GAP DETECTION TEST - DEVELOPMENT OF NORMS

Register No. 02SH0016

An Independent Project submitted as part of fulfillment for the

First year M.Sc, (Speech and Hearing) to University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING,

MYSORE - 570 006

JUNE 2003

Dedicated To

My

Amma, Appaji, Divya Teju

&

My Teachers

Certificate

This is to certify that the independent project entitled ***"Gap Detection Test - Development of Norms"*** is a bonafied work done in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student (Register No. 02SH0016)

Director"

Dr. Jayaram
All India Institute of
Speech and Hearing
Mysore-6

Mysore
June 2003

Certificate

This is to certify that the independent project entitled *"**Gap Detection** Test* - ***Development*** *of Norms "* has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any other Diploma or Degree.

Manjula P

Guide

P. Manjula
Lecturer in Audiology
All India Institute of
Speech and Hearing
Mysore-6

Mysore
June 2003

Declaration

I hereby declare that this independent project entitled ***"Gap Detection Test - Development of Norms"*** is the result of my own study under the guidance of **P. Manjula,** Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other University for the award of any other Diploma or Degree.

Mysore
June 2003 Register No. 02SH0016

ACKNOWLEDGEMENTS

/ would like to express my sincere gratitude to my guide ***(P. Manjula,*** **l***ecturer in audiology, Department of Audiology, All India Institute of Speech & Hearing, for her constant help, valuable suggestions* e£ *support throughout the project. Ma'm, a* **'thank you** *is just not enough to express myself.*

I would like to thank Dr. ***M. Jayaram,*** *Director, AII India Institute of Speech and Hearing, for permitting me to carry out the study.*

I extend my sincere thanks to ***akka, anna, Suresh B*** *for their valuable suggestions in a situation where I -was* ***"nowhere".***

'Thanks to ***Dr. Rajalakshmi , Mr Animesh Berman, Mr. Reddy sivaprasad, Mr. Ajith, Mrs. Poornima, Mr. Vinay for*** *their help and suggestions.*

Banu, Ann *you've Seen turned out to be a good friend. Thank you for your affection and inspiration.*

A special thanks to you,Vinay, for your constant help offers and the good time you'd with me during using u'r computer.

I am thankful to ***Dr. Balakrisdna Acharya, Dr. Venkatashen*** *for helping me out in the Statistical analysis.*

I thank my friends ***Varghese, Gopi, Bini, Vijay& also to Gowri, Ravanan*** *who were encouraging me in all circumstances.*

A special thanks to JK, ***Rajkumar & Sandeep,*** *for being good friends and supporting me at every stage.*

*A special thanks to R****icha, Tanu, Anita, Shereen, Gowri, Amita, Anjana, Poornima, Deepa, Shiwanis***

I thank all my classmates *for their timely help, moral support and their* ***timely nonsense!!!***

I would also like to express my sincere thanks to all the ***subjects,*** *who patiently sat through the whole data collection and made this project possible.*

My sincere thanks to all the ***MrM.ahadeva, Mr.Lokesh, Mr.Gopal, MrShiva prakash & Dr. Raju for*** *their help in reaching the 6ooks and Journals.*

My sincere thanks to ***Mr. Shivappa*** *and* ***graphic's Juggi,*** *who shaped this project to be as it is in your hand.*

Finally, I thank God, for being my friend & giving me the strength and the inspiration for what I'm being now...

TABLE OF CONTENTS

INTRODUCTION

Time is a very important dimension in hearing, since almost all sounds fluctuate over time. Further more, for sounds, that convey information, such as speech and music, an important step in describing the performance of the human auditory system is to measure its temporal response to time varying changes in acoustic parameters. It was claimed that auditory temporal processing and resolution is a pre-requisite condition for linguistic abilities as well as for reading and spelling. As Viemeister and Plack (1993) pointed out, for speech and other acoustic communication sounds, the temporal pattern of spectral changes is essentially, the informational substrate.

Temporal resolution refers to the ability of the auditory system to follow rapid changes in the envelope of sounds. Temporal resolution is measured in various ways, including detection threshold for amplitude modulation (Viemeister, 1979), forward masking and backward masking (Moore, Glasberg, Plack & Biswas, 1988), temporal order discrimination (Green, 1973). Another test which is similar to gap detection is the Auditory Fusion Test-Revised (AFT-R), designed to measure one aspect of audition discussed by the ASHA consensus panel, namely temporal resolution. Another psychophysical method, which recently well established, is a gap detection test. It measures a listener's ability to detect a 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. 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 naive listeners, including infants. The gap detection thresholds obtained from naive listeners are close to those obtained from well-trained listeners (Werner, Marean, Halpen, Spetner & 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 & Saunders, 1990; Klump & 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 & Hausler 1989; Eggermont, 1995, 1999; Walton, Frisina, Ison & O'Neill, 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 & Bocirnea, 1991; Kelly & 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. That 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 a band of modulation filter following a peripheral processing has done an excellent job of predicting psychophysical results with realistic cochlear filtering (Dau, Kollmeier & Kohlrausch, 1997)

