Gap Detection test using MLP toolbox- Development of Normative in Children (7-9 years)

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CERTIFICATE

This is to certify that this dissertation entitled "***Gap Detection Test using MLP toolbox- Development of normative in children (7-9 years)***" is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 16AUD019. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
April, 2018

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CERTIFICATE

This is to certify that this dissertation entitled "***Gap Detection Test using MLP toolbox- Development of normative in children (7-9 years)***"is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 16AUD019. This has been carried out under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "***Gap Detection Test using MLP toolbox- Development of normative in children (7-9 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 University for the award of any other Diploma or Degree.

Mysuru
April 2018

Registration No.16AUD019

I DEDICATE
MY WORK TO
MY APPA,
AMMA,
SISTER &
TO MY
DEAREST
BROTHER

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Abstract

Temporal resolution is the one of the important central auditory processing function which involves fine segregation of temporal events over a period of time. Gap detection test is the most commonly used test of assessing temporal resolution. The study aimed to develop normative of GDT using MLP toolbox implemented in MATLAB in children in the age range of 7-9 years. A total of 120 children participated in the study consisting of 60 children from each age group (7-7.11 years & 8-8.11 years). The GDT was obtained using MLP for both the age groups across the right and left ears (N=120 ears). Results of the study showed no significant difference in GDT of right and left ear indicating that there is no ear differences evident in gap detection test. Further, study also showed that there is a developmental trend that is being observed in GDT. When GDT obtained using MLP was compared with the mean GDT obtained using old norms across (Shivaprakash & Manjula, 2003) the age groups revealed a significant difference between the two procedures which could be attributed to the procedural differences between two studies. Thus, the norms obtained from the present study can be used to assess temporal processing in children in the age range of 7-9 years.

Keywords: Gap detection threshold, Maximum likelihood procedure, MATLAB

Chapter 1

Introduction

Temporal perception involves resolving fine details in spectrum and temporal envelope of speech signal which are cues for speech perception **(**Moore, 2003; Moore, 2006; Summerfield, 1987). Normal temporal processing is very essential for most of our auditory processing capabilities including pitch perception, voice identification (Sheft & Yost, 1996) and speech perception (Strouse, Ashmead, Ohde & Grantham, 1998). The sensory encoding of temporal information, such as the duration, interval, and order of different stimulus features, provides vital information to the nervous system in the speech perception (Wright, 1997). Temporal processing involves a wide range of auditory skills including temporal resolution or temporal discrimination, temporal ordering, temporal masking and as well as localization and pitch perception (ASHA, 1996).

Temporal resolution is defined as the shortest time period required to discriminate two signals (Gelfand, 2004). Temporal resolution is measured in various ways including gap detection threshold (GDT), amplitude modulation detection threshold (Viemeister, 1979), Auditory Fusion Test-Revised (AFT-R; Mc Croskey & Keith, 1996), Random Gap Detection Test (RGDT; Keith, 2000), Gap-in-Noise test (GIN) (Musiek, Shinn, Jirsa, Bamiou, Baran & Zaida, 2005).

The well-established and clinically available procedure of measuring temporal resolution is the gap detection which is a relatively simple psychoacoustic method (Florentine, Buus, & Geng, 1999). Gap detection threshold represents the smallest silent interval in a stimulus that a listener can detect (Lister, Besing and Koehnke, 2002). Main advantages of GDT over other measures are that it provides a description of temporal resolution based on a single threshold and it is easy to measure in naive listeners, even in infants. This has been evidenced by literature suggesting that the gap detection threshold obtained from naive listeners was similar to those obtained from well-trained listeners (Werner, Marean, Halpen, Spetner & Gillenwater, 1992).

Gap discrimination is based on the extent of the decline in neural activity that occurs during the gap. The normal auditory system is remarkable in its capacity to extract and encode temporal features of a stimulus waveform. Psychophysical evidences indicate that trained normal-hearing listeners can discriminate fluctuations in a waveform that occur in time intervals as brief as 2 to 3 msecs. Resolution thresholds in this range come from several studies that were designed to measure auditory temporal acuity. (Miller & Taylor, 1948; Hirsh, 1959; Plomp, 1964; Green, 1971, 1973).

