Gap Detection Test using MLP toolbox - Development of Normative in Children (9-11 Years)

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CERTIFICATE

This is to certify that this Masters dissertation entitled **"Gap Detection Test using MLP toolbox-Development of Normative in Children (9-11 Years)"** is a bonafide work in part fulfillment for the degree of Master of Sciences (Audiology) of the student with Registration Number: 16AUD007. This has been carried out under the guidance of faculty of this institute and has not been submitted earlier to any other Universities for the award of any Diploma or Degree.

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This is to certify that this Masters dissertation entitled **"Gap Detection Test using MLP toolbox - Development of Normative in Children (9-11 Years)"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This Master dissertation entitled **"Gap Detection Test using MLP toolbox - Development of Normative in Children (9-11 Years)"** is the result of my own study under the guidance of Dr. Chandni Jain, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other Universities for the award of any Diploma or Degree.

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Dedicated to

My Mom,

My Dad,

My Brother

and

My Guide

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Abstract

Temporal resolution is the capacity of the hearing system to detect the occurrence of two consecutive auditory events. Gap detection test is a well-established and commonly used psychophysical method for measuring temporal resolution. A maximum likelihood procedure (mlp) is an adaptive psycho-physical procedure in which trail by trail, the maximum likelihood algorithm estimates the gap detection threshold. The present study aimed to develop the normative data for gap detection threshold using maximum likelihood procedure implemented in MATLAB in children aged 9 to 11 years. A total of 120 children in the age range of 9 to 11years were equally divided in to two groups of 9 to 9.11 years and 10 to 10.11 years. All the participants with normal hearing sensitivity and had passed in Screening Checklist of Auditory Processing. Gap detection thresholds was calculated in both groups using mlp toolbox in MATLAB. The results showed that there was no significant difference in GDT between right and left ear for both the age groups. Further it was also noted that there was a significant difference in GDT between both the age groups and also when the normative of the present study was compared with the old norms (Shivaprakash & Manjula, 2003), it showed a significant difference. The normative data developed in the present study would be useful in detecting temporal processing deficits in children in the age range of 9 to 11 years.

Keywords: GDT-Gap Detection Test, SCAP- Screening Checklist for Auditory processing Disorder, Temporal resolution

Chapter 1

Introduction

Sound signals vary over time and the time domains play a great role in encoding the information at various levels of the auditory system. Speech is also characterized by a rapid change of intensity and frequency over time and the accurate processing of temporal changes is essential for the optimal perception of speech (Phillips, 1999; Zeng et al., 1999). Sounds in the natural environment have complex temporal structures that include both slowly and rapidly changing acoustic transients. Temporal processing is associated with the perception of the sounds that vary with time, especially in relation to the thresholds of the capacity to detect changes in time (Moore, 1997). It refers to the time-related aspects of acoustic processing that comprises of a wide range of auditory skills including temporal resolution or temporal discrimination, temporal masking (i.e., backward and forward masking), temporal integration, and temporal ordering (ASHA, 1996).

One temporal processing skill is the temporal resolution that can be defined as the capacity of the hearing system to detect the occurrence of two consecutive auditory events and, consequently, avoid that they be detected as a single event (Williams, 1972). Temporal resolution helps in resolving brief dips in the intensity of interfering noise that is found in everyday listening environments and therefore it is critical for understanding speech in these situations (Dubno, Horwitz, & Ahlstrom, 2003). Temporal resolution is measured in various ways, including random gap detection threshold (RGDT; Keith, 2000), extended random gap detection test (RGDT-EXP), gap in noise test (GIN; Musiek et al., 2005) and the Auditory Fusion Test-Revised (AFTR; Mc Croskey & Keith, 1996).

Gap detection (GDT) is the most commonly used measure of assessing temporal resolution. GDT is a well-established and commonly used psychophysical method that helps to measure an individual's ability to follow rapid change over time (Florentine, Buus, & Geng, 1999). The gap detection paradigm normally involves the presentation of two relatively long sounds, a leading and a trailing sound, with a brief silent period or gap between them (Phillips, 1999). The gap detection threshold represents the smallest silent interval in a stimulus that a listener can detect (Lister, Besing, & Koehnke, 2002). The main advantages of GDT over other measures to assess temporal resolution are that, it provides a description of temporal resolution based on a single threshold and it is easy to measure in naive listeners, including infants. It has been reported that the gap detection thresholds obtained from naïve listeners was similar to those obtained from well-trained listeners (Werner, Marean, Halpin, Spetner, & Gillenwater, 1992).

The gap detection test can be performed using varied stimulus. The experimental stimulus that commonly used are broadband noise, narrow band noise, or pure tones (Morrongiello, Kulig, & Clifton, 1984). Broadband stimulus are popular over other stimulus because it has the advantage of masking the spectral splatter without causing significant changes in stimulus energy spectrum. (Fitzgibbons & Wightman, 1982 ; Florentine & Buus, 1982 ; Shailer & Moore, 1983). Although the gap detection threshold differences observed in the various studies probably result from the parameters applied in each different investigation, there is a certain concordance that, for white noise, the approximated gap detection thresholds range from 2 to 3 ms (He, Horwitz, Dubno, & Mills, 1999; Wiegrebe & Krumbholz, 1999).

Gap detection threshold can be assessed by using either adaptive or non-adaptive procedures. In adaptive procedure the stimulus to be presented to the subjects at each specific trial depends on the subjects response (Leek, 2001) and in non-adaptive procedure stimuli are pre-set before the beginning of the experiment. In comparison to non-adaptive procedures, adaptive procedures maximize the ratio between the stimuli presented close to the threshold and those presented far from the threshold (Grassi & Soranzo, 2009).

A maximum likelihood procedure (mlp) is an adaptive psycho-physical procedure that can be applicable to a variety of psychoacoustic tasks (Hall, 1968; Pentland, 1980). In this procedure the experimenter hypothesizes several psychometric functions called hypotheses. Trail by trail, the maximum likelihood algorithm estimates which hypothesis has the highest likelihood of being similar to the actual subject's psychometric function according to the responses. The most likely hypothesis is assumed to contain, most likely, the threshold. The mlp can track any point of the psychometric function and can use either nAFC or yes/no experiments. It is reported that within 12 trials, the mlp generally meets the fairly stable approximation of the most probable psychometric function, which can be used to approximate thresholds (Grassi & Soranzo, 2009; Green, 1993). This procedure has been widely used to assess psychophysical abilities and found to have good reliability and validity (Kumar & Sangamanatha., 2011). But the normative for GDT using mlp in children is still not established.

1.1. Need for the Study

The temporal resolution is the shortest time period in which the ear can discriminate two signals (Gelfand, 2004). There are several evaluation procedures to detect the temporal resolution ability in children and gap detection test is the most commonly used evaluation procedure in clinical setups.

It is generally known that auditory temporal processing improves substantially over first several years of life, but there is considerable disagreement about the specific developmental trend by several researchers. For example, according to some investigators the age of achievements of adult-like temporal acuity is reported to be 5 to 6 years (Morrongiello et al., 1984; Jensen & Neff, 1993), whereas it is reported to be 9 to 11 years of age by others (Davis & McCroskey, 1980; Grose et al.1993; Irwin et al. 1985, as cited in Trehub, Schneider, & Henderson, 1995). These, difference could be attributed to differences in experimental tasks and stimuli used.

In Indian setup GDT norms are available for stimulus presentation using CD involving non adaptive procedure (Shivaprakash & Manjula, 2003). In this study, GDT was assessed on 60 participants with normal hearing sensitivity. The participants were divided into six cross-sectional groups of 7 to 12.11 years and 30 normal hearing adults. The results indicated that normal hearing adults could detect a mean gap of 3.3 ms and children aged 7 years could detect a gap of 4.05 ms. However, the significant difference between children and adults was not obtained. Using this conventional method there is lack of randomization in the stimulus presentation, time consuming and child may lose interest during the testing procedure.

Hence, the present study aimed to develop norms of GDT in children aged 9 to 11 years using maximum likelihood procedure implemented in MATLAB. These norms will be useful in detecting temporal processing deficits in children and will also overcome the drawback of conventional methods.

1.2. Aim of the Study

The aim of the present study was to develop the normative data for gap detection threshold using maximum likelihood procedure implemented in MATLB in children in the age range of 9-11 years.

1.3. Objectives of the Study

- To establish normative for GDT in children (9-11 years) using maximum likelihood procedure.
- To compare the estimated GDT scores with the previously established data (using CD presentation).
- To validate the norms of GDT developed from the present study.

Chapter 2

Review of Literature

Temporal processing is the perception of the auditory stimuli that vary with time, especially in relation to the thresholds to detect changes in time (Moore, 2003). Various temporal processing abilities include temporal integration, temporal resolution, temporal masking and temporal ordering. Temporal resolution has been defined as the minimum time interval within which different acoustic events can be distinguished (Eddins & Green, 1995). Numerous researchers say that children's performance in temporal resolution improves with age (Davis & McCroskey, 1980).

Temporal resolution abilities are poorer in children compared to adults and it reaches adult like by around 9 years of age (Morrongiello, Kulig, & Clifton, 1984). Thus, the maturing effects of the central auditory system seem to directly impact their skill to detect small differences in tone duration (Elfenbein, Small, & Davis, 1993, Grose, Hall 3rd, & Gibbs, 1993).

Temporal resolution has been investigated in psychoacoustic paradigms since the 70's; nonetheless, temporal resolution tests were only commercially available in the late 90's. Auditory temporal resolution ability enables the detection of changes in the duration of a sound stimulus and/or the detection of gaps inserted in an auditory stimulus.

2.1. Tests to assess temporal resolution abilities

Currently, there are few tests commercially available to assess temporal resolution in clinical settings and they are the Auditory Fusion Test-Revised (AFT-R), the Random Gap Detection Test (RGDT) and the Gaps in Noise (GIN).

2.1.1. Auditory Fusion Test-Revised. AFT-R measures the auditory fusion threshold of the listener's perception in identifying one stimulus or two, when the stimuli duration varies between 0 and 40 ms. This threshold is measured for frequencies between 500 and 4000 Hz (Mc Croskey & Keith, 1996). The bursts are presented with the gaps between the pairs of bursts or inter pulse intervals (IPIs) increasing in duration from 0, 2, 5, 10, 15, 20, 25, 30, and 40 ms (ascending) and then decreasing in duration from 40 ms to 0 ms (descending). The listener's task is to judge whether a single sound was audible or two sounds were audible. When the listener perceives the gap between the two pulses, the pulses are identified as two pulses.

In a study by McCroskey & Kidder (1980), they investigated the temporal integrity of the auditory system using an auditory fusion threshold technique. A total of 135 children aged 7 to 9 years were studied. They were grouped in equal numbers of children who were normally achieving, reading disordered, and learning disabled. Auditory Fusion Thresholds 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 gap detection thresholds between the children who were considered normal and the other two groups. In another study GDT was measured in children from 9 to 18 years and were divided subjects into 2 groups. The first group had language/learning disabilities and the second group included normally achieving children. Auditory Fusion Thresholds were significantly different between the groups, with language/learning disabled children having larger auditory fusion threshold than control subjects (Isaacs, Horn & Keith, 1982).

2.1.2. Random Gap Detection Test. The RGDT is an adapted version of the AFT-R. The tones or clicks with silence intervals varying from 0 to 300 ms in between the tones is used (Keith, 2001). Stimuli used are pure tones (500 Hz, 1000

Hz, 2000 Hz & 4000 Hz) or clicks with variable inter stimulus interval durations. The task the individual has to perform in these procedures is to identify whether he/she heard one or two sounds.

The original RGDT study was carried out in the United States, in children between 5 and 11 years of age without any hearing or academic related difficulties. The results showed that the mean threshold in children aged five to seven years was 7.3 ms (SD: 4.8 ms); in 8 year-old children the average threshold was 6.0 ms (SD: 2.5 ms); in nine year-olds was 7.2 ms (SD: 5.3 ms) and in 10 and 11 year-old children it was 7.8 ms (SD: 3.9 ms) (Keith, 2001). In another study, RGDT was performed on two groups of participants in which first group had 131 children with central auditory processing disorder (CAPD) and second group included 94 children with normal auditory processing. Results showed that 48% of children with CAPD failed the RGDT and the percentage decreased as a function of age. The highest percentage (86%) was found in the 5–6 year-old children (Dias, Jutras, Acrani, & Pereira, 2012).

2.1.3. Gaps-In-Noise Test. The GIN test consists of six-second-long segments of broadband noise that contain none or up to three gaps. The gaps vary in duration from 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 ms. The approximate gap detection threshold is defined as the shortest gap duration which is correctly identified at least four out of six times. The percentage of correct responses out of the total 60 gaps can be calculated. The participant is required to press a button each time a gap in the noise is detected.

In a study, GIN test was performed on 72 children ranging from 7 through 18 years of age. No statistically significant differences were seen in Gaps-in-noise test thresholds among age groups indicating no developmental trend in thresholds between the ages of 7 and 18 years. In addition, within group analysis yielded no statistically significant differences between ears within each age group. The absence of ear differences suggests that temporal resolution as measured by the GIN is an auditory process that develops relatively early and symmetrically (Shinn, Chermak, & Musiek, 2009).

In another study, GIN test performance was seen in subjects with confirmed central auditory nervous system involvement (Musiek et al., 2005). Results showed mean approximated GDT of 4.8 ms for the left ear and 4.9 ms for the right ear in control group. In comparison, results for experimental group demonstrated a statistically significant increase in gap detection thresholds, with approximated thresholds of 7.8 ms and 8.5 ms being noted for the left and right ears, respectively.

2.1.4. Gap Detection Test. It is one of the psychophysical method that measures auditory temporal processing in the gap detection paradigm. Gap detection test is a well-established test that measures the individual’s ability to identify brief temporal gap between two stimuli. GDT is one of the popular measures because it provides a description of temporal resolution based on a single threshold; where as other methods need multiple threshold estimates. Another advantage is that it is easy to measure in naïve listeners and infants and the threshold that obtained is very close to threshold of very well trained listeners (Werner et al., 1992).

In a study by Shivaprakash & Manjula, (2003) normative data for GDT in children was developed and comparison was done with GDT in adults. The GDT was estimated on 60 participants with normal hearing sensitivity. The participants were divided into six cross-sectional groups of 7 to 12.11 years and 30 normal hearing adults and GDT was measured using noise bursts of 300 ms duration with a silence of different duration at 40 dB SL. The results indicated that normal hearing adults could detect a mean gap of 3.3 ms and children aged 7 years could detect a gap of 4.05 ms. It was found that there was no improvement in GDT as age increased after 7 years of age. This study also suggests that normal hearing individuals start performing like adults on gap detection by the age of 6-7 years.

2.2. Factors affecting gap detection test

There are several factors that affect gap detection test that includes stimulus related factors and subject related factors.

2.2.1. Stimulus related factor. It includes various factors like type of stimulus, duration of noise burst, location and uncertainty of gap and gap onset and offset.

Type of stimulus. Detection of the silent gap is highly dependent on the characteristics of the stimulus that bound the gap. The stimuli that are used in the gap detection test are band pass noise, broad band noise, wide band noise and sinusoidal tones.

Gap detection in band pass noise. Thresholds in a gap detection task decreases monotonically with increasing center frequency (Shailer & Moore,1983). 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). When both noise bandwidth and auditory bandwidth increased, the fluctuations in the noise at the output of auditory filter are rapid and not very confusable with the gap.

For band pass noise, a majority of hearing impaired subjects' showed larger-than normal gap thresholds whether the comparison with normal ears is made at equal sound-pressure level (SPL) or equal sensation level (SL) (Fitzgibbons & Wightman, 1982; Glasberg et al., 1987). When tested at the same relatively high SPL, subjects with similar audiograms can show very different gap thresholds (Glasberg et al., 1987). These results suggest that, for at least some subjects,' the enlarged gap thresholds cannot be explained in terms of elevations in absolute threshold.

Gap detection in broad band noise. Human detect gaps in broadband noise according to effective gap duration without much additional cues from abrupt envelope change (Allen, Virag, & Ison, 2002). This advantage can be obtained from broad band noise gap detection. A silent gap of 4 to 5 ms or less can be detected by using sinusoidal and broad band noise (Shailer & Moore, 1987). This minimum detectable gap duration has been interpreted as revealing fundamental “sluggishness” in the auditory system response to very rapid change in sound level.

For broadband noise, the enlarged gap thresholds for some hearing impaired subjects may be partly attributed to the reduced audibility of high-frequency components in the noise; these components give rise to the lowest gap thresholds for normally hearing subjects (Fitzgibbons, 1983; Shailer &Moore, 1983). However, the gap thresholds of some subjects are too large to explain in this way (Florentine & Buus, 1984).

Gap detection with sinusoidal markers. Shailer and Moore (1987) reported gap detection thresholds for conditions where the silent gap was positioned temporally between a pair of sinusoidal markers of the same frequency. The durations of the sinusoidal markers were approximately 200 ms before and after the silent gap and were presented at signal-to-noise ratios of 22 to 25 dB. 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 without interruption. Results showed that the gap detection thresholds were about 5 ms that was relatively independent of frequency from 200 to 2000 Hz (Shailer & Moore, 1987).

In another study, Moore & Glasberg (1988) presented the sinusoids at a slightly higher signal-to-noise ratio and reported gap detection thresholds ranging from 3.3 to 4.2 ms over the frequency range from 500 to 2000 Hz. Perhaps the most intriguing of the gap detection experiments with sinusoidal markers is an earlier report by Williams & Perrott (1972) for conditions where the silent gaps were positioned temporally between pairs of sinusoids of different frequency. These authors measured detection for sinusoidal markers as a function of marker duration and frequency separation. Stimuli were presented at 15 dB SL to negate confounding acoustic transients due to gating the stimuli off and on abruptly to produce the silent gap. Results showed that for sinusoidal markers of 100- and 300-ms durations, silent gaps 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. The 300-ms markers yielded the largest gap detection thresholds. The largest value was around 43 ms when the frequency separation between the markers was 480 Hz. For shorter marker durations (3, 10, & 30 ms), the gap detection thresholds were essentially independent of frequency separation. The authors speculated that the pattern of their results might reflect the role of the critical band process and its narrowing with increasing stimulus duration.

The idea that the width of the critical band (and auditory frequency selectivity generally) 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 and because the bandwidth of a time-dependent critical band process should be relatively broad in response to brief marker durations, we would expect the listener to be relatively poor at resolving differences between brief sinusoidal markers (Formby, Sherlock, & Li, 1998).

Effect of duration of noise burst. In many auditory perception tasks, performance decreases with decreasing stimulus duration (Garner & Miller, 1947; Hall & Fernandes, 1983; Lee & Bacon, 1998 ; Sheft & Yost, 1990; Viemeister, 1979) thus suggesting a common underlying temporal integration process. However, reports of the noise-burst duration effect on gap detection are inconsistent. Forrest & Green (1987) found little difference in (< 1 ms in gap) threshold for noise-burst durations ranging from 5 to 400 ms with a minimum gap at 25 and 50 ms. For noise durations shorter than 25 ms, the trend was different than that reported by an earlier study by Penner (1978), where the gap threshold progressively increased from 1 to 3 ms as the noise duration increased from 5 to 20 ms. Forrest & Green (1987) attributed the inconsistency to procedural differences. In their study, the overall duration of the noise burst was kept constant, whereas Penner (1978) used a pair of identical noise bursts so that the total duration varied with gap length. This duration cue became increasingly significant as the noise-burst duration decreased. In a large-sample study, (Muchnik et al., 1985) they showed that gap-detection thresholds of young, normally hearing subjects increased as noise burst duration decreased from 85 to 10 ms. A similar trend was observed for subjects in two other age groups (40–60 & 60–70 years) in the same study. There were age-related differences in the increment of gap thresholds when the noise-burst duration decreased; however, this potential age effect could be confounded by the subjects' hearing loss.

Location and uncertainty of gap. Gap stimuli used in psychoacoustic studies are acoustically analogous to voice-onset time (VOT) for consonants in speech. However, unlike a conventional gap-detection paradigm, where the gaps are typically fixed at the center of a stimulus burst, the acoustic gaps in a continuous speech stream occur pseudo randomly 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, & Grantham, 1998). Phillips et al., (1997), measured GDT between a leading wideband noise burst and 300 ms narrow-band noise burst as a function of the duration of the leading noise burst. When the leading noise burst was 5 to 10 ms, the threshold was about 30 ms for young, normally hearing subjects. This value is close to the VOT boundary that separates voiced and unvoiced consonants.

Few studies have examined the effect of the temporal location of the gap within a noise burst and the effect of randomness of the gap location. Forrest & Green (1987) measured gap thresholds with the gap fixed at 10, 30, 50, 70, or 90 ms after onset of a 100 ms noise burst. They found that the location had essentially no effect on gap threshold except for the location of 30 ms, where the detection threshold was slightly lower. However Penner (1977) showed that when the second noise-burst duration was kept constant (2 ms), 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 first noise burst actually changed the relative location of the gap. Thus, the effect of varying the relative location of a temporal gap within a noise burst remains unclear.

Green & Forrest (1989), investigated the effect of uncertainty of gap location. When the gap threshold was measured with gaps located randomly from 6% to 94%

of a 500-ms noise burst, the gap threshold averaged 1.4 times larger than with the gap fixed at the center of the noise burst. Because there were no comparisons of gap detection at specific locations between fixed and random presentations, it is not clear whether the observed differences were due to the effect of uncertainty, the effect of location, or a combination of both effects.

Gap onset and offset. Effect of gap onset and offset are basically independent of noise burst duration and its effect on gap threshold is more in aged age group than in young groups. If the gap location is near to the onset and offset of the stimulus then it results in poor gap detection (Fitzgibbons & Wightman, 1982; Florentine & Buus,1984).

2.2.2. Subject related factors. It includes various factors like age, degree and configuration of hearing loss and language disabilities.

Effect of Age. Gap detection has been studied by various authors across age. They have witnessed a developmental trend in the gap detection thresholds obtained. Davis & McCroskey, (1980) measured GDT in children aged 3-11 years to detect a brief temporal separation between two tone bursts and they found that the minimum separation decreased with age. In another study, Irwin, Ball, Kay, Stillman and Rosser, (1985) studied the development of auditory temporal acuity in 56 children aged 6-12 years and compared with that of 8 adults. It shows that temporal acuity improves with age and it reaches adult like value by 11 or 12 years of age. Trehub et al. (1995) assessed GDT on participants in the age of 6.5 months, 12 months, 5 years, and 21 years of age. The stimuli were a pair of 500-Hz, Gaussian-enveloped tone pips of the same duration and total energy. They reported that GDT for infants (6.5- and 12-month-olds), children and adults were 11, 5.6, and 5.2 ms, respectively. However, study by Shivprakash and Majula (2003) showed contrary results wherein they found that children as young as 7 years of age had adult like scores in GDT

The effects of age on elderly subjects in gap-detection ability are not clear (Schneider et al. 1994). They reported that gap thresholds of elderly subjects were more variable and about twice as large as those from young subjects. Moore, Peters, & Glasberg (1992) also observed an age-related difference in GDT, these authors noted that the mean differences were mainly due to the data of a few elderly subjects who had markedly large gap thresholds, and that the majority of elderly subjects had gap thresholds within the range of young subjects. Although considerable overlap in gap thresholds between young and aged subjects has also been reported (Snell, 1998). Analyses of individual data showed that the mean differences in GDT between age groups reflected shifts in the distributions of the aged subjects toward poorer temporal resolution. A confounding factor in measuring temporal resolution for elderly subjects may be hearing loss, which is commonly associated with age.

Degree and configuration of hearing loss. Study of temporal resolution in ears with sensorineural impairment has not been pursued extensively. Elliott, (1975) and Cudahy & Elliott, (1975) inferred from masking data that some listeners with sensorineural impairment have reduced temporal resolving capacity. Cudahy, (1977) also reported cases of elevated gap thresholds in subjects with high frequency hearing loss. In another study, Jesteadt, Bilger, Green, & Patterson, (1976) reported that temporal acuity anomalies in some of their impaired listeners, though acuity measures in this study were different from gap threshold and are not easily compared to it.

In another 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. Recently, however, using a related paradigm, Fitzgibbons & Gordon-Salant

(1996) measured difference limen for gaps from both young and aged subjects with or without hearing loss and reported that elderly listeners performed more poorly than young listeners, and that hearing loss had no systematic effect on gap detection. Large inter subject variability in the performance of hearing-impaired listeners is cited in many of these reports. Temporal resolution in hearing-impaired subjects is clearly poorer than normal (Fitzgibbons & Wightman, 1982).

Language disabilities. Gap detection procedure is a non-verbal test. Some studies find that temporal processing ability predicts language outcome whereas other studies do not. In a study by Muluk, Yalçinkaya, & Keith, (2011), they found that the temporal processing (shown in 500–4000 Hz lowest gap detection) was delayed in children with previous language delay and current speech sound delay, compared to children with normal speech sound and language development levels. And they also found that, minimum detectable gaps of the children with previous language delay in RGDT and RGDTEXP were inconsistent in different frequencies of the children. The children with previous language delay have difficulties in perception of speech sounds at a certain rate, even they have not language learning difficulties. Therefore, difficulty in distinguishing of speech sounds may cause receptive language development delay.

2.3. Measures for assessing GDT

Threshold estimation in psychoacoustic research can be done by using adaptive and non-adaptive procedures. In adaptive procedure the stimulus to be presented to the subjects at each specific trial depends on the previous answers (Leek, 2001) and in non-adaptive procedure stimuli are pre-set before the beginning of the experiment. In comparison to non-adaptive procedures, adaptive procedures maximize the ratio between the stimuli presented close to the threshold and those presented far from the threshold. Different adaptive procedures include simple up down procedure/ staircase procedure, transformed up down procedure, PEST, maximum likelihood procedure.

2.3.1. Simple up down procedure. In this procedure, it allows the experimenter to target the staircase at specific stimulus levels. The simple up-down (or staircase) method involves increasing the stimulus when the subject did not respond to the previous stimulus presentation and decreasing the intensity when there was a response to the prior stimulus. An ascending run begins with a negative response and ends with a positive response. As stimulus intensity is always increased after a negative response and decreased after a positive response, this method converges upon the 50% point on the psychometric function. Threshold value is calculated either as the average of the midpoints of the runs, or as the average of their peaks and troughs (Kaernbach, 1991).

2.3.2. Transformed up down procedure. This is a modification of simple up-down procedure. In the transformed up-down methods the strategy is changed in such a way that the next presentation level is determined by the last few responses. In the simple up-down method only the last response is used to determine the next presentation level, but in the transformed methods it's the sequence of the last two or more responses that are used for this decision. Unlike up-down procedure which converges on the 50% point of the psychometric function; this procedure can converge other points of psychometric function (Wetherill & Levitt, 1965).

2.3.3. Parameter estimation by sequential testing. The PEST staircase converges on a target stimulus level by decreasing stimulus amplitude when a number (N) of responses are correct and increasing stimulus amplitude when one response is incorrect. For example, in a three-down, one-up staircase (3D1U) the stimulus amplitude decreases after three correct responses and increases when one response was incorrect (Taylor & Creelman, 1967).

2.3.4. Maximum likelihood procedure. In mlp trial by trial, the maximum likelihood algorithm estimates the hypothesis that has the highest likelihood of being similar to the actual subject's psychometric function according to the subject's responses and the most likely hypothesis is assumed to contain, most likely, the threshold. Maximum likelihood procedure can track any point of the psychometric function and can use either *nAFC* or *yes/no* experiments. This procedure is the fastest whereas transformed up-down and PEST procedure requires more time. It is less robust and threshold estimation might be affected by errors such as attention lapses. This is especially true when they occur within the first five trials of a block. The transformed up-down and the PEST procedures are relatively insensitive to these errors. While *yes/no* experiments are relatively fast, in *nAFC* the experiment duration depends on the number of alternatives. In daily laboratory practice, *nAFC* tasks usually do not exceed four alternatives-intervals (i.e., *4I-AFC*) otherwise the experiment duration is excessive (Grassi & Soranzo, 2009).

Chapter 3

Methods

3.1. Participants

A total of one hundred twenty participants in the age range of 9 to 11 years participated in the study. The participants were equally divided into 2 groups (9-9.11; 10-10.11 years). All the participants met the following inclusion criteria:

- Presence of normal hearing sensitivity (≤ 15 dBHL) at octave frequencies from 250 Hz to 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone conduction.
- No history of any relevant otological problems.
- No history or presence of any neurological problems.
- ‘Pass’ in APD screening test. (SCAP, Yathira & Mascarenhas, 2002)

3.2. Instrumentation

1) Calibrated two channel portable PROTON Dx-Screening audiometer was used for threshold estimation (pure tone audiometry and speech audiometry) and to rule out any hearing loss components to meet the inclusion criteria. Calibrated Telephonic TDH 39 headphones for AC threshold and Radioear B-71 bone vibrator for BC threshold were used.
2) Screening Checklist for Auditory Processing Disorder (SCAP, Yathiraj & Mascarenhas, 2002) was administered to rule out auditory processing disorder.
3) HP Pavilion 15 laptop loaded with MATLAB version 8.3 software and the mlp toolbox (Pentland, 1980; Green, 1993; Shen, Dai, & Richards, 2015).

3.3. Testing Environment

Pure tone audiometry and GDT was done in a quiet room with good illumination, ventilation and minimum distraction.

3.4. Procedure

Written consent was taken from the parents/ guardian of the children before participating in the study.

3.4.1. Pure tone Audiometry. Using the modified Hughson and Westlake procedure, air conduction threshold with the TDH 39 headphones and bone conduction thresholds with radioear B-71 bone vibrator was used to obtain hearing threshold of each participant for octave frequencies from 250 to 8000 Hz and 250 to 4000 Hz respectively.

3.4.2. Checklist for Auditory Processing Disorder. To rule out Auditory Processing Disorder (APD), SCAP was administered on all children. SCAP consists of 12 questions and the response format is 'yes' or 'no'. The clinician asked the questions to the participants/teacher with clear and adequate voice. The response was noted and analysis was done based on number of 'YES' responses. (≤6 'yes' considered as 'PASS' & ≥ 6 as 'REFER').

3.4.3. Gap Detection Test. Gap detection test was done using mlp implemented in MATLAB using a laptop and a calibrated HDA-200 head phone. A 3AFC (three-interval, alternate force-choice method) was used in which the standard was always a 750 ms broadband noise with no gap whereas the variable contained the gap and the gap duration varied according the listener's performance from 0.1 ms to 64 ms. The noise had 0.5 ms cosine ramps was used at the beginning and end of the gap. A total of 30 trails was given to the subject with 5-6 practice trails prior to testing. The stimulus was presented at 60 dB SPL (calibrated using sound level meter) and presented monaurally (each ear separately). The MLP stimulus was generated at 44,100 Hz sampling rate. A 79.4% correct response criterion of psychometric function was used to track the threshold. The participants were instructed as "please listen to the sequence of three noise bursts, out of which one noise burst contain a gap of varying duration". Subject had to indicate verbally or press the button (i.e. PC keyboard 1, 2, 3) from the set of noise bursts in which the gap appears.

3.5. Validity Assessment of the Developed Norms

To assess the validity of the developed norms, the test was administered on another group of participants who were not included in the actual study to obtain normative for GDT using MLP. For this purpose, 20 children, 10 from each group were selected and the GDT was measured. The results were analysed to determine whether the GDT in these children were similar to the age specific norms obtained for the test.

3.6. Statistical Analyses

The data obtained from the study was subjected to statistical analyses using the Statistical Package for the Social Sciences (Version 20). Descriptive statistics was carried out to estimate the mean and standard deviation for both the age groups. Following this Shapiro-Wilk test of normality was done to check the normality of the gap detection thresholds. The Wilcoxon's signed rank and Mann-Whiteny U test was done to analyze the significance difference with in the age groups and between the age groups. One sample Wilcoxon signed rank test was used to compare the mean GDT of the present study with the old GDT norms (Shivaprakash & Manjula, 2003).

Chapter 4

Results and Discussion

The aim of the present study was to develop norms of gap detection thresholds in children between 9 to 11 years of old using Maximum likelihood procedure toolbox implemented in MATLAB. Prior to statistical analysis, Shapiro-Wilk test of normality was performed on the raw gap detection thresholds and it was noted that the thresholds in both age groups did not to fulfill the assumptions of normality ($p>0.05$). Thus, non-parametric tests were used in the study to analyze the following:

1. Comparison of GDT of right and left ear within the age group
2. Comparison of GDT between the age group
3. Comparison of newly established GDT with the old norms

   [* Normative data for younger adults was taken from the Shivaprakash & Manjula (2003), Gap Detection Test – Development of Norms]
4. Validation of the developed norms

4.1. Comparison GDT of right and left ear within the age group

Table 4.1 gives the mean, standard deviation (SD), median and range of gap detection threshold for right and left ear, across the two age groups. Figure 4.1 shows the mean and SD of right and left ear for both the age groups.

Table-4.1

Mean, SD, Median and Range of GDT for right and left ears in two age groups

Age Group	Ear	Mean (ms)	SD	Median	Maximum	Minimum
9 To 9.11 Years	Right (N=60)	4.64	1.52	4.21	6.98	1.95
	Left (N=60)	4.68	1.50	4.59	6.94	1.78
10 To 10.11 Years	Right (N=60)	3.37	1.14	3.20	7.20	1.32
	Left (N=60)	3.44	1.14	3.29	6.96	1.36

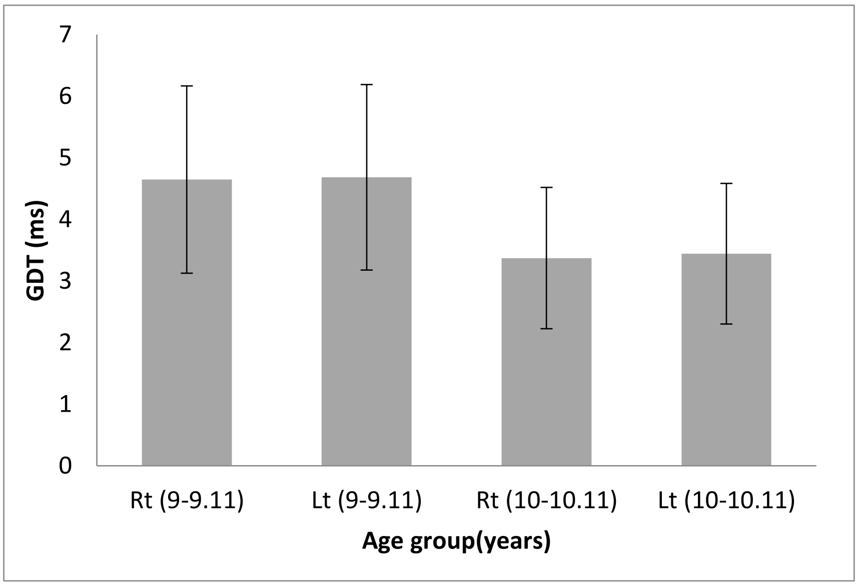

Figure 4.1 Mean and SD of GDT for right and left ears in two age groups

It can be noted from the Figure 4.1 that the mean gap detection thresholds between ears did not differ much. Further to assess the significant difference in gap detection threshold of right and left ear within the age group (between the ears), Wilcoxon's signed rank test was used. Results showed that there was no significant difference between the gap detection thresholds for right and left ears for 9 to 9.11 years ($Z = 0.209$, $p > 0.05$) and 10 to 10.11 years ($Z = 0.729$, $p > 0.05$), As there was no significant difference between the gap detection thresholds for right and left ears, the gap detection threshold of right and left ears were combined for each age groups for further analysis. The findings of the present study is supported by earlier studies in literature (Shivaprakash & Manjula, 2003; Shinn et al., 2009). Shivapraksh and Manjula, (2003), reported in their study that there was no significant difference in GDT between the right and left ears in children of age group 7 to 12 years. Shinn et al (2009) also reported that the auditory system maturation of temporal resolution abilities occurs similarly in both ears. Also, the absence of inter-aural differences has been reported in adults for a number of temporal processes (Mustek & Pinheiro, 1987). In the present study no difference in right and left ear GDT score was seen from which it can be inferred that there is no hemispheric advantage seen in GDT in children of 9 to 12 years of age.

In contrary, inter aural differences have been reported for temporal resolution in children as measured through topographic brain maps, indicating greater activation with right ear stimulation (i.e., privileged access to the left hemisphere) but less activation in the left hemisphere. This asymmetrical processing could suggest an immaturity or inefficiency within the CANS, although behavioral measures of GDT may not reflect underlying neurophysiologic asymmetry.

4.2. Comparison of gap detection threshold between the age group

To compare GDT across age groups, the gap detection thresholds of left and right ear were combined for further statistical analysis as results showed that there was no significant difference between the GDT obtained in two ears. Table 4.2 shows the combined mean, SD, median, range and "z" value of GDT between age groups. Figure 4.2 shows the mean and SD of GDT between age groups.

Table-4.2

Mean, SD, Median, Range and "z" value of GDT between age groups (9 to 9.11 years and 10 to 10.11 years)

Age Group	Mean(ms)	SD	Median	Maximum	Minimum	"z" value
9 to 9.11 Years (N=120)	4.66	1.50	4.36	6.98	1.78	6.505*
10 to 10.11 Years (N=120)	3.40	1.13	3.21	7.20	1.32	

*indicates significance at 0.05 level

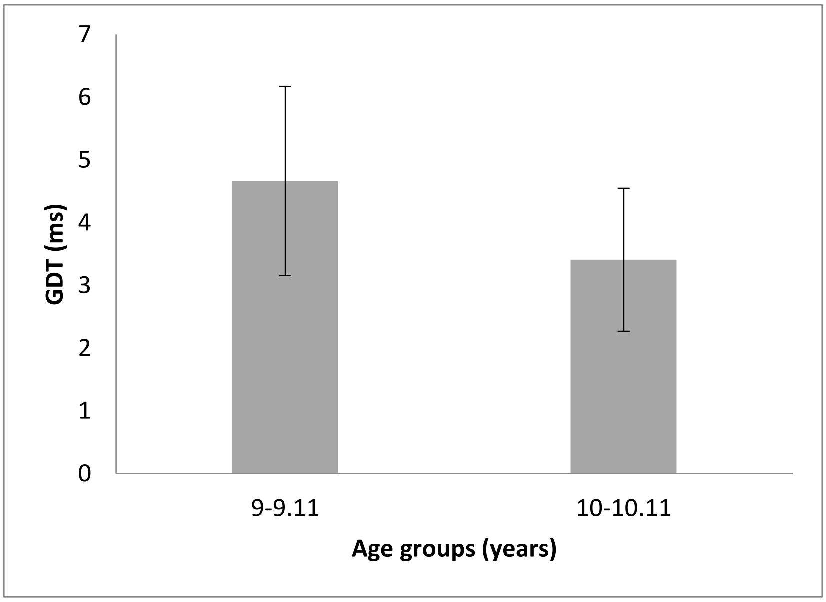

Figure 4.2. Mean and SD of GDT between age groups (9 to 9.11 years and 10 to 10.11 years)

From the Figure 4.2 it is evident that participants in the age range of 10-10.11 years had better gap detection threshold compared to participants of 9-9.11 years of age. Further to check significance, Mann-Whitney U test was performed and it showed that there was a significant difference in gap detection thresholds of children between the two age groups ($Z= 6.505$, $p< 0.05$).

Thus, in the present study maturational effect in GDT is seen. Similar results have been reported in the literature (Davis & McCroskey, 1980). Davis & McCroskey, (1980) measured GDT in children aged 3-11 years and found that the GDT decreased with increase in age. In another study, development of auditory temporal acuity was studied in 56 children aged 6-12 years and compared with that of 8 adults. It showed that temporal acuity improves with age and by 11 or 12 years of age, temporal acuity reaches adult values (Irwin et al., 1985). Further in their study, they used criterion-free psychophysical procedure, hence the improvement can be attributed to an age-related change in auditory processing and not to a systematic change in response criterion.

Several factors would have influence the age trends observed in the current study. For example, central attention or processing can exert control over the accuracy of reception, short-term storage, coding, and response selection processes (Wickens, 1974). While factors such as motivation, incentive and attentiveness were monitored carefully during the course of the experiment, it is possible that such elements could have contributed in some unidentified manner to the outcome of the investigation. The possibility also exists that younger children may have a different criterion for deciding what comprises a single stimulus.

However, the result of the present study is not in agreement with the previous study done by Shivaprakash and Manjula (2003) where they found no significant difference between the age groups on GDT, which may be due to the procedural differences, the stimulus parameters variations and number of participants considered. Thus, we attempted to compare the normative data on gap detection threshold established using CD presentation given by Shivaprakash and Manjula (2003) with the present study established using Maximum Likelihood Procedure toolbox.

4.3. Comparison of newly established GDT score with the old norms data

Table 4.3 shows the mean and SD of gap detection threshold of the present study and also of GDT norms by Shivaprakash & Manjula (2003).

Table-4.3

Mean and SD of GDT for the present study and old established norms (Shivaprakash & Manjula, 2003) across two age groups.

Age Group	Mean (ms)	SD
9 to 9.11 Years (N=120)	4.66	1.50
9 to 9.11 Years * (N=20)	3.8*	0.58*
10 to 10.11 Years (N=120)	3.40	1.13
10 to 10.11 Years * (N=20)	3.9*	0.44*

[* Normative data taken from Shivaprakash & Manjula (2003), Gap Detection Test– Development of Norms]

One Sample Wilcoxon signed rank test was performed between the norms and results showed that there was significant difference between the norms of the two study ($p < 0.05$). This statistical difference in the results between two studies could be due to the procedural differences in estimating gap detection test. In the present study, higher mean values were obtained compared to the previous study which may be due to the differences in the procedures used that is mlp toolbox implemented in MATLAB. In the present study mlp uses adaptive psychoacoustic procedure (3AFC method) whereas the other study uses non-adaptive procedure (Bracketing method). In mlp procedure, there is randomization of the stimulus in terms of varying gap durations based on the subject's response using the psychometric function curves and estimates threshold within 30 trials whereas in the other procedure, there is no randomization in the stimulus presentation.

4.4. Validation of the developed GDT norms

To assess the validity of developed norms GDT was measured on additional 10 (20 ears) participants in each group (9 to 9.11 years and 10 to 10.11 years). It was found that the mean gap detection threshold of these participants for each age group lies within the newly established normative thresholds (Table 4.4). Thus, it can be inferred that the norms developed in the present study is valid.

Table-4.4

Mean and SD of GDT for the present study and additional participants used for validation.

Age Group	Mean (ms)	SD
9 to 9.11 Year (N=120)	4.66	1.50
9 to 9.11 Years * (N=20)	4.11*	1.03*
10 to 10.11 Years (N=120)	3.40	1.13
10 to 10.11 Years * (N=20)	3.42*	0.65*

* indicated additional participants

Chapter 5

Summary and Conclusion

Temporal resolution is an important part of temporal processing and it refers to the ability of the auditory system to follow rapid changes in the envelope of sound. The gap detection test is one of the important psychophysical methods among the tests to measure temporal resolution, which in turn has a great importance in speech perception.

The objectives of the present study were to establish normative for gap detection threshold in children (9-11 years) using Maximum Likelihood Procedure (MLP) implemented in MATLAB and to compare the estimated GDT scores with the previously established data (using CD presentation). To fulfill the objectives, total of 120 participants with normal hearing sensitivity were included. They were equally divided in to two age groups of 9-9.11 years and 10-10.11 years.

All participants had no history of any relevant oto-logical and neurological problems and were pass in APD screening test (SCAP, Yathiraj and Mascarenhas, 2002). Further, GDT was obtained through mlp in both the age groups for right and left ears (N=120 ears). Results of the study showed that:

i. There was no significant difference in gap detection thresholds between right and left ear within two age groups.
ii. There was a significant difference in gap detection threshold between the two groups (9-9.11 & 10-10.11 years).
iii. There was a significant difference in gap detection threshold when comparison of newly established norms was done with the old norms (Shivaprakash & Manjula, 2003).

iv. Validation of the developed GDT norms was done with 10 additional participants from each group and it was inferred that the norms developed in the present study was valid.

5.1. Clinical implications

1. The normative data obtained from the present study would be help in detecting temporal processing deficits in children.
2. The data can be used as a baseline during the management procedure for children with auditory processing deficits.
3. The procedure used in the present study is quick as compared to the already established non-adaptive procedure (Shivaprakash & Manjula, 2003).

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APPENDIX A

Screening checklist for central auditory processing (SCAP)

Yathiraj and Mascarenhas (2003)

All India Institute of Speech and hearing

Manasagangothari, Mysore-6

Name: Age/Sex:

Class:

Class teacher:

School Name:

Medium of instruction:

Language(s) spoken at home:

Home address and telephone No:

Father's occupation:

Mother's occupation:

Please place a tick (√) mark against the choice of answer that is most appropriate.

No s	Questions	Yes	No
1	Does not listen carefully and does not pay attention (requires repetition of instruction)		
2	Has a short attention span of listening (appr 5-15mins)		
3	Easily distracted by background sound		
4	Has trouble in recalling what has been heard in the correct order		
5	Forgets what is said in few minutes		
6	Has difficulty in differentiating one speech sound from other similar sound		
7	Has difficulty in understanding verbal instruction and tent to misunderstand what is said which other children of the same age would understand		
8	Show delayed response to verbal instruction or questions		
10	Poor performance in listening task, but performance improves with visual cues		
11	Has pronunciation problem (mispronunciation of words)		
12	Performance is below average in one or more subjects, such as social subjects. I/II language		