Gap stimuli used in psychoacoustics studies are acoustically analogous to voice-onset- time for consonants in speech (or formants) and it is also necessary for linguistic ability during developmental ages. Gap detection is generally the preferred behavioral measure of temporal resolution. The experimental stimuli are generally constructed from broadband noise, narrow band noise, or pure tones. Although broadband noise has the advantage of masking the spectral splatter that may result from abruptly interrupting the signal, it obscures the specific frequencies used in detecting the gap (Florentine & Buus, 1982, 1984; Fitzgibbons & Wightman, 1982; Shailer & Moore, 1983). Because of several reports of frequency dependent differences in absolute threshold between adults and children (Schneider, Trehub, Olsho, & Trehub, as cited in Sandra, Trehub, Bruce, Schneider & Joannal, 1995), it may be especially difficult to separate the effects of sensitivity difference in different frequency regions from temporal resolution differences in the context of broadband noise. The use of narrow band noise permits the specification of stimulus frequency, but introduces amplitude fluctuation that the listener may confuse with gaps. Gap detection threshold will be influenced by an ability to discriminate difference between local amplitude fluctuations and an actual gap in a narrow-band noise (Glasberg, Moore & Bacon, 1987; Moore, Glasberg & Biswas 1988; and Glasberg &

Moore, 1992). By contrast, the use of signals constructed from pure tones precludes the frequency specification problems of broadband noise and the amplitude fluctuation of narrow band noise.

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 & Clifton, 1984; Jensen & Neff, 1993) 9 and 11 years of age by others (Davis & Me Croskey; Irwin; Grose, as cited in Sandra et al., 1995). No doubt, difference in stimuli and experimental tasks account for the apparent differences.

In contrast to the evolving picture of temporal resolution in early and later childhood, relatively little is known about temporal acuity in infant listeners. Nevertheless, the hearing threshold of 6-month-old infants for duration discrimination (Morrongiello & Trehub, as cited in Sandra et al., 1995) and the precedence effect seem to be twice the size of those reported for adults. Similarly, gap detection threshold for infant listeners (3, 6 & 12 months) are five to eight times that of adults (Werner, Marean, Halpin, &Spetner, 1992).

In a series of studies on the relationship between temporal processing and speech perception (Gorden-Salant & Fitzgibbons, 1993) a robust aging effect was observed in the recognition of speech stimuli modified by several temporal factors such as speech rate, time compression or reverberation. These observations suggest that impaired temporal resolution may contribute to the diminished speech perception of aged subjects and auditory processing disorder cases, though straight forward relationship between speech perception and temporal resolution has not been established (Tyler, Summerfield, Wood, Fernandes, 1982; Glasberg & Moore, 1988; Strouse, Ashmead, Ohde, & Grantham 1998). If a general deficit in temporal resolution is a cause for dyslexia, the gap threshold of dyslexics should be higher than that of normals.

In this study, it is aimed at developing normative data of gap detection threshold in children (from 7 to 12 years of age range) and comparing this with that in adults (from 18 to 35 years). This can serve as a reference to measure one aspect of temporal processing (temporal resolution) in the clinical population.

Need for the study

Various tests to evaluate different aspects of temporal processing are available. Gap detection test is one of them. Gap detection has long been used as a measure of temporal resolution in the auditory system (Plomp, 1964; Penner, 1977; Buus & Florentine, 1985 & Moore, 1993). 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. Also regional differences are reported in auditory processing abilities (Musiek, Baran & Pinheiro, 1990 as cited in Bellis, 1997). Hence, in the present study it is intended to study the normative aspects of gap detection in children under different age groups. These norms would be useful for comparison with the clinical population who have temporal processing problems.

Aim of the study

To develop normative data for gap detection threshold in children, in different age groups, and comparing it with gap detection threshold in adults.

REVIEW OF LITERATURE

Rapid Auditory Processing (RAP) skills are believed to underlie successful language acquisition. Further more, for sounds which convey information, such as speech and music, much of the information appears to be carried in the changes themselves, rather than in the parts of the sounds which are relatively stable, with respect to the time. The ability to perceive a stimulus, which are presented, in very rapid succession as different is called "TEMPORAL PROCESSING". 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.

In temporal processing it is important to distinguish "Temporal resolution" and "Temporal integration" (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.

The major difficulty in measuring the temporal resolution of the auditory system is that changes in time pattern of a sound are generally associated with changes in its magnitude spectrum. Thus, the detection of a change in time pattern, can sometimes, depend not on temporal resolution per se, but on the detection of the spectral change. There have been two general approaches to study this aspect. One is to use signals whose magnitude spectrum is not changed when the time pattern is altered; E.g. Magnitude spectrum of white noise remains flat if the noise is interrupted. Second approach uses stimuli whose spectra are altered by the changes in time pattern, but extra background sounds are added to mask the spectral changes.

Auditory Fusion Test- Revised (AFT- R) and Gap Detection Test (GDT) are the measures of temporal resolution. Auditory Fusion Test-Revised (AFT-R) is designed to measure one aspect of audition discussed by the ASHA consensus panel, namely temporal resolution. The method of evaluating temporal resolution in the AFT-R is through determination of the Auditory Fusion Threshold (A F Threshold). The auditory fusion threshold is measured in milliseconds (msec) and is obtained by having a listener attend to a series of pure tones presented in pairs. The silent time interval (the interpulse interval) 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 tone or two tones. The auditory fusion threshold is the average of the points at which the two tones, for the ascending and descending interpulse interval (IPI) series, are perceptually fused and heard as one.