GDT can be measured using different stimuli such as pure tones, narrow band noise and broadband noise. Further, these stimuli can be modified by varying the frequency, intensity, stimulus duration, gap position and presentation time of the auditory stimulus. These variables can result in a wide variety of thresholds (Schneider & Hamstra, 1999). The use of narrow band noise permits the specification of stimulus frequency but it is suggested that the gap thresholds are partly limited by fluctuations in the noise (Glasberg, Moore & Bacon, 1987; Shailer & Moore,1983). Dips in the noise envelope may be confused with the gap to be detected. In case of pure tones, though it permits frequency specificity but the reduction in the gap leads to spectral splatter.

In case of broadband noise (white noise), the gaps are introduced in between the noise. Jerger and Musiek (2000) suggested that gap detection tests should utilize broadband noise stimuli. Although some disadvantages exist (e.g., equalization of overall loudness across intervals, lack of frequency specificity, influence of sloping hearing loss on effective bandwidth), broadband noise has an advantage over other stimuli in that it masks the spectral splatter that results from abruptly interrupting a signal (Trehub, Schneider & Henderson,1995).

GDT can be assessed using different non-adaptive and adaptive psychophysical procedures. In non-adaptive procedure, the stimulus is recorded and is presented through a CD routed to the audiometer. The stimuli are pre-set before the beginning of the experiment and the stimulus is not randomized based on the subject’s response. However, in adaptive procedure, the stimulus is varied based on the response of the subject. GDT using adaptive procedure can be measured with the use of various software’s like Psycon (Kwon, 2012) and maximum likelihood procedure (MLP) implemented in MATLAB (Grassi & Soranzo, 2009).

The MLP is one of the fast adaptive psychophysical methods. In MLP, the experimenter hypothesizes several psychometric functions called hypotheses. Trial by trial, the maximum likelihood algorithm estimates which hypothesis has the highest likelihood of being similar to the actual subject's psychometric function according to the subject's responses. The most likely hypothesis is assumed to contain, most likely, the threshold. It includes two processes, either a yes/no or alternate force choice method (nAFC). GDTs obtained using a multiple-interval, multiple alternative, forced-choice procedure are both reliable and valid as demonstrated by numerous studies (Lister, Koehnke, & Besing, 2000; Roberts & Lister, 2004). Usually, 3AFC is preferred for a quick and more reliable result. 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, 1990, 1993). This procedure has been widely used to assess psychophysical abilities and found to have good reliability and validity (Kumar & Sangamanatha, 2011).

1.1. Need for the Study

Temporal resolution refers to the minimal time required to segregate or resolve acoustic events (Irwin, Ball, Kay, Stillman & Rosser, 1985; Shinn, 2003). There are several procedures to assess the temporal resolution ability in children and gap detection test is the most commonly used evaluation procedure in clinical setups.

In the literature, it has been reported that the temporal resolution abilities substantially improves over the first few years of life and thus there is a developmental trend seen in temporal resolution abilities. However, there is considerable disagreement in the specific developmental trend showing that GDT reaches adult like value by around 5 to 6 years of age by some authors (Jense & Neff , 1993) and in other studies it has been shown that GDT matures till the age of 9-11 years of age (Irwin et al., 1985; Grouse, Hall & Gibbs, 1992; Davis & Mc-Croskey, 1980). This difference in developmental trend can be accounted to the difference in experimental procedures and stimulus parameters used for threshold estimation.

In Indian setup also there are norms available for GDT in children in age group of 7-12 years and comparison has also been done on normal hearing adults through CD presentation (Non-adaptive procedure) (Shivaprakash & Manjula., 2003**)**. Stimuli consisted of 300 msec noise bursts with a silent interval of 750 msec varying in duration at 40 dB SL. The gap duration was reduced in 2 msec steps from 20 msec to 11 msec and after 11 msec, it was reduced in 1 msec steps. Results showed that children as young as 7 years of age had GDT similar to adults. Using this method, there is lack of randomization in the stimulus presentation, time consuming and child may lose interest during the testing procedure.

Hence, in the present study GDT norms for children in the age range of 7-9 years by using MLP toolbox, which implements maximum likelihood procedure for threshold estimation in MATLAB (Grassi & Soranzo ,2009) was developed. These norms will be useful in detecting temporal processing deficits in children and also overcome the drawback of conventional methods.

1.2. Aim of the Study

The aim of the present study was to develop normative data for gap detection threshold using MLP in children in the age range of 7-9 years.

1.3. Objectives of the Study

- To establish normative for GDT in children (7-9 years) using Maximum Likelihood Procedure toolbox implemented in MATLAB.
- To compare the estimated GDT scores with the previously established data (using CD presentation).
- To validate the norms of GDT developed from the study.

Chapter 2

Review of Literature

Temporal processing can be defined as the perception of sound or the alteration of sound within a restricted or defined time domain (Shinn, 2003). It is important for resolving brief dips in the intensity of the interfering noise and, therefore, is critical for understanding speech in these situations (Dubno, Horwitz, & Ahlstrom, 2003; Oxenham, & Bacon, 2003; Peters, Moore, & Baer, 1998). Normal temporal processing is necessary for most of our auditory processing capabilities including pitch perception, voice identification (Yost et al, 1996), and better speech perception (Strouse et al, 1998) in quiet and adverse listening conditions.

There are various sub-processes to assess temporal processing ability in children such as the temporal resolution/temporal discrimination, temporal ordering, temporal masking and temporal integration. Temporal resolution refers to the ability of auditory system to identify changes in envelope of sound over time. Temporal resolution can be defined as the perception of the temporal characteristics of a sound or the alteration of durational characteristics within a restricted or defined time interval (Shinn,2003).

2.1. Tests to assess temporal resolution

Clinically, the tests available to assess temporal resolution are the Auditory Fusion Test-Revised (AFT-R) (Mc Croskey & Keith,1996), the

Random Gap Detection Test (RGDT) (Keith, 2000), Gaps in Noise (GIN) test (Musiek et al., 2005), Gap Detection Test (GDT) (Plomp,1956).

2.1.1. Auditory Fusion Test-Revised. The AFT-R is designed to measure temporal resolution through determination of the Auditory Fusion Threshold (AF threshold). The auditory fusion threshold is measured in milliseconds (msec) and is obtained by having a listener to attend to a series of pure tones presented in pairs. The silent time interval (the inter pulse interval, IPI) between each pair of tones increases and decreases in duration. As the silent interval changes, the listener reports whether the stimulus pairs are heard as one or two tones. The interval at which the tone pairs are perceived as two (when the IPI is increasing) is averaged with the interval at which the tone pairs are perceived as one (when the IPI is decreasing) and that average is called the AF threshold. This stimulus protocol is sometimes called "gap detection'' interchangeably used in clinical settings.

In a study by McCroskey and 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 grouped into typically developing children, children with reading disability and learning disabled. The children were administered the original version of the Wichita Auditory Fusion Test (WAFT). 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 between the typically developing children and the other two groups. In another study AFT was administered on children aged 9 to 18 years with a control group consisting of typically developing children and an experimental group of children with learning disability. Auditory Fusion Thresholds were significantly different between groups and showed a higher AFT for children with learning disability than the control counterparts (Isaacs, Horn, & Keith, 1982)

2.1.2. Random Gap Detection test. The RGDT is an adapted version of the AFT-R. This procedure uses tones, clicks, and the interval presentation is randomized. The tones or clicks with silence intervals varying from 0 to 300 msec in between the tones are used. Stimulus is either pure tones (500 Hz, 1000 Hz, 2000 Hz& 4000 Hz) or clicks with variable ISI durations. The task the individual has to perform in these procedures is to identify whether he/she heard one or two sounds (Keith, 2000).

Dias, Jutras, Acrani and Pereira, (2012) measured GDT on 225 participants who were divided in two groups of131 children with central auditory processing disorder (CAPD) and 94 children with normal auditory processing. Following the auditory processing assessment, the RGDT was administered to the participants and 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 to 6-year-old children.

2.1.3. Gap-In-Noise Test. The GIN consists of 0 to 3 silent intervals ranging from 2 to 20 msec gaps embedded in 6 sec segments of white noise. The location, number, and duration of the gaps-per-noise segment vary throughout the test for a total of 60 gaps presented in each of four lists (Musiek et al, 2005). The inter-stimulus interval between segments of white noise was 5 s, and the gap durations were 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 msec. Both the gap duration and the location of gaps within the white noise segments were pseudo randomized and the number of gaps per noise segment also varied.

Shinn, Chermak and Musiek, (2009) measured GIN thresholds on 72 children in the age range of 7 to 18 years of age. The results revealed no statistically significant differences in GIN thresholds among age groups. In addition, within group analysis yielded no statistically significant differences between ears within each age group. Children as young as 7 years were able to complete the GIN task without much difficulty and perform at levels commensurate with normal adults. The absence of ear differences suggests that temporal resolution as measured by the GIN is an auditory process that develops relatively early and symmetrically (i.e., no laterality or ear dominance effects).

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 GIN thresholds of 4.8 msec for the left ear and 4.9 msec for the right ear for control group. In comparison, results for experimental group demonstrated a statistically significant increase in GIN thresholds, with approximated thresholds of 7.8 msec and 8.5 msec being noted for the left and right ears, respectively.

2.1.4. Gap Detection Test (GDT). The participant's ability to detect a temporal gap in the center of a 750 msec broadband noise is measured. In a two-interval alternate forced-choice task, the standard stimulus is a 750 msec broadband noise with no gap whereas the variable stimulus contains the gap. Gap detection is a reasonably well-established paradigm which measures a listener's ability to detect a brief temporal gap at which separates two successive stimuli. Most often, stimuli employed in this task have consisted of bursts of broadband noise, 100-200 msec in duration, or greater. 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 and Manjula, (2003) normative data for GDT in children was developed and comparison was done with GDT in adults. He estimated GDT 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 using noise bursts of 300 msec 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 msec and children aged 7 years could detect a gap of 4.05 msec. 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. Gap detection using different psychophysical procedures

GDT can be estimated majorly by means of two classes of procedures: adaptive and non-adaptive.

2.2.1. Non-adaptive procedures. In non-adaptive procedures the stimuli levels (or differences between standard and variable level) are preset before the beginning of the experiment. The stimuli will span from below to above subject’s threshold. During the experiment, the stimuli are presented to the subject in random order and the proportion of yes (or correct) responses is calculated for each stimulus. In other words, the subject’s threshold will be interpolated from a fully-sampled psychometric function making the measurement of the threshold expensive in terms of experiment's time. This represents the major drawback of this class of procedures when the experimenter needs to estimate the subject's threshold only. For the above reason, when they need to estimate a threshold, psychophysicists prefer adaptive over non- adaptive procedures.

2.2.2. Adaptive procedures. It maximizes the ratio between number of stimuli presented at/near threshold and number of stimuli presented far from threshold. They can be grossly divided in two types: nonparametric (also known as staircases) and parametric. Non-parametric procedures, has an assumption of the psychometric function to be monotonic whereas parametric procedures, on the contrary, make more assumptions. For example, it assumes the shape of the psychometric function. They pose a major disadvantage of more time consuming (e.g., Amitay, Irwin, Hawkey, Cowan, & Moore, 2006; Leek, 2001). Examples of non-parametric procedures are the method of limits (Fechner,1889), the simple up-down (Békésy, 1947) and the transformed up-down (Levitt, 1971). Examples of parametric procedures are the PEST, (Taylor & Creelman, 1967), the "best" PEST (Pentland, 1980) and the QUEST (Watson & Pelli, 1983) and Maximum Likelihood Procedure (MLP, Green, 1990).

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).

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).

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)

*Maximum Likelihood Procedure***.** The MLP is an adaptive procedure where the experimenter hypothesizes several psychometric functions called hypotheses (Green, 1990 & 1993). Trial by trial, the maximum likelihood algorithm estimates which hypothesis has the highest likelihood of being similar to the actual subject's psychometric function according to the subject's responses the most likely hypothesis is assumed to contain, most likely, the threshold.

It includes two tasks, either a yes/no or alternate force choice method (nAFC). In yes/no tasks, the subject is presented with a succession of different stimuli levels spanning from below to above subject's detection threshold and is asked to report whether he/she has detected the stimulus by 'yes' or 'no'. In nAFC task, the subject is presented with a series of n stimuli differing in level. A major difference between these tasks is that in yes/no tasks, the subject's response criterion is not under control of the experimenter, on the contrary, to the nAFC tasks (Green & Swets, 1966; Stanislaw & Todorov, 1999). GDTs obtained using a multiple-interval, multiple alternative, forced-choice procedure are both reliable and valid as demonstrated by numerous studies (Lister et al., 2002; Lister, Koehnke, & Besing, 2000; Roberts & Lister, 2004). Usually, 3AFC is preferred for a quick and more reliable result. 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, 1990, 1993). This procedure has been widely used to assess psychophysical abilities and found to have good reliability and validity (Kumar & Sangamanatha, 2011). Green (1993) claimed that twelve trials of maximum likelihood are sufficient for a reliable threshold estimate. Although, recent evidences suggest that this initial claim was too optimistic (e.g., Leek, Dubno, He, & Ahlstrom, 2000; Amitay et al., 2006). In threshold estimation, the stimulus level eliciting the p-target proportion of yes (or correct) responses is looked for. Treutwein (1995) proposes that the p-target should be the middle of the psychometric function (e.g, 50% for yes/no tasks, 75% for

2AFC, 66% for 3AFC, etc.). However, other authors suggest that higher values should be targeted (e.g., Green, 1990; Baker & Rosen 1998, 2001; Amitay et al., 2006).

2.3. Different stimuli used for GDT

GDT can be measured using different stimuli such as pure tones, narrow band noise and broadband noise. Further, these stimuli can be modified by varying the frequency, intensity, stimulus duration, gap position and presentation time of the auditory stimulus. These variables can result in a wide variety of thresholds (Schneider & Hamstra, 1999).

2.3.1. Narrowband noise. The use of narrow band noise permits the specification of stimulus frequency but it is suggested that the gap thresholds are partly limited by fluctuations in the noise (Glasberg, Moore & Bacon, 1987; Shailer & Moore, 1983). Dips in the noise envelope may be confused with the gap to be detected. In case of pure tones, though it permits frequency specificity but the reduction in the gap leads to spectral splatter.

2.3.2. Using broadband noise. In case of broadband noise (white noise), the gaps are introduced in between the noise. Jerger and Musiek (2000) suggested that gap detection tests should utilize broadband noise stimuli. Although some disadvantages exist (e.g., equalization of overall loudness across intervals, lack of frequency specificity, influence of sloping hearing loss on effective bandwidth), broadband noise has an advantage over other stimuli in that it masks the spectral splatter that results from abruptly interrupting a signal (Trehub et al.,1995).

2.3.3. Using sinusoidal maskers. 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.

2.4. Maturational effects on gap detection

Gap detection has been studied by various authors across age. They have witnessed a developmental trend in the gap detection thresholds obtained. Trehub et al. (1995) assessed GDT on subjects in the age of 6.5 months, 12 months, 5 years, and 21 years of age. The stimuli was a pair of 500-Hz, Gaussian-enveloped tone pips of the same duration and total energy. They were measured on single gap duration of 8, 12, 16, 20, 28 or 40 msec for the subjects. Gap-detection thresholds for infants (6.5- and 12-month-olds), children and adults were 11, 5.6, and 5.2 msec, respectively.

In another study, Snell (1997) measured GDT on 20 young and 20 older participants with normal hearing sensitivity who were matched in audiometric configuration for frequencies between 250 Hz to 4000 Hz. Stimulus used was 150 msec low pass noise bursts digitized with cutoff frequencies of 1000 or 6000 Hz with an inter stimulus interval of 600 msec. GDT was estimated in quiet, in the presence of white noise and high frequency masker at two intensity levels (70 & 80 dB SPL) and at two levels of modulation (0% & 12.6 %). Results indicated that mean gap of older participants was larger than younger participants and they were more sensitive to noise. Mean GDT scores was higher in both groups for high frequency masker.

In an Indian study, Shivaprakash and Manjula, (2003) estimated GDT on 60 participants with normal hearing sensitivity. The participants were divided into six cross-sectional age groups of 7 to 12.11 years and 30 normal hearing adults using noise bursts of 300 msec duration with a silence of different durations at 40 dB SL. The results indicated that normal hearing adults could detect a mean gap of 3.3 msec and children aged 7 years could detect a gap of 4.05 msec. However, GDT did not differ significantly between children and adults.

A study done by Kumar and Sangamanatha, (2011) measured GDT in 176 participants with normal hearing sensitivity in the age range from 20 to 85 years divided into six cross-sectional age groups. GDT was measured with a 750 msec broadband noise and temporal gap was presented in the center of the noise. GDT in individuals >70 years of age was almost eight folds greater than those for young adults (20–30 years of age).

Moreover, few studies have shown that GDT reaches adult like value by around 5 to 6 years of age (Jensen & Neff., 1993) and in other studies it has been shown that GDT matures till the age of 9-10 years of age (Davis & Me Croskey; Irwin; Grose, as cited in Sandra et al., 1995). Thus, there is a disagreement about the developmental trend in GDT.

2.5. GDT in individuals with hearing loss

Fitzgibbons and Wightman (1982) compared GDT in individuals with normal hearing sensitivity and cochlear hearing loss. Results showed that the temporal resolution was significantly poorer in individuals with hearing loss compared to individuals with normal hearing. This was seen regardless of whether the comparison was made at the equal SPL or at the equal SL. Cudahy (1977) also reported cases of elevated gap thresholds in subjects with high frequency hearing loss. 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.

2.6. GDT in disordered population

Farmer and Klein (1995) did a review study of underlying temporal deficit being linked to dyslexia. They reported that early phonological deficits are related to a poor temporal processing skill which has to be evaluated. Boets, Wouters, Wieringen and Ghesquiere (2006) studied temporal resolution in two groups of five-year-old pre-school children who were divided based on familial high risks and low risks. They were assessed using gap detection, frequency modulation detection and tone in noise detection using three-interval forced-choice adaptive staircase paradigm embedded within a computer game. The results showed that both frequency modulation and tone-in-noise detection were significantly related to phonological awareness.

Thus, studies show that assessing temporal processing in language disorders, reading and writing disorders like dyslexia, learning disability is important to rule out the cause and identify the disorder at the earliest. Also, studies show that temporal processing acts as an underlying cause for phonological processes being affected.

Chapter 3

Methods

3.1. Participants

A total of 120 participants in the age range of 7 to 9 years participated in the study. The participants were equally divided into 2 subgroups: 7-7.11 years and 8-8.11 years). Further, additional 12 participants were included for the validation of the developed data. 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 SCAP (Screening Checklist for Auditory Processing Disorder, Yathiraj and Mascarenhas, 2003 and 2004) (Appendix 1).

3.2. Instrumentation

1) A Clinical portable Screening audiometer Porton DX was used for threshold estimation (pure tone audiometry). Calibrated TDH 39 headphones for AC threshold and calibrated B-71 bone vibrator for BC threshold were used.
2) A Screening checklist for Auditory Processing Disorder (SCAP, Yathiraj and Mascarenhas., 2002) was administered to screen for auditory processing disorder.

3) A personal laptop (DELL Inspiron 15) loaded with MATLAB version 8.3 having Maximum Likelihood Procedure (MLP) toolbox (Appendix 2) was used and calibrated HDA 200 headphones was connected with the laptop to assess ear wise GDT.

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 they participated in the study. Hearing thresholds was tracked using modified Hughson and Westlake method (Carhart & Jerger, 1959) for air conduction and bone conduction. Pure tone average (PTA) was calculated by taking mean of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz and participants who had thresholds within 15 dB HL were considered for the study. Further SCAP was administered and participants who had a “pass” in SCAP, on them GDT was measured.

3.4.1. Screening Checklist for Auditory Processing Disorder (SCAP). SCAP was administered which consisted of 12 questions. The clinician asked questions to the parents/guardian with clear and adequate voice. Response format was ‘yes’ or ‘no’ and analysis was done on basis of number of ‘YES’ responses. (≤6 ‘yes’ considered as ‘PASS’ & ≥ 6 as ‘REFER’). Participants who had a “pass” only was considered for the further study.

3.4.2. Gap Detection Test. GDT was carried out using MLP toolbox implemented in Matlab (Grassi & Soranzo, 2009). The MLP made use of a large number of participant's psychometric functions which gives the highest likelihood was used to decide the stimulus to be presented in the next trial. In each trial, it estimated the likelihood of arriving at the listener's response for all the stimuli that had been presented. The stimulus of MLP was generated at 44,100 Hz sampling rate.

The stimulus contained a temporal gap in the center of a 750 msec broadband noise. The noise had a 0.5 msec cosine ramps at the beginning and end of the gap. The testing was done at 60 dBSPL through the calibrated HDA 200 headphones connected to the laptop. A three-interval, alternate force-choice method (3AFC) was used to track the threshold. A 79.4% correct response criterion of psychometric function was used to track the threshold. In a three-interval alternate forced-choice task, the standard stimulus was 750 msec broadband noise with no gap whereas the variable stimulus contained the gap. The minimum and maximum gap duration was 0.1 msec to 64 msec.

The children were instructed to respond either verbally or press the number keys (1, 2 or 3) in response to the variable stimulus containing the gap. 5-6 practice trials were given to familiarise them and the actual test of 30 trails were given. The stimulus was presented to each ear and GDT was measured separately for each ear.

3.4. Validity Assessment

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, 12 children, 6 from each group (10%) were selected and the GDT was administered. The results were analysed to determine whether the GDT in these children were similar to the age specific norms obtained for the test.

3.5. Statistical analyses

The obtained data was statistically analysed using Statistical Software for the Social Sciences (SPSS V.20). Shapiro Wilks test of normality was done to check the normality of the data. Descriptive statistics was used to obtain mean and standard deviation of each age group. Wilcoxon signed rank test was done to check the within the group comparison and Man-Whitney U test was done to compare the between the group comparison. One sample Wilcoxon signed rank test was used to compare the newly established norms with the old norms.

Chapter 4

Results and Discussion

The aim of the present study was to develop normative data for gap detection threshold using MLP toolbox in children (7-9 years). A total of 120 participants were included with 60 children in each age group**.** The Shapiro Wilks test of normality was done on the obtained data in both the groups and the results revealed the data did not follow normal distribution ($p > 0.05$). Hence, non-parametric test was used for further analyses. Descriptive statistics was done to find the mean, standard deviation (SD), median and range for right and left ears of each age group**.** (See Table 4.1)

Results are discussed under the following headings:

1. Comparison of gap detection thresholds of right and left ears within the age groups. (Wilcoxon signed rank test)
2. Comparison of gap detection thresholds between the age groups. (Man-Whitney U test).
3. Comparison of newly established data (using mlp) with the previous data (CD presentation*).

(* Shivaprakash & Manjula, 2003) Gap Detection Test – Development of Norms)

4. Validation of developed norms

4.1. Comparison of gap detection thresholds of right and left ears within the age groups

Table 4.1 shows the mean, SD, median and range of the gap detection thresholds of right and left of the two age groups. Figure 4.1 shows the mean and SD of GDT for both the groups across ears.

It is evident from the figure 4.1 that the mean gap detection thresholds for both the groups were similar across ears.

Table 4.1

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

Age Group (in years)	Ears	Mean (msec)	S. D	Median	Min	Max	Interquartile Range
7-7.11	RIGHT N=60	5.66	0.53	5.56	4.22	6.89	0.59
	LEFT N=60	5.72	0.58	5.65	4.45	7.24	0.90
8-8.11	RIGHT N=60	4.84	0.50	4.64	4.12	6.50	0.71
	LEFT N=60	4.86	0.55	4.70	4.12	7.43	0.66

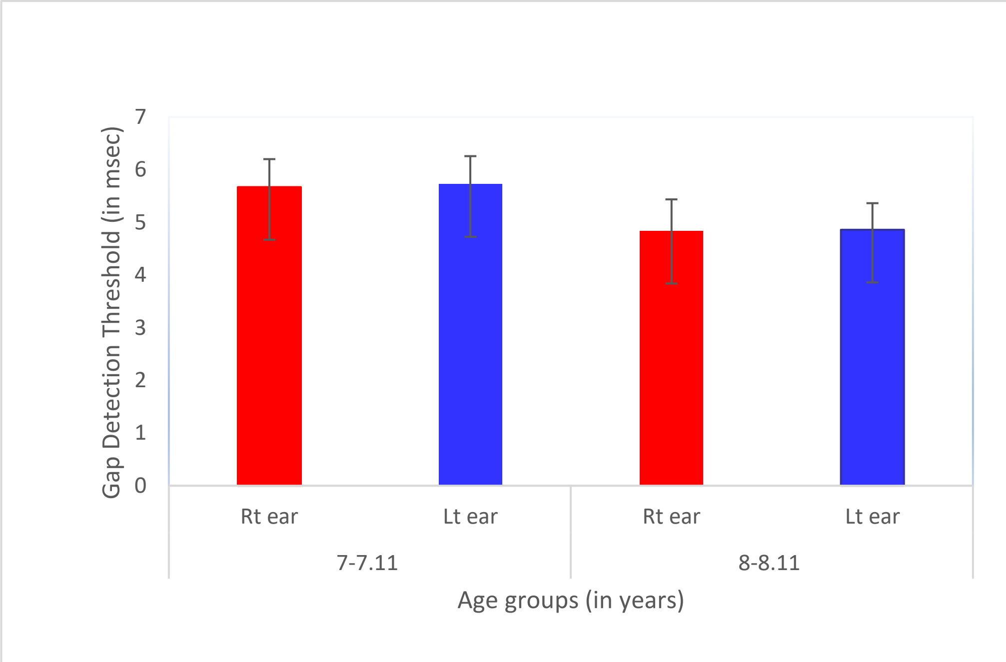

Figure 4.1 The mean and SD of gap detection thresholds for right and left ear across age groups

Further, Wilcoxon signed rank test was done to compare the gap detection thresholds of right and left ears within the groups. The results indicated that there was no significant difference between the right and left ears for 7 to 7.11 years ($Z=0.512$, $p>0.05$) and 8-8.11 years ($Z=0.088$, $p>0.05$). This suggested that the gap detection thresholds in right and left ears did not differ within the age groups. Similar results have been reported by the other studies (Shivaprakash & Manjula, 2003; Baran & Musiek, 1999; Shinn et al, 2009). Shivaprakash and Manjula (2003) reported that gap detection thresholds of 7-12 years did not differ significantly across right and left ears within the groups. They hypothesized that there is no right ear advantage seen in the age range of 7-

9 years which is attributed to the fact that there is no hemispheric advantage seen in gap detection tasks even in children by the age of 7 years.

Moreover, it can be inferred that monotic tests are useful for detecting but not locating these changes, as ipsilateral and contralateral pathways participate in this process, which results in similar right and left ear performance (Baran & Musiek,1999). Shinn et al (2009) also reported that the auditory system maturation of temporal resolution abilities occurs similarly in both ears.

4.2. Comparison of gap detection thresholds between the age groups

For the comparison of GDT between age groups the thresholds of right and left ear were combined as there was no significant difference between GDT across ears. Thus, Table 4.2 shows the combined mean, SD, median and range for both the age groups and Figure 4.2 shows the combined mean and SD of both the age groups. From the table it is evident that the older age group (8 to 8.11 years) had better GDT compared to the younger age group (7 to 7.11 years). Man-Whitney U test was done to compare the GDT between the groups. The results revealed that there was a significant difference in GDT between the groups (/Z/=7.38, $p<0.05$). It indicates that there is a developmental trend in gap detection threshold and also as age increases, the gap detection threshold improves that is older age group require a only minimum duration to identify the gaps in the stimulus.

Table 4.2

The combined mean, S.D, median of gap detection thresholds for 7-7.11 years and 8-8.11 years

Age group (in years)	Combined mean (msec)	S. D	Median	Min	Max
7-7.11 Years	5.69 (N=120)	0.49	5.69	4.22	4.12
8-8.11 Years	4.85 (N=120)	0.50	4.67	7.24	7.43

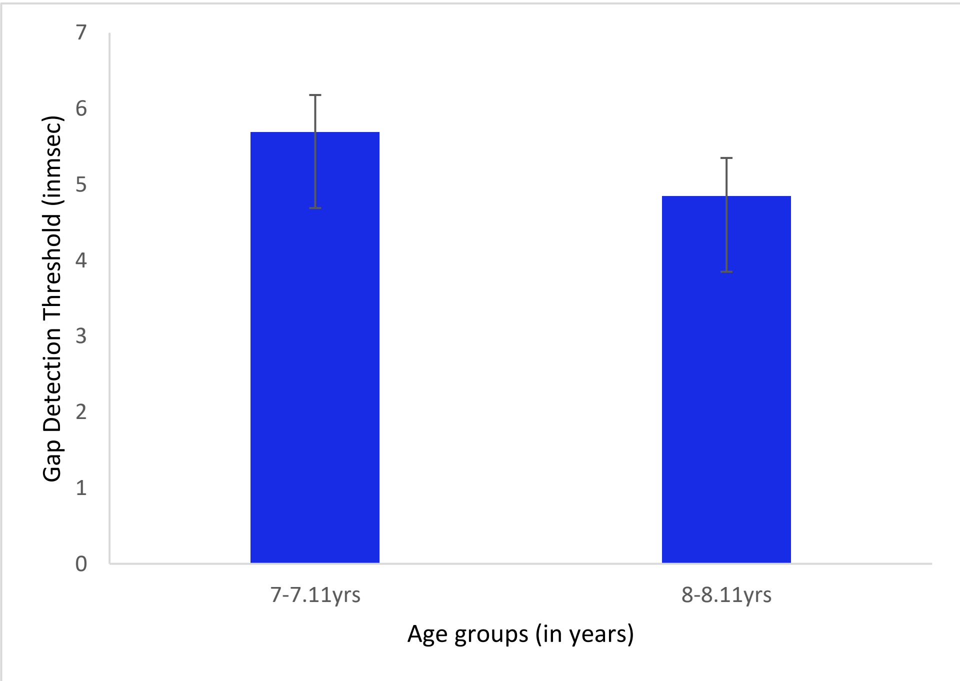

Figure 4.2. The mean and SD of GDT for the two age groups (7-7.11 years & 8-8.11 years)

These results are in accordance with the research reported in the literature (Fischer and Hartnegg, 2004; Hall and Grose,1994, Shinn et al., 2009). Studies have shown that the gap detection skills improve with increase in chronological age; although adult like performance is reported as early as age 10 but observed as late as 16-18 years of age also (Fischer & