss in young and old subjects was studied separately.

A) Comparison between flat Vs sloping configurations in young adults with hearing loss

Table: 5 Mean & Standard deviation of young and old adults in terms of configuration of hearing loss (Flat Vs Sloping) in Right ear on Gap Detection Threshold.

Age group	**Configuration of HL- Right**	**Mean**	**Std. deviation**
Young	**Flat**	3.75	1.50
	Sloping	5.60	0.89
Old	**Flat**	6.00	0.82
	Sloping	7.20	2.68

Table – 6: Comparison of young and old adults in terms of configuration of hearing loss (Flat Vs Sloping) in left ear on Gap Detection Threshold.

Age group	**Configuration of HL- Left**	**Mean**	**Std. deviation**
Young	**Flat**	5.00	0.82
	Sloping	5.50	1.29
Old	**Flat**	6.60	0.82
	Sloping	6.33	1.21

Table 5 shows the mean and standard deviation of young adults and older adults in terms of configuration of hearing loss (Flat Vs Sloping) on gap detection threshold for right ear.

Table 6 shows the mean and standard deviation of young adults and older adults in terms of configuration of hearing loss (Flat Vs Sloping) on gap detection threshold for left ear

To see the effect of configuration of hearing loss in young adults with sensorineural hearing loss, the Mann Whitney 'U' test was performed to compare Flat Vs Sloping configuration for right and left ears separately. The results shown that:

For Right Ear: -

The Mann Whitney 'U' test on right ear revealed a 'Z'value of -1.917, $P>0.05$. Hence there is no significant difference between the flat and sloping configuration of hearing loss in young adults with sensorineural hearing loss on Gap detection threshold for right ear.

For Left Ear: -

The Mann Whitney 'U' test on left ear revealed a 'Z'value of -1.623, $P>0.05$. Hence there is no significant difference between the flat and sloping configuration of hearing loss in young adults with sensorineural hearing loss on Gap detection threshold for left ear.

Hence there is no significant difference between the flat and sloping configuration of hearing loss in young adults with sensorineural hearing loss on Gap detection threshold for both the ears.

B) Comparison between Flat Vs Sloping configurations in older adults with hearing loss

Table 5 shows the mean and standard deviation of young adults and older adults in terms of configuration of hearing loss (Flat Vs Sloping) on gap detection threshold for right ear.

Table 6 shows the mean and standard deviation of young adults and older adults in terms of configuration of hearing loss (Flat Vs Sloping) on gap detection threshold for left ear.

To see the effect of configuration of hearing loss in older adults with sensorineural hearing loss, the Mann Whitney 'U' test was performed to compare Flat Vs Sloping configuration of hearing loss for right and left ears separately. The results shown that:

For Right Ear: -

The Mann Whitney 'U' test on right ear revealed a 'Z'value -0.582, P>0.05. Hence there is no significant difference between the flat and sloping configuration of hearing loss in older adults with sensorineural hearing loss on Gap detection threshold for right ear.

For Left Ear: -

The Mann Whitney 'U' test on left ear revealed a 'Z'value of -0.189, P>0.05. Hence there is no significant difference between the flat and sloping configuration of hearing loss in older subjects with sensorineural hearing loss on Gap detection threshold for left ear.

Hence there is no significant difference between the flat and sloping configuration of hearing loss in young adults with sensorineural hearing loss on Gap detection threshold for both the ears.

From these we can conclude that there is no significant difference between the flat and sloping configuration of hearing loss in young adults and older adults with sensorineural hearing loss on Gap detection threshold for both the ears.

Figure 3 shows the comparison of young adults and older adults in terms of configuration of hearing loss (Flat Vs Sloping) on gap detection threshold for right ear

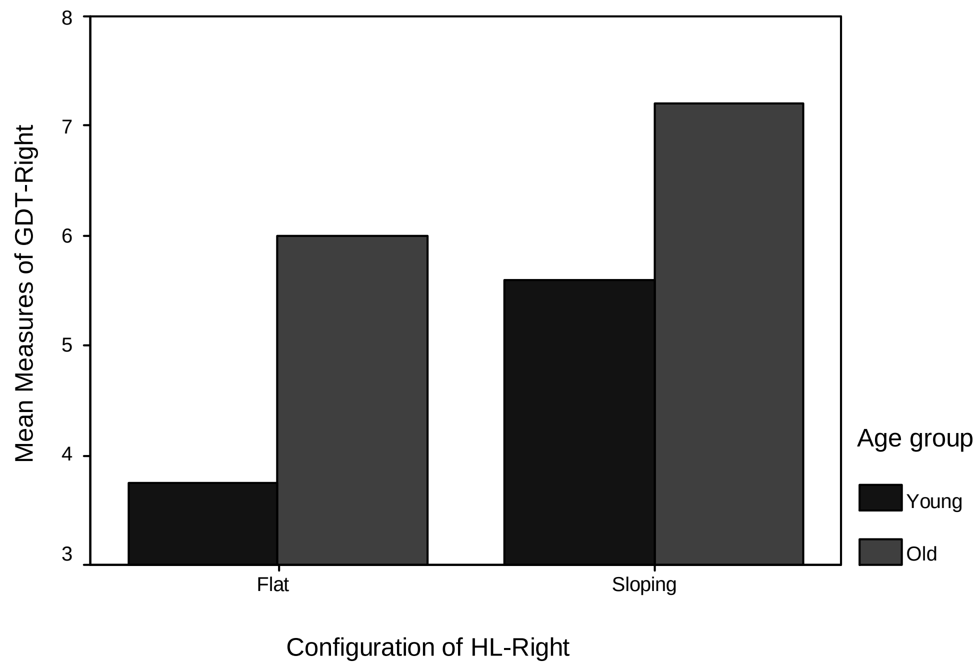
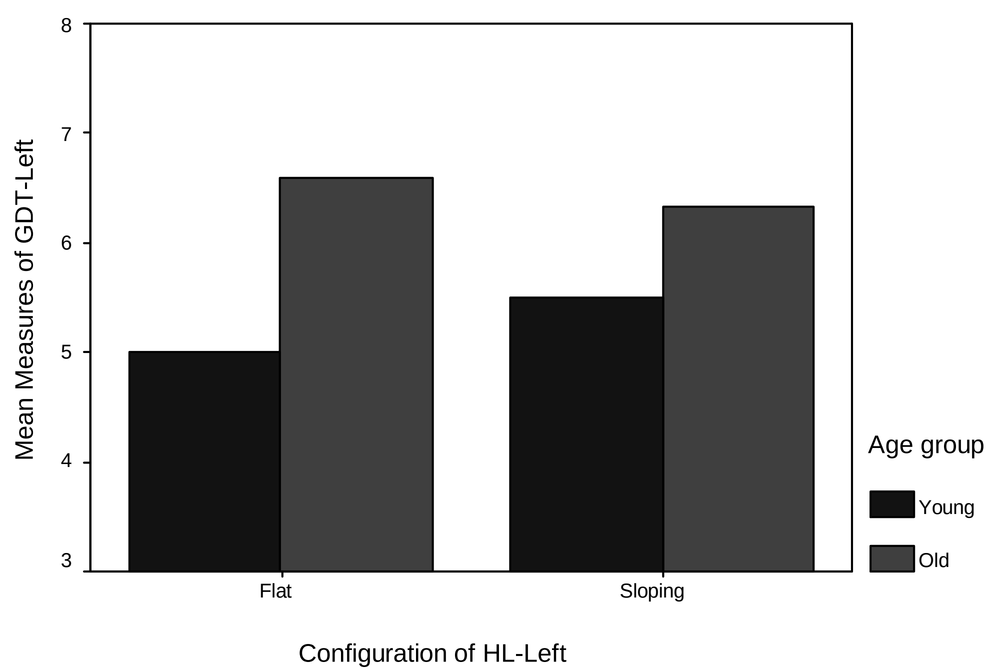


Figure 4 shows the comparison of young adults and older adults in terms of configuration of hearing loss (Flat Vs Sloping) on gap detection threshold for left ear.



Comparison of Right and Left ear

a) Comparison between right and left ear in young adults with hearing loss

Table 4 shows Mean & Standard deviation values for right and left ears in young adults (18 to 40 years) with sensorineural hearing loss on the Gap detection threshold in the present study.

To see the difference in right and left ears of young adults with sensorineural hearing loss on gap detection threshold the paired t- test was performed and $t(6) = 1.549$, $p > 0.05$. Hence there is no significant difference between right and left ears of young adults with sensorineural hearing loss on gap detection threshold.

b) Comparison between right and left ear in older adults with hearing loss

Table 3 shows Mean, Standard deviation values for right and left ears in older adults (> 55 years) with sensorineural hearing loss on the Gap detection threshold.

To see the difference in right and left ears of older adults with sensorineural hearing loss on gap detection threshold the paired t- test was performed and $t(7) = 0.174$, $p > 0.05$. Hence there is no significant difference between right and left ears of older adults with sensorineural hearing on gap detection threshold.

c) Comparison between right and left ear in older adults normal hearing

Table1 shows Mean & Standard deviation values for right and left ears in older adults (>55 years) on the Gap detection threshold.

To see the difference in right and left ears of older adults with normal hearing on gap detection threshold the paired t-test was performed and $t(7) = 1.468$, $p > 0.05$. Hence there is no significant difference between right and left ears of older adults with normal hearing on gap detection threshold. Therefore there is no significant difference between right and left ears in all groups.

CHAPTER 5

DISCUSSION

The purpose of the present study was

a) To see the effect of age, hearing loss and configuration of hearing loss in young and older adults with and without hearing loss on Gap Detection Threshold.

b) To develop norms for the older adults.

The results of the present study showed that

a) There is a significant effect of age in older adults with and without hearing loss on Gap Detection Threshold.

b) There is a significant effect of hearing loss in young adults on Gap Detection Threshold

c) There is no significant effect of hearing loss in older adults for both the ears at 0.05 level, but there is a significant effect of hearing loss in older adults for right ear at 0.1 level on Gap Detection Threshold.

d) There is no significant difference between flat and sloping configuration of hearing loss in both young adults and older adults with hearing loss on Gap Detection Threshold.

e) There is no significant difference between right and left ears in all groups on Gap Detection Threshold.

Effect of Age

To see the effect of age on Gap Detection Threshold, comparison between young adults and older adults with and without hearing loss was done.

In the present study, results showed larger Gap Detection Thresholds for right and left ears in older adults with normal hearing than young adults with normal hearing [taken from Shiva Prakash, (2003)]. The results are in accordance with the results of the following studies:

Schneider et al (1994) reported that Gap Detection Thresholds were significantly higher in older adults with normal hearing than in young adults with normal hearing. They reported gap detection threshold of 6.4 msec for their older subjects with normal hearing (puretone threshold ≤25 dB HL from 0.25 to 3 KHz). The present study also reported the Gap Detection Threshold of 5.67 & 5.93 for right ear and left ear respectively showed the good agreement with Schneider et al (1994) values.

Schneider and Hamstra (1999) reported that older adults have poorer temporal resolution than younger adults for shorter duration stimuli, but not for longer stimuli. This is consistent with a temporal window model that includes the effect of adaptation. According to the adaptation version of temporal window–model, temporal acuity at shorter duration is reduced in older adults because recovery from adaptation is not rapid as it is in younger adults. Thus older adults have more difficulty in detecting a gap than younger adults when short marker durations, but not long marker durations are employed. Since the durations at which older adults show a deficit are those characteristics of speech sounds, this deficit might have an adverse effect on older adult's ability to perceive speech.

Some of the investigation used simple tonal or noise signal and reported age related difficulties for tasks such as temporal gap resolution (Schneider, Pichora–Fuller, Kowalchuk, and Lamb, 19994; Snell, 1987). The results of these studies indicate that reduced temporal processing in older listeners may occur independently of hearing loss for fixed frequency stimuli. Normal puretone threshold are not indicative of normal temporal processing; rather, age may be the stronger predictor of silent gap resolution.

Lister, Besing, & Koehnke (2002) proposed a hypothesis that the perceptual channel that appears to narrow with age are not limited by peripheral Auditory filter widths, but are influenced by both peripheral and central encoding mechanisms that become less acute with age.

Green and Forrest (1989) observed that gap threshold with random gap location were 1.3 to 1.5 times higher than those with a fixed gap location. Performance on gap detection threshold varies for various gap locations e.g., 5%, 50% or 95% of total burst duration.

When the gap was at the center of the noise burst (50% and middle panels), gap detection was independent of the uncertainty of gap location for both young and aged subjects. Furthermore, there was only a small difference in performance between two groups in either condition. When the gap was located away from the center position to the two extreme end locations (5% and 95%), performance declined.

In the fixed condition (when the gap location is fixed trail to trail, at either 5%, 50% or 95% of total duration of narrow band), the functions for the 5% and 95% gap locations shifted towards larger gap duration, compared to the 50% location. Also at the fixed 95% location elderly subjects were unable to perform this task. Thus, for aged subjects only, gap thresholds were significantly lower at the middle location than at the end location, and were significantly lower at the 5% location than at the 95% location.

In summary, the significant main effect of age was due to the significantly higher gap threshold of the aged subjects when the gap was at the end locations and was presented randomly. Comparing only the 50% location with the 27.5% and 72.5% locations, the analysis revealed that the difference in slope was not significant for either young or aged subjects. When the gap was located sufficiently away from both ends of the burst (e.g., 27.5% and 72.5%) perception was robust, regardless of the uncertainty about the gap location.

Studies suggest that reduced within channel and across channel temporal resolution in older subjects may occur independent of peripheral hearing sensitivity (Fitzgibbons and Gordon-Salant, 1994; Lister, Besing and Koehnke 2000). This affect is attributed to age related changes with in central auditory system and to slowed auditory processing (Fitzgibbons and Gordon-Salant, 1994). Therefore it is reasonable to consider factors other than peripheral hearing loss that could account for age related differences in monaural temporal resolution.

In the present study, results showed that there is a significant difference between older adults and young adults with hearing loss for both the ears on Gap Detection Threshold. The results are in accordance with the results of the following studies:

Snell's (1997) older adults, who were matched to a group of younger listeners with respect to their audiometric thresholds, had Gap Detection Thresholds that were 27-37% larger than those of the younger listeners for gaps in short noise burst.

In the present study, the results showed that significant difference on Gap Detection Threshold is more in older adults without hearing loss. The results are in accordance with the results of the following studies.

Schneider et al (1994) and Snell (1997) studies suggest that in the absence of significant sensorineural hearing loss, there is more age-related loss in temporal acuity.

Findings suggest that age-related factors other than peripheral hearing loss contribute to temporal processing deficits of elderly listeners.

Effect of Hearing Loss

To see the effect of hearing loss on gap detection threshold for right and left ears, comparisons were made

a) In young adults with and without hearing loss

b) In older adults with and without hearing loss

n the present study, results showed larger gap detection thresholds for right and left ears in young adults with sensorineural hearing loss (present study) than young adults with normal hearing [Shivaprakash, (2003)]. These results are in accordance with the following studies:

Several groups of workers have reported that thresholds for the detection of temporal gaps in noise stimuli are usually larger for subjects with cochlear hearing impairment than for normally hearing subjects. This is true both for broadband noise stimuli (Irwin et al 1981; Florentine & Buus, 1984) and for band pass noise stimuli presented in a broadband or band stop back ground (Fitzgibbons and Wightman, 1982; Tyler et al 1982; Buus and Florentine, 1985; Moore et al 1985b).

Fitzgibbons & Wightman (1982) found that hearing-impaired subjects had larger hap thresholds than normal subjects regardless of whether comparison was made at equal SPL or equalSL.

A number of studies have shown that Gap detection thresholds are elevated in the individuals with sensorineural hearing losses. (Irwin et al 1981; Fitzgibbons & Wightman, 1982; Florentine and Buus, 1984; Buus & Florentine, 1985; Glassberg et al 1987; Long & Cullen, 1988; Moore & Glassberg, 1988; Moore et al 1989)

As Florentine and Buus demonstrated in their experiment, the enlargement of gap detection threshold observed with broadband stimuli maybe the consequence of insufficient audibility of high frequency signal spectrum for impaired listeners. For sensorineural hearing loss, the measured gap detection threshold is frequently associated & observed to be larger than normals (Boothroyd, 1973; Irwin & Purday, 1982; Giraudi-Perry et al 1982;Salvi & Arehole, 1985).

Experiments on Gap Detection in octave band of noise have shown that temporal resolution is much better at high than low frequencies (Buus & Florentine, 1982; Florentine and Buus, 1983; Fitzgibbons, 1983; Shailer and Moore, 1983; Fitzgibbons and Wightman, 1982). This indicates that the high frequencies are primarily responsible for the detection of gap in a broadband noise and that impaired listeners may have enlarged gap thresholds because they simply cannot hear the high frequency part of the white noise. In fact, limiting the temporal gap to frequency below 2 KHz increases the Minimum Detectable Gaps (MDGs) in normal listeners to values similar to those observed in listeners with high frequency hearing impairments (Florentine & Buus, 1982). These findings point to the role of the audiometric configuration in Gap detection. In addition to important parts of the signal being inaudible, it is also possible that hearing impaired persons truly have reduced temporal resolution.

In the present study, results showed that there is no significant difference on gap detection threshold for both the ears in older subjects with and without hearing loss at 0.05 level. But there is a significant difference on gap detection threshold for right ear in older adults with and without hearing loss at 0.1 level. The results are in accordance with the following studies.

Moore et al (1992) measured thresholds for the detection of temporal gaps in sinusoidal signals as a function of frequency in elderly hearing impaired subjects and elderly subjects with near normal hearing (audiometric thresholds ≤ 25 dB HL from 250 to 2000Hz). Results were compared to previous data collected from normal hearing subjects (Moore et al 1993), revealing that elderly subjects with near normal hearing had higher Gap Detection Thresholds than young subjects. Moore et al (992) attributed this result to the inclusion in the elderly group of some individual who had large gap detection thresholds. Nevertheless, when they compared gap detection thresholds in elderly subjects with near normal hearing to those with hearing impairment, they found no difference between the two groups. Schneider et al (1994) reached a similar conclusion.

In Moore et al (1993) has not compared the right ear and left ear in older adults with and without hearing loss.

Effect of Configuration of Hearing Loss

To see the effect of configuration of hearing loss, the comparison between flat Vs sloping configurations of hearing loss in young adults and older adults with sensorineural hearing loss was done for right and left ear separately.

The results showed that there is no significant difference between flat and sloping configuration of hearing loss on both right and left ear on gap detection threshold in young adults and older subjects with mild and moderate sensorineural hearing loss.

Experiments on gap detection in octave band of noise have shown that temporal resolution is much better at high than at low frequencies (Buus, Florentine, 1982; Florentine and Buus, 1983; Fitzgibbons and Wightman, 1982). This indicates that the high frequencies are responsible for the detection of gap in a broadband noise and that impaired listeners may have enlarged gap thresholds because they simply cannot hear the high frequency part of the white noise. In fact, limiting the temporal gap to frequency below 2 KHz increases the Minimum Detectable Gap (MDGs) in normal listeners to values similar to those observed in listeners with high frequency hearing impairments (Florentine and Buus, 1982). These findings point to the role of audiometric configuration in gap detection.

But these studies did not report the presence or absence of difference between flat and sloping configuration of hearing loss. However, in the present study, the results showed no significant difference between flat and sloping configuration of hearing loss on gap detection threshold in young adults and older subjects with mild and moderate sensorineural hearing loss for both the ears.

Comparison between Right and Left ear

In the present study, results showed no significant difference between right and left ear on gap detection threshold in young adults and older adults with hearing loss and older adults with normal hearing.

Shivaprakash (2003) reported no significant difference in Gap Detection threshold between the right and left ears in children and young adults with normal hearing.

There are no review of literature to report the presence or absence of significant difference between the right and left ear on gap detection threshold in young adults and older adults with hearing loss. However, in the present study, the results showed that there is no significant difference between right and left ears on gap detection threshold in young adults and older subjects with mild and moderate sensorineural hearing loss & older subjects with normal hearing. However, in the present study, an older adult (89 years) with bilateral mild to moderate steeply sloping sensorineural hearing loss had the gap detection threshold of 7 msec in left ear and 12 msec in right ear. He had difficulty in identifying the gaps when they were placed initially in the three-stimulus presentation or sequence.

CHAPTER 6

SUMMARY AND CONCLUSION

Temporal resolution refers to the ability of the auditory system to follow rapid changes in the envelope of sound. It is measured in various ways and using various stimuli. The gap detection test is one of the important psychophysical methods among them to measure temporal resolution, which in turn is important for speech perception.

A review of literature shows that impaired ability to process and discriminate rapidly changing auditory information would lead to severe impairment in the perception of rapid changes in speech. This is seen in most of sensorineural hearing loss cases and elderly subjects with near normal hearing. It is also reported in that temporal resolution is affected by higher central deficits i.e., processing problem. E.g., SLI. These should be checked in the early age itself to have a proper management.

Gap Detection, which is necessary for speech perception, is an effective and easy to evaluate aspect of temporal resolution or acuity. The objective of the present study was to develop a normative data for older adults with normal hearing and to see the effect of age, hearing loss and configuration hearing loss (Flat Vs Sloping) on GDT in young adults and older adults separately for both the ears.

To study the objectives total 40 subjects with and without hearing loss were divided in three groups.

a) Group1 consist of 15 old adults with normal hearing (> 55 years),

b) Group 2 consist of 10 young adults with sensorineural hearing loss (18 to 40 years).

c) Group3 consist of 15 old adults with sensorineural hearing loss (>55 years),

Group1 Elderly subjects with normal hearing: -

In this group, the subjects were selected based on the following criteria.

a) No significant history of otological / neurological disorders.

b) Hearing thresholds of subjects were less than or equal to 25 dB HL in the frequency range of 250 – 2 000Hz.

c) On immittance screening, they had 'A' type tympanogram & reflexes present.

d) A checklist used to rule out subjects with APD's.

e) All subjects had average/above average intellectual functioning.

Group 2 & Group 3: Young adults & Elderly subjects with hearing loss: -

a) All subjects had mild to moderate sensorineural hearing loss.

b) All subjects had 'A' type tympanogram with reflexes present/elevated.

c) Subjects had sloping / flat configuration of audiogram.

The stimuli recorded on a CD along with calibration tone and were routed through headphone to each ear of each subject. Each stimulus set consisted of three noise bursts of 300msec duration with gap located at the center (50% of total burst duration of each burst). The noise bursts were separated by a silence of 750 msec in each set. The gap was introduced in one among the three noise bursts. The duration of the gap started from 20 msec. Here subject's task was to identify the burst in the sequence, which had the gap (of varying duration). The minimum gap, which could be detected by the individual, was taken as gap detection threshold. This gap detection threshold for each ear for each subject was tabulated. The data tabulated was subjected to statistical analysis. The results reveal that

1) There is significant effect of hearing loss in young adults for both right and left ears separately on gap detection threshold

2) There is a no significant effect of hearing loss in elderly subjects for both right and left ear separately on gap detection threshold, but there is significant effect of hearing loss for right ear at 0.01 on gap detection threshold.

3) There is significant effect of age in elderly subjects with and with out hearing loss and the difference is more in normals than compared to the older adults with hearing loss.

4) There is no significant effect of configuration of hearing loss (flat Vs sloping) in both young adults and older adults for right and left ears separately on gap detection threshold.

5) There is no significant difference between right and left ears in all three groups.

From the above results we can conclude that

a) The age has the effect on gap detection thresholds

b) The hearing loss has the effect on gap detection thresholds in young adults and there is very minimal effect of hearing loss on gap detection threshold in older adults than in young adults.

c) There is no effect of configuration (Flat and Sloping) of hearing loss on gap detection threshold in old and young adults with mild and moderate sensorineural hearing loss.

Clinical Implications: -

a. Normative data for elderly listeners with normal hearing can be used as baseline on which the management procedures can be evaluated for elderly listeners.

b. This is used to identify older individuals who might require auditory training for temporal cues or who might benefit from signal processing devices aimed at enhancing temporal cues.

Limitations of the study: -

1) Only limited number of subjects were studied among the normal older population, hence norms could not established.

2) This GDT test was limited only to the maximum duration of 20 msec gaps. Due to this three older adults with moderate sensorineural hearing loss were not included in the statistical analysis.

Future suggestions for Research: -

1) A larger group of subjects can be included in older subjects to develop normative data for the older adults with normal hearing.

2) The RGDT – Expand test can be carried out to find the Gap detection threshold of individuals who were unable to detect the gap of 20 msec duration on GDT – CD developed by Shivaprakash (2003).

CHAPTER 7

REFERENCES

Allen, P.D., Tracy, M., Virag, & Ison, J.R. (2002). Humans detect gaps in Broadband noise according to effective gap detection without additional cues from abrupt envelope changes. Journal of the Acoustical Society of America, 112(6), 2967-2974.

Bellis, T.J. (1997). Assessment and management of Central Auditory Processing Disorders in the Educational setting. London: Singular Publication.

Bertoli, S., Smurzynski, J., & Probst, R. (2002). Temporal resolution in young and elderly subjects as measured by mismatch negativity and a Psychoacoustic gap detection task. Journal of Clinical neurophysiology, 113 (3), 396-406.

Buchfellner, E., Leppelsack, H. J., Klump, G. M., & Hausler, U. (1989). Gap detection in the Starling II. Coding of gaps by forebrain-neurons. Journal of comparative Physiology (A), 164, 539-549. Abstract retrieved from http://www.ncbi. nlm.nib.gov.

Busby, P. A., & Clark, G.M. (1999). Gap detection by early-deafened cochlear-implant subjects. Journal of the Acoustical Society of America, 105 (3), 1841 – 1852.

Buumen, T.J., & Van Valkenberg, D.A. (1979). Auditory detection of a single gap in noise. Journal of the Acoustical Society of America, 65 (2), 534-536.

Dau, T., Kollmeier, D., & Kohlruncsch, A. (1997). Modeling auditory processing of amplitude modulation II. Spectral and temporal integration. Journal of the Acoustical Society of America, 102 (5), 2906-2919.

Dubno. J. R., Dirks, D.D., & Morgan, D.E. (1984). Effects of age and mild hearing loss on speech perception in noise. Journal of the Acoustical Society of America, 76 (1), 87-96.

Eggermont J.J. (1995). Neural co-relates of gap detection and auditory fiction cat auditory cortex. Neuro report. 6, 1645-1648. Abstracts retrieved from http://www.ncbi. nlm.nib.gov.

Eggermont J.J. (1995). Neural correlates of gap detection in three auditory cortical fields in the cat. Journal of Neuro physiology, 81, 2570-2580. Abstract retrieved from http://www.ncbi. nlm.nib.gov.

Eggermont, J.J. (2000). Neural responses in primary auditory cortex mimic psychophysical, across-frequency channel, gap-detection threshold. Journal of Neuro physiology, 84, 1453-1463. Abstract retrieved from http:// www.Ncbi.nlm.nib.gov.

Elliot, L.L. (1975). Temporal and masking phenomena in persons with sensorineural hearing loss. Audiology. 14, 336-353.

Feng, A.S., Lin, W.Y., & Sun, L. (1994). Detection of gaps in sinusoids by frog Auditory nerve fibers: importance AM coding. Journal of comparative Physiology (A), 175 (5) 531-546.

Fitzgibbons, P. J., & Gordon-Salant, S. (1986). Temporal gap resolution in listeners with high-frequency sensorineural hearing loss. Journal of the Acoustical Society of America, 81 (1), 133-137.

Fitzgibbons, P. J., & Gordon-Salant, S. (1987). Minimum stimulus level for temporal gap resolution in listeners with sensorineural hearing loss. Journal of the Acoustical Society of America, 81, (5), 1542-1556.

Fitzgibbons, P.J. & Gordon – Salant, S. (1995). Age effects on duration discrimination with simple and complex stimuli. Journal of the Acoustical Society of America, 98, (6) 3140-3145.

Fitzgibbons, P. J. & Wightman, F.L. (1982). Gap detection in normal and hearing impaired listeners. Journal of the Acoustical Society of America, 72 (3), 761-765.

Florentine, M., & Buus, S. (1984). Temporal gap detection in sensorineural and simulated hearing impairment. Journal of Speech and Hearing Research. 27, 449-455.

Florentine, M., Buus, S, & Geng, W. (1999). Psychometric function for gap detection in Yes- No procedure. Journal of the Acoustical Society of America, 106 (6), 3512-3520.

Formby, C., Gerber, M.J., Sherlock, L.P., & Magder, L.S. (1998). Evidence for an across-frequency, between-channel process in asymptotic monaural temporal gap detection. Journal of the Acoustical Society of America, 103 (6), 3554-3560.

Forrest, T.G., & Green, D. M. (1987). Detection of partially filled gaps in noise. Journal of the Acoustical Society of America, 82 (6), 1933-1943.

Glassberg, B. R. & Moore, B. C. J. (1988). Gap detection with sinusoids and noise in normal, impaired and electrically simulated ears. Journal of the Acoustical Society of America, 83 (3), 1093-1101.

Glassberg, B.R. & Moore, B.C.J. (1992). Effects of envelop fluctuations on gap detection. Hearing Research, 64, 81-92.

Glassberg, B. R., Moore, B. C. J., & Bacon, S. (1987). Gap detection and masking in hearing-impaired and normal-hearing subjects, Journal of the Acoustical Society of America 61 (5), 1564-1556.

Gordon–Salant, S., & Fitzgibbons, P.J. (1993). Temporal factors and speech recognition performance in young and elderly, listeners. Journal of Speech and Hearing research, 36, 1276-1285.

Gordon– Salant, S., & Fitzgibbons, P.J. (1999). Profile of Auditory Temporal Processing in older listeners. Journal of Speech, Language, and Research, 42, 300-311.

Green D.M., & Forrest, T.G. (1989). Temporal gaps in noise and sinusoids. Journal of the Acoustical Society of America, 86 (3), 961-970.

Grose, J.H., Hall, J.H., Buss, E., & Hatch, D. (2001). Gap detection for similar and dissimilar gap markers, Journal of the Acoustical Society of America, 109 (4), 1587-1595.

Hall, J. W. & Fernandes, M.A (1983). Temporal integration, frequency resolution and off frequency listening in normal hearing and cochlear impaired listeners, Journal of the Acoustical Society of America, 74 (4), 1172-1177.

Hall, J. W., Grose, J.H., & Joy, S. (1996). Gap detection for pairs of noise bands; Effect of stimulus level and frequency separation. Journal of the Acoustical Society of America, 99 (2), 1091-1095.

He, N.J, Horwitz, A.R., Dubno, J. R., & Mills, J.H. (1999). Psychometric functions for gap detection in noise measured from young and aged subjects. Journal of the Acoustical Society of America, 106 (2), 966-978.

Hanekom, J.J., & Shannon, R.V. (1998). Gap detection as a measure of electrode interaction in cochlear implants. Journal of the Acoustical Society of America, 104 (4), 2372-2384.

Irwin, R. J., & Purday, S. C., (1982). The minimum detectable duration of auditory signals for normals and hearing impaired listeners. Journal of the Acoustical Society of America, 71 (4), 967-974.

Irwin, R. J., Hinchliff, L. K., & Klump, S. (1981). Temporal acuity in normal and hearing impaired listeners. Audiology, 20 (3), 234-243.

Ison, J. R., O' Conner, K., Bowen, G.P., & Bocirnea,A. (1991). Temporal resolution of gaps in noise by the rat is last with functional decartication. Behavioral Neuroscience, 105, 33-40

Jensen. K., & Neff, D. L.(1993). Development of basic auditory dysfunction in preschool children. Psychology Science, 4, 104-107.

Jesteadt, W., Bilger, R. C., Green, D. M., & Patterson, J. H. (1976). Temporal acuity in listeners with sensorineural hearing loss. Journal of Speech and Hearing Research, 19, 3157-3160.

Kelly, J.B., & Rooney, B. J. (1996). Effect of bilateral auditory cortical lesions on gap detection thresholds in the ferret. Behavioral Neuroscience, 110, 542-550. Abstract retrieved from http:// www.ncbi.nlm.nib.gov.

Klump, G. M., & Glitch, O. (1991). Gap detection in the European starting (Sturnus Vulgaris) III. Processing in the peripheral auditory system. Journal of comparative Physiology, 168, 469-479. Abstract retrieved from http://www.ncbi.nlm.nib.gov.

Lister, J.J., & Roberts, R.A. (2004). Effects of Age & Hearing loss on Gap Detection and the Precedence Effect: Broadband stimuli. Journal of Speech, Language and Hearing Research, 47, 965-978.

Lister, J.J., & Roberts, R.A. (2005). Effects of Age & Hearing loss on Gap Detection and the Precedence Effect: Narrow–Band stimuli. Journal of Speech, Language and Hearing Research, 48, 482-493.

Lister, J.J., Besing, J., & Koehnke, J. (2002). Effects of age and frequency disparity on gap discrimination, Journal of the Acoustical Society of America, 111 (6), 2793-2800.

Lutman, M. E. (1991). Degradations in frequency and temporal resolution with age and their impact on speech identification. Acta otolaryngology supplement, 476, 120-125.

Moore, B. C. J. (1993). Temporal analysis in normal and impaired hearing. Annals of New York Academy of Science, 682, 119-136. Abstract retrieved from http://www.ncbi.nlm.nib.gov.

Moore, B. C. J. (1997). An Introduction to Psychology of hearing. London. Academic press.

Moore, B. C. J. (1998). Cochlear hearing loss. Whurer Publishers.

Moore, B. C. J., Glassberg, B. R., Plack, C. J., & Biswas, A.K. (1988). The shape of the ear's temporal window. Journal of the Acoustical Society of America, 83 (3), 1102-1116.

Moore, B. C. J., Glassberg, B. R., & Peters, R.W. (1992). Detection of temporal gaps in sinusoids by elderly subjects with and without hearing loss. Journal of the Acoustical Society of America, 92 (4), 1923-1932.

.

Morrongiello, B. A., Kulipg, J. W., & Clifton, R. K. (1984). Developmental changes in auditory temporal perception. Child Development, 55 Abstract retrieved from http://www.ncbi.nlm.nib.gov.

Neff. D. L., Jesteadt, W., & Brown, E. L. (1982). The relation between gap discrimination and auditory stream segregation. Perception Psychophysics, 31, 493-501.

Nelson, D.A., & Freyman, R.L. (1987). Temporal resolution in sensorineural hearing-impaired listeners. Journal of the Acoustical Society of America, 81 (3), 709-720.

Oxenham, A.J. (2000). Influence of spatial and temporal coding on auditory gap detection. Journal of the Acoustical Society of America, 107 (4), 2215-2223.

Rupp, A., Gutschalk, A., Uppenkany, S., & Seherg, M. Middle latency auditory-evoked fields reflect psychoacoustic gap detection thresholds in human listeners. Journal of Clinical neurophysiology, 92 (4), 2239-2247.

Schneider, B.A., & Hamstra, S.J. (1999). Gap detection threshold as a function of tonal duration for younger and older listeners. Journal of the Acoustical Society of America, 106 (1), 371-380.

Schneider, B. A., Pichora-Fuller, M. K., Kowalchuk, D., & Lamb. K. (1994). Gap detection and the precedence effect in young and age adults. Journal of the Acoustical Society of America, 95 (2), 980-991.

Shailer, M. J., & Moore, B. C. J. (1983). Detection of temporal gaps in band limited noise: Effects of variation in Bandwidth and signal to ratio. Journal of the Acoustical Society of America, 77 (2), 635-639.

Shailer, M. J., & Moore, B. C. J. (1987). Gap detection and auditory filter: Phase effects using sinusoidal stimuli. Journal of the Acoustical Society of America, 81 (4), 1110-1117.

Shannan, R. V., & Otto, S. R. (1990). Psychophysical measures from electrical stimulation of the human cochlear nucleus. Hearing Research, 47, 159-168.

Shivaprakash, S. (2003). Gap Detection Test – Development of Norms. Unpublished Independent Project. Mysore: University of Mysore.

Sinex, D. G., & Mc Donald (1988). Average discharge rate representation of voice onset time in chinchilla auditory nerve. Journal of the Acoustical Society of America, 83 (5), 1817-1827.

Sinex, D. G., & Narayana, S. S. (1994). Auditory nerve fibers representation temporal cues to voicing in word-medial stop consonants. Journal of the Acoustical Society of America, 95 (4), 897-903.

Snell, K. B. (1997). Age related changes in temporal gap detection, Journal of the Acoustical Society of America, 101 (4), 2214-2220.

Snell, K. B., & Frisina, D. R. (2000). Relationships among age related differences in gap detection and word recognition. Journal of the Acoustical Society of America, 107 (3), 1615-1626.

Strous, A., Ashmead D.H., Ohde. R.N., & Grantham B. W. (1998). Temporal processing in aging auditory system. Journal of the Acoustical Society of America, 104 (4), 2385-2399.

Smurznski, J., & Probst, R. Detection of temporal gaps in noise stimuli in subjects with and without spontaneous otoacoustic emissions (SOAEs). Article retrieved from http://www.ausp.memphis.edu/ierasg/abstract99/Smurzyns.html

Trehub, S.E., Schneider, B.A., & Henderson, J.L. (1995). Gap detection in infants, children, and adults. Journal of the Acoustical Society of America, 98 (5), 2532-2541.

Tyler, R. S., Summerfiled, Q., Wood, E. J., & Fernandes, M. A. (1982). Psychoacoustic and phonetic temporal processing in normal and hearing impaired listeners. Journal of the Acoustical Society of America, 72 (3), 740-752.

Van. Rooij, J.C. & Plomp, R. (1990). Auditive and cognitive factors in speech perception by elderly listeners. II. Multivariate analysis. Journal of the Acoustical Society of America, 88 (6), 2611-2624.

Viemeister, N.F., & Plack, C. J. (1993). Time analysis, Human Psychophysics (pp. 116-154). New York: Springer, Verlay.

Walton, J. P., Frisina, R. D., Ison, J. R., & O'Neill, W. E. (1997). Neural correlates of behavioural gap detection in the inferior colliculus the young CBA mouse. Journal of comparative Physiology, 181, 161-176. Abstract retrieved from http://www.ncbi.nlm.gib.gov.

Werner, L.A., Marean, G. C. Halpin, C. F., Spetner,N. B., & Gillenwater, J.M. (1992). Infant auditory temporal acuity: Gap detection. Child development. 63, 260-272. Abstract retrieved from http:// www.ncbi.blm.nib.gov.

Werner, L.A., Folson, R.C., Manel, L.R., & Syapin, C.L. (2001). Human Auditory Brainstem Response to Temporal Gaps in Noise. Journal of Speech, Language, and Hearing Research, 44, 737-750.

Zeng, Oba, Grade, Sininger & Starr (1999). Temporal and speech processing deficits in auditory neuropathy. Neuroreport. 10, 3429-3435.

Zhang, W., Salvi, R. J., & Saunders, S. S. (1990). Neural correlates of gap detection in auditory nerve fibers of the chinchilla, Hearing Research, 46, 181-203.

http://www.capdtest.com/rgdt

http://www.audiology online.com/articles/article_ detail. asp? article_id = 282.