One of the psycho- physiological methods for measuring auditory temporal processing is the gap detection paradigm. Gap detection is a reasonably well-established method, which measures the ability of the listener to detect a 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 a naive listener, including infants. The gap detection thresholds obtained from 3. naive listeners are close to those obtained from well-trained listeners (Werner, Marean, Halpen, Spetner & Gillenwater, 1992). Forrest and Green (1987) have reported that gap detection and the temporal modulation transfer function yield similar estimates of temporal acuity.

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

Type of stimuli:

1. A. Band pass noise
   B. Wide band 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

1. Type of stimuli:

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; Glasberg, 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 (Glasberg et al, 1987; Moore & Glasberg, 1988).

Gap detection threshold 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 filter are rapid and not very confusable with the gap. When the noise band width is small, or when the noise is centered at a low frequency where the auditory filter band width is small, the fluctuations at the out put of the filter are slower, and more confusable with the gap.

Most studies showing decreasing 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 band width at the highest center frequency used), gap threshold for normal subjects decreased with increasing center frequency, but at a lower rate than when relative bandwidth is held constant (Shailer & Moore, 1985). For narrow bandwidth, gap threshold for both normal and impaired subjects hardly change with center frequency (Shailer & Moore, 1985). This is consistent with the idea that fluctuation in the noise plays a significant role. Fluctuation 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 fluctuation 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 idea that fluctuations in the noise play an important role.

B. Gap detection in wide band noise

The detection of gap in broadband 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 & Saunders, 1990), inferior colliculus neurons in the mouse (Walton, Frisina, Ison & O' Neill, 1997), and primary auditory cortex neurons in the cat (Eggermont, 2000), to behavioral techniques such as pre-pulse inhibition in the rat (Ison & Leitner; as cited in Allen et al. 2002), as well as psychophysical perceptual measures in humans (e.g.; Plomp, 1964; Green & Forrest, 1989; Snell, 1997; Florentine, Buus & 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 & Fernandes, 1982; Busby & Clark, 1999; Snell & Frisina, 2000). But it obscures the specific frequencies used in detecting gap (Florentine & Buus, 1982, 1984; Fitzgibbons & Wightman, 1982; Shailer & Moore, 1983; Glasberg, Moore, Bacon, 1987). Broadband noise stimuli are popular since they can be varied in duration or interrupted for precise specification of At, 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, Virage, James & Ison, 2002). This advantage can be obtained from BBN gap detection. For sinusoids and broadband noise, silent gaps of 5 msec or less can be detected. This minimum detectable gap duration has been interpreted as revealing fundamental "sluggishness" in the auditory system's response to very rapid changes in sound level. In another 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 gaps in BBN is typically between 2 and 3 msec

(Plomp, 1964; Irwin & Purday, 1982; Forrest & 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 & van Valken Berg, 1979; Buus & Florentine, 1985; Forrest & Green, 1987). The typical threshold for detection of a gap in wideband noise burst is 2 to 3 msec (Green, 1985 as cited in He et al., 1999). Plomp (1964) suggested that temporal resolution is limited by the decay of sensation produced by the first part of the stimulus, which would fill in the gap.

C. Gap detection in sinusoidal markers

Temporal gap detection threshold measured with sinusoidal stimuli (as a function of the frequency separations between the sinusoidal markers) appears to offer the opportunity to evaluate both temporal acuity and frequency selectivity simultaneously. Most studies of temporal gap detection have been done with noise burst stimuli having similar physical properties before and after the silent gap. Only a few studies of temporal gap detection have used sinusoidal stimuli. 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) reported gap detection threshold for condition, where, the silent gap was positioned temporally between a pair of sinusoidal markers were approximately 200 msec before and after the silent gap. The stimuli before and after the gap are known as markers. The second marker began at the end of the silent gap and started with the phase it would have had if the first marker had continued with-out interruption. This stimulus condition was referred to as "preserved phase". Shailer and Moore measured gap detection threshold of about 5 msec that were relatively independent of frequency from 200 to 2000 Hz.

Perhaps the most intriguing of the gap detection experiment with sinusoidal marker is an earlier report by Williams and Perrott (1972) for a condition where the silent gap was positioned temporally between pairs of sinusoids of different frequency. 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 as the frequency separation between two markers, which were spaced equidistantly above and below 1000 Hz, was increased from 8 to 480 Hz. For shorter marker duration (3,10, and 30 msec), the gap detection thresholds were essentially independent on frequency separation.

Williams and Perrott speculated that the pattern of their results might reflect the role of the critical band process and it's narrowing with increasing stimulus duration. The idea that the width of the critical band is time dependent and is affected by signal duration has long been an issue of interest to auditory theorists. Because gap detection thresholds appear to increase in magnitude as a function of increasing frequency differences between the frequencies of the sinusoidal markers. Also, the band width of a time dependent critical band process should be relatively broad in response to brief marker duration. The listeners are expected to be relatively poor at resolving differences between brief sinusoidal markers. In contrast, for longer marker duration, the critical band process presumably has time to achieve characteristic narrow bandwidth. The listener should then be better able to resolve frequency difference between the longer markers. A lower gap detection threshold at the lower Fl frequencies, 500 and 1000 Hz, than at 4000 Hz has been typically observed. This pattern is probably due to the increased signal- to- noise ratio that results from using narrower critical bands at the lower frequencies. These patterns reflect at least two artifacts in the preliminary gap detection measurement procedure - 1. Onset of artifacts may have arisen from confounding overall duration cues for condition yielding large gap detection thresholds. 2. Second artifact may have been due to an extraneous gating transient cue that was often detectable under conditions where the stimuli were most audible. The latter artifact, due to gating transients at the lower F2/F1 ratio and, appeared to be ignored by our listeners when the marker frequencies were more widely spaced. An obvious way to minimize the phase artifact, which accompanied the silent gap at onset of F2, was to present the sinusoidal markers at reduced sensation levels (or to negate confounding acoustic transients due to gating the stimuli 'off and 'on' abruptly to produce the silent gap).

It is reported through research that listener could be deterred from using gating transient cues for small F2/F1 marker ratios by randomizing the onset phases of F2 in both the standard and comparison intervals. It was also found that randomizing overall marker duration could extend the effective range of measurement for gap detection threshold. The experiment revealed that the listeners may rely on one or more extraneous cues, which accompany the presence of the silent gap, for gap detection, and it has been found that the availability and use of a particular extraneous cue depended on the stimulus design of the experiment. Moreover, studies suggest that while one listener may use the silent gap for performing the gap detection task, a second listener in the same experiment may rely on an extraneous cue used by a third listener in performing that task. Thus, the accurate measurement of gap detection thresholds with sinusoidal markers is not a trivial matter.

2. Effect of noise burst duration

In many auditory perception tasks, performances decrease with decreased stimulus duration (Moore, 1973-, Viemeister, 1979; Hall & Fernades, 1983). However, reports of the effect of noise burst duration on gap detection are inconsistent. Muchnik (as cited in He et al., 1985) showed that gap detection thresholds of young normally hearing subjects increased as noise burst duration decreased from 10 msec.

3. Effect of location and uncertainty of gap on speech perception

A few studies examined the effect of the 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 a 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 a 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 pseudorandom 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, Ashmead, Ohde & 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 fixed and random condition (Green & Forrest, 1989). The condition related differences was smaller than the between subject variability, indicating high reliability of individual subject's performance. Below the 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. Further more, there was only a small difference in performance between the two groups in either conditions. When the gap was located away from the center position to the two extreme ends location (5% & 95%), performance declined. In the fixed condition (when the gap location is fixed trial to trial, at either 5%, 50% or 95% of total duration of NB), 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 detection threshold 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% & 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 & Wightman, 1982; Irwin, Hinchcliff & Klump, 1981; Florentine & Buus, 1984).

5. *Subject related factors*

5 a). Effect of subject's age:

The studies that have examined gap threshold in infants and children have all reported age differences. Werner, Marean, Halpin, Spetner, Gillenwater (1992) found that the gap thresholds in 3-, 6-and 12-month-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. The results of Irwin (1985) and Wightman (as cited in Formby & Forrest, 1991) disagree on the age at which gap threshold mature. Irwin found that gap threshold was not mature, until 10 to 12 years, where as, Wightman obtained adult-like gap threshold among 5 to 7 year old. Schneider (as cited in Schneider, Fuller-Fuller, Kowalchule, 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.

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 He et al., 1999). Many studies (Van Rooj, & Plomp, 1990; Dubno, Dirks & 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 & Wieghtman, 1982; Irwin, 1981; Florentine & Buus, 1984). However, there is a relatively large body of evidence showing age related difference in the perception of temporally distorted speech.

In a series of studies (Gordon-Salant & 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 may contribute to diminished speech perception of the aged subject, though straight forward relation between speech perception and temporal resolution has not been established (Tyler et al., 1982; Glasberg & Moore, 1988; Strous, et al., 1998)

In a large scale study, 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 with out hearing loss, and, reported that elderly listeners 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.

5 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 fluctuation in a waveform that occur in time intervals as brief as 2-3 ms. (Resolution thresholds in this range come from several studies that were designed to measure auditory temporal acuity (Miller & Taylor, 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 the hearing-impaired observer's 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.

Study of temporal resolution in ears with sensori neural (SN) impairment has not been pursued extensively. Cudahy and Elliott (as cited in He et al., 1999) inferred from data that some listeners with sensori neural 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 the 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 frequencies.

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 it didn't 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 that 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 equated 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 doesn't 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 listener 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 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 & Klump, 1981; Florentine & Buus, 1984) and for band pass noise stimuli presented in a broadband or band stop background, (Fitzgibbons & Wightman, 1982; Tyler et al., 1982; Buus & 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 & Whightman, 1982; Shailer & 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 decreasing 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 a shorter time.

Auditory filter of subjects were broader in their impaired ear than in their normal ear (Glasberg & 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 band width 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 & Moore, 1983, 1985). For subjects with high frequency hearing loss, performance might be poorer simply because the higher frequency component in the stimuli are inaudible (Bacon & Viemeister, as cited in Brian, Glasberg & Moore, 1986). This would decrease both the effective bandwidth and the effective upper cut-off frequency.

When making comparison between normal and impaired hearing based on the level at which subjects are tested, gap threshold decreases with increasing level both for normal and for hearing impaired subjects (Shailer & Moore, 1983: Florentine & Buus, 1983, 1984; Buus & Florentine, 1985). It remains unclear whether impaired and normal subjects should be compared at equal SPL, equal SL 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, Grose & 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 & Wightman, 1982; Fitzgibons, 1983; Florentine & Buus, 1984). Second, there is some evidence that the gap detection performance supported by the 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 200 Hz), perhaps because the narrow filters of the low frequency; cochlea has longer response times ("ringing") (Moore & Glasberg , 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 or 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 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 within 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 (Carnaey & Geisler, as cited in Snell, 1997) but it 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, McDonald, 1988; Sinex & Narayan, 1994). In the extreme case of the stimulus elements, having no spectral overlap, however, the relative timing operation must presumably be 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 & 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.

5 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 deficits in speech perception and, in turn, impaired language development.

Developmental language learning disabilities, such as developmental dyslexia (specific reading disability) and specific language impairment (SLI), are characterized by a 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, Garde, Sininger & 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 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 a fundamental dysfunction in the ability to process brief auditory stimuli followed in rapid succession 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 and the processing of stimuli that are presented in rapid succession."

These findings have been assimilated into a theoretical framework advanced by Tallal and colleagues (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 dyslexic brains, and auditory processing deficits 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 a 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.

A review of literature suggests that broadband noise stimuli are popular since they can be varied in duration or interrupted for precise specification of At, without causing significant change in the stimulus energy spectrum used in gap detection test. And also it has been reported that 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, central auditory processing disorders, learning disability and different hearing loss subjects. Auditory processing abilities are well developed in infancy and thus such deficits should be detectable in infants. It will be useful for proper management. At the later age it will be difficult for identification as well as management also. So in this study on "gap detection test"(using broad band noise) development of age related norms is attempted. This helps in comparing the results with clinical population.

METHOD

Subjects

Ninety normal hearing subjects participated in the study. The subjects were selected based on the following criteria:

1) No significant history of external, middle and inner ear problem.
2) Hearing thresholds of all the subjects were less than 20 dB HL at audiometric frequencies. On immittance screening, they had 'A' type tympanogram and reflex present.
3) A checklist was used to rule out subjects with APDs
4) Average or above average intellectual functioning

The subjects were divided into seven groups. They are:

Group 1: Ten subjects in the age from 7 to 7.11 years

Group 2: Ten subjects in the age from 8 to 8.11 years

Group 3: Ten subjects in the age from 9 to 9.11 years

Group 4: Ten subjects in the age from 10 to 10.11 years

Group 5: Ten subjects in the age from 1 lto 11.11 years

Group 6: Ten subjects in the age from 12 to 12.11 years

Group 7: Thirty subjects in the age range from 18 to 35.11 years.

Instruments used:

A calibrated diagnostic audiometer (Madsen Orbiter-922, Version 2)

A calibrated immitance meter

PC with audio lab software (V2) and sound generator software to develop gap detection test.

Tape recorder (Philips AZ 2160 V) with CD on gap detection test.

Test Environment:

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

Procedure'

The procedure involved two phases

Phase 1: Development of Gap Detection Test.

Phase2: Administration of GDT to develop normative data.

Phase 1: Development of Gap Detection Test (GDT)

There were sixty stimuli sets (including 4 practice sets and 6 catch trials to avoid false positive and false negative responses) in the Gap Detection Test recorded on the CD. Each stimulus set consisted of three noise bursts of 300 msec duration separated by a silence of 750 msec. A gap was introduced at the center (50% of total ,. burst duration of each burst) in one of the three bursts. The duration of the gap started from 20 msec. The gap was reduced step- by- step. That is, from 20 msec to 11 msec, it was reduced in 2 msec steps. After 11 msec, it was reduced in 1 msec steps. The sixty stimuli were recorded on a CD with 1 kHz calibration tone. This CD with the GDT was used to develop norms in phase 2.

Phase 2: Administration of GDT to develop normative data

The subject was seated comfortably on a chair in the patient room. He/she was made to wear the headphone of the audiometer. The subject was instructed as "please listen to the set of three noise bursts. One of the three-noise bursts in the set will contain a gap of varying duration. You have to indicate to me, verbally, which of the three noise bursts in the set had the gap. For practice, please listen to the sets now and tell me which of the three noise bursts has the gap".

Before the actual test sets, four practice sets were given to train the subject. The gap duration in the four practice sets were 20, 16, 12 and 10 msec. The fifty six stimuli sets (including six catch trials) of the gap detection test were routed through each ear separately, for each subject, in each age group. The subject was presented the stimuli sets monaurally, at 40 dBSL (re: PTA), through the Orbiter-922 audiometer.

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 was reduced to trace the smallest gap that he could detect using the bracketing technique. The minimum gap that could be detected by the subject was taken as gap detection threshold. The smallest gap was then tabulated for each ear, of each subject, in different age groups. Age related normative threshold on gap detection test was established using appropriate statistical procedure.

RESULTS AND DISCUSSION

Data on gap detection threshold were collected for different age groups in order to develop norms. The data was tabulated for statistical analysis. The SPSS (Statistical Package for Social Science, 7.5) on the personal computer was utilized for analysis.

Table 1 shows the mean, range, standard deviation and "t" values of the Gap Detection Threshold, for the right and left ears, in different age groups. The mean values of gap detection threshold overlap between the age groups. The range and standard deviation values reveal less variability among different age groups. From the "t" values of paired sample t-test of statistical significance, it can be inferred that there is no significant difference in gap detection threshold between the right and left ears in different age groups studied. As there was no significant difference between the gap detection thresholds of right and left ears, the gap detection threshold of left and right ears were combined for each age group.

Table 2 shows the mean, range, standard deviation and "t" values of the Gap Detection Threshold between age groups. Here also the mean values overlap across the age groups. There was no significant difference between the age groups studied. Hence, it can be concluded that the gap detection threshold reach the adult values by the age of seven years, the lowest age group studied.

This finding conforms with that reported by Davis and Mc.Croskey; Irwin; Grose (as cited in He et al., 1999) which reported that achievement of adult-like temporal acuity is by five to six years of age. However, Morrongiello, Kulipg and Clifton, 1984; Wightman, 1989 and Jensen and Neff, 1993, have reported the age of achievement of adult-like temporal acuity as nine and eleven years of age.

Table 1: Mean, Range, Standard Deviation and 't' values for right and left ears in different age groups on Gap Detection Threshold.

AGE	*EARS*	*MEAN*	*SD*	*"t" VALUES*
7 YEARS	RIGHT (N=10)	**3.9**	0.73	1.406 (NS)
	LEFT (N=10)	**4.2**	0.78	
8 YEARS	RIGHT (N=10)	**3.8**	0.63	1.309 (NS)
	LEFT (N=10)	**4.2**	0.78	
9 YEARS	RIGHT (N=10)	**4.0**	0.66	1.406 (NS)
	LEFT(N=10)	**3.7**	0.48	
10 YEARS	RIGHT (N=10)	**3.9**	0.56	0.00 (NS)
	LEFT (N= 10)	**3.9**	0.31	
11 YEARS	RIGHT (N=10)	**3.4**	0.51	1.627 (NS)
	LEFT (N=10)	**4.1**	0.56	
12 YEARS	RIGHT (N=10)	**3.6**	0.51	1.964 (NS)
	LEFT (N=10)	**3.9**	0.56	
ADULTS	RIGHT (N=10)	**3.6**	0.51	1.682 (NS)
	LEFT (N=10)	**3.0**	**0.66**	

(NS) = **Not significant**

Table 2: Mean, Range, Standard deviation and "t" values between age groups

AGE	*MEAN*	*SD*	*"t" VALUES*
7 YEARS	4.05	0.75	0.224 (NS)
8YEARS	4.0	0.72	
8 YEARS	4.0	0.72	0.719 (NS)
9 YEARS	3.8	0.58	
9 YEARS	3.8	0.58	0.295 (NS)
10 YEARS	3.9	0.44	
10 YEARS	3.9	0.44	1.422 (NS)
11 YEARS	3.6	0.58	
11 YEARS	3.6	0.58	0.623 (NS)
12 YEARS	3.7	0.55	
12 YEARS	3.7	0.55	0.438 (NS)
ADULTS	3.3	0.66	

(NS) = Not significant

In this study, it was found that there was no improvement in gap detection threshold as age increased after 7 years of age. This study is in accordance with the earlier studies reported in literature (Morrongiello, Kulipg, Cliften, 1984; Wightman, 1989; Jensen & Neff, 1993). The results of the present study suggest that normal hearing individuals start performing like adults on gap detection by the age of 6 to 7 years, the lowest age group studied.

Since the test can to be administered to 6 to 7 year old children, this test can be used to find out the temporal resolution in early age itself. Information on temporal resolution has implication on good speech perception. It can also be used in different developmental language disabilities including developmental dyslexia, specific language impairment, and impairment in processing rapidly presented auditory stimuli. Gap detection is expected to be effective to find out temporal resolution or acuity, which is necessary for speech perception.

The results can be useful in identifying problems in temporal acuity or temporal resolution in different types of hearing loss. Buus and Florentine, 1982; Fitzgibbons & Wightman, 1982; Shailar & Moore; 1983, have found poor gap detection threshold in high frequency hearing loss because the high frequencies are primarily responsible for the detection of a gap in broad band noise. The hearing impaired listeners may get lower gap thresholds because they are not able to perceive the high frequency part of the broad band noise and it appears that subjects primarily use information from the highest frequency region available (Shailer & Moore, 1983, 1985). Bacon and Viemeister, 1988, found for subjects with high frequency hearing loss, performance might be poorer simply because the higher frequency components in the stimuli are inaudible. Elliott (1975) also inferred from masking data that some listeners with sensori neural hearing impairment have reduced temporal resolving capacity. On the contrary, jasteadt (1976) found that impaired ears sometimes showed better temporal resolution than normals, since auditory filter is broader than the normal. Hence, this test can be used to find out temporal resolution in hearing impaired listeners.

Temporal acuity or temporal resolution is affected by higher central deficits, i.e.; processing problem. While processing problem may be noted in developmental language disabilities, including developmental dyslexia and specific language impairment. These problems exhibit impairment in processing rapidly presented auditory stimuli. It has been hypothesized that these deficits are associated with concurrent deficit in speech perception and in turn impairment in language development.

Tallal (as cited in Zeng et al., 1999) predicted that an impaired ability to process and discriminate rapidly changing auditory information would lead to severe impairment in rapid changes (i.e., formant transitions). On the contrary, no group difference in gap detection threshold was found for adults and gap detection threshold appeared 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 and easy to measure in naive listeners, the present test and data may be a useful diagnostic tool in identifying auditory temporal resolution deficits in children. This helps in assessing the speech perception problems in children which in turn can serve as a guideline for proper therapy management.

In summary, the normative data on gap detection task can be used to detect temporal processing deficit (temporal acuity or temporal resolution) in developmental language disabilities such as developmental dyslexia, specific language impairment and central auditory processing disorder. 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. One single test in isolation may not have much significance in assessing, but the combination of many related tests may be useful in identifying temporal acuity deficit.

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, the gap detection is one of the important psychophysical method 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. It is also reported 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 is expected to be effective and easy to evaluate an aspect of temporal resolution or acuity, which is necessary for speech perception. The objective of the present study was to develop normative data for gap detection threshold in children in different age groups and comparing it with gap detection threshold in adults to know the age at which the child achieves adult- like temporal acuity.

To study the objectives seventy normal hearing subjects in two groups- children from seven years to twelve years, and adults from eighteen to thirty five years (10 subjects in each age group among children - seven years, eight years, nine years, ten years, eleven years, 12 years & 30 subjects in adults were taken in each age groups).

Each subject was required to have normal pure tone thresholds, normal middle ear conditions and should have passed APD cheklist.

The stimuli recorded on a CD along with calibration tone and were routed through head phone to each ear of each subject. Each stimulus set consisted of 3 noise bursts of 300 msec 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 3 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 a 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 was no significant difference in gap detection threshold between the ears.
2) There was no significant difference in gap detection threshold across age from seven years to twelve years in children and eighteen to thirty five years in adults, in present study i.e., since there was no significant difference in threshold between seven years to twelve years in children and eighteen to thirty five years in adults, from this data we can conclude that adult - like temporal resolution is achieved at the age of seven, the youngest age studied.

Clinical Implication

1) By having these normative data, Gap Detection Test may be a useful clinical tool for identifying temporal resolution in early age it self to asses developmental language disabilities such as Developmental Dyslexia, SLI etc.
2) This data can be used as baseline on which the management procedures can be evaluated.

REFERENCES

Allen, P. D., Tracy, M., Virag & Ison, J. R. (2002). Humaen detect gap in BBN according to effective gap detection with out additional cues from abrupt envelope changes. *Journal of the Acoustical Society of America, 112,* 2002.

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

Buchfellner, E., Leppelsack, H.J., Klump, G.M., & Hausler, U. (1989). Gap detection in the starting II. Coding of gaps by forebrain-neurons. *Journal of comparative physiology (A), 164,* 539-549. Abstract retrieved on January 21, 2003 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,* 1841-1852.

Buss, S., & Florentine, M. (1985). Gap detection in normal and impaired listeners. The effect of level and frequency" In A. Michelsen, *Time Resolution in Auditory System " (pp. 159-179)* ;Ed, New York. Springer-Veriag

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

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

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

Eggermont J.J. (2000). Neural responses in primary auditory cortex mimic psychophysical, across-frequency channel, gap-detection threshold. *Journal of Neurophysiology, 84,*1453-1463. Abstract retrieved on February 13, 2003, from http://www.ncbi.nlm.nib.gov.

Eggermont, J.J. (1995). Neural co-relates of gap detection and auditory fiction n cat auditory cortex. *Neuroreport. 6,* 1645-1648. Abstract retrieved on January 13, 2003 from http://www.ncbi.nlm.nib.gov.

Eggermont, J.J. (1999). Neural correlates of gap detection in three auditory cortical fields in the cat. *Journal of Neurophysiology, 81,* 2570-2580. Abstract retrieved on February 1, 2003 from http://www.ncbi.nlm.nib.gov.

Elliott, L. L. (1975). Temporal and masking phenamena in person with sensorineural hearing loss. *Audiology. 14,* 336-353. Abstract retrieved on June 2, 2003, from http://www.ncbi.nlm.nib.gov.

Fitzgibbons, P. J. & Gordon- Salant, S. (1995). Age effects on duration discrimination with sample and complete stimuli.. *Journal of the Acoustical Society of America.* PS, 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*, 761-765.

Fitzgibbons, P.J. (1983). Temporal gap detection in noise as a function of frequency, bandwidth and level. *Journal of the Acoustical Society of America, 74,* 67-72.

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

Florentine, M., & Buus, S. (1982). In the detection of a temporal gap frequency dependent? *Journal of the Acoustical Society of America, 72,* 767-765.

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

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

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

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

Forrest, T.G. & Green,D.M. (1987). "Detection of partially filled gaps in noise," J. Acoust. SocAm., 82,1933-1943.

Glasberg, B. R & Moore, B. C. J. (1986). Gap detection and masking in hearing impaired and normal hearing subjects.. *Journal of the Acoustical Society of America.* 57,1987.

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

Glasberg, B. R., Moore, B. C. J & Bacon, S. P. (1981). Gap detection and masking in hearing impaired and normal hearing subjects. *Journal of the Acoustical Society of America,* 57,1546-1556.

Glasberg, 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,* 1093-1101.

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

Gordan - 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.

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

Green, D. M (1973). Temporal acuity as a function of frequency. *Journal of the Acoustical Society of America, 54,* 373-379.

Green, D M. (1993). Temporal gaps in noise and sinusoids. *Journal of the Acoustical Society of America. 86,* 961-970.

Gross, J. H (1991). Gap detection in multiple narrow bands of noise as a function of spectral configuration. *Journal of the Acoustical Society of America , 90,* 3061-3068.

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,* 1172-1177.

Hall, J. W., Grose , J . H., & Joy. S (1996). Gap detection for pairs of noise bands; Effects of stimulus level and frequency seperation. *Journal of the Acoustical Society of America, 99, 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*, 966-978.

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, 961-91 A.*

Irwin, R. J., Hinchcliff, L. K., & Klump, S. (1981). "Temporal acuity in normal and hearing-impaired listeners." *Journal of the Acoustical Society of America. 71,* 967-974.

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. *Behavioural Neuroscience, 105,* 33-40. Abstract retrieved on October 10, 2002 from http://www.ncbi.nlm.nib.gov.

Jensen, J.K. & Neff, D.L. (1993). Development of basic auditory disfunction in preschool children. *Psychology Science, 4,* 104-107. Abstract retrieved on October 5, 2002, from http://www.ncbi.nlm.nib.gov.

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.* 79,3157-3160.

Kelly, J.B., & Rooney, B.J. (1996). Effect of bilateral auditory cortical lesions on gap detection thresholds in the ferret. *Behavioural Neuroscience, 110,* 542-550. Abstract retrieved on October 16, 2002 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 on January 29, 2003, from http://www.ncbi.nlm.nib.gov.

Lutman, M.E. (1991) Degradations in frequency and temporal resolution with age and their impact on speech identification. *Journal of the Acoustical Society of America, 19,* 151-163.

Miller, G. A., & Taylor, W. G. (1948). The perception of short bursts of noise. *Journal of the Acoustical Society of America, 20,* 160-170.

Moore, B. C. J. (1973). Frequency difference limens for short duration tone. *Journal of the Acoustical Society of America, 54,* 610-619.

Moore, B.C.J. (1993). Temporal analysis in normal and impaired hearing. Annals of New York Academy of Science, 682, 119-136. Abstract retrieved on September 9, 2002, 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. & Glasberg, B.R. (1988). Gap detection with sinusoidals and noise in normal, impaired and electrical, simulated ears. *Journal of the Acoustical Society of America, 83,* 1093-1101.

Moore, B.C.J., Glasberg, 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,* 1102-1116.

Morrongiello, B.A., Kulipg, J.W., & Clifton, R.K. (1984). Developmental changes in auditory temporal perception. *Child Development, 55* Abstract retrieved on December 23, 2002,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.* 37,493-501.

Penner, M.J. (1977). Detection of temporal gaps in noise as a measure of the decay of auditory sensation. . *Journal of the Acoustical Society of America*, *61,* 552-557.

Plomp. R. (1964). Rate of decay of auditory sensation. *Journal of the Acoustical Society of America, 36,* 277-282.

Sandra, Trehub, Bruce, Schneider & Joannal (1995). Gap detection in infants, children and adults. *Journal of the Acoustical Society of America, 98.*

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

Shailer, M.J., & Moore, B.C.J. (1983). Gap detection as a function of frequency, bandwidth and level. *Journal of the Acoustical Society of America, 74,* 467-473.

Shailer, M.J., & Moore, B.C.J. (1985). 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,* 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,* 1110-117.

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

Sinex, D. G., & Me Donald (1988). Average discharge rate representation of VOT in chinchilla auditory nerve. *Journal of the Acoustical Society of America.* 53,1817-1827.

Sinex, D. G., & Me. Donald, L. P. (1988). Average discharge rate representation of voice onset time in chinchilla auditory nerve. *Journal of the Acoustical Society of America. 83,* 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,* 897-903.

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

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

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

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

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

Tyler, R. S., Summerfield, 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,* 740-752.

Van. Rooji, J. C. G. M. & Plomp. R (1990). Auditory and cognitive factors in speech perception by elderly listeners. *Journal of the Acoustical Society of America,* 55,2611-2624.

Viemeister, N.F. (1979). Temporal modulation transfer function band upon modulation threshold. *Journal of the Acoustical Society of America, 66,* 1364-1380.

Viemeister, N.F., & Plack, CJ. (1993). Time analysis, *Human Psychopysics* (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 on November 5, 2002 from http://www.ncbi.nlm.nib.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 on April 6, 2003, from http://www.ncbi.nlm.nib.gov.

Wilber.LA., (1994). Calibration, Puretone, speech and noise signal. In J. Katz (Ed) *Handbook of clinical audiology.* London; William and Wilkins.

Williams, K.N., & Perrott, D.R. (1972). Temporal resolution of tonal pulses. *Journal of the Acoustical Society of America, 51,* 644-647.

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,* 181-2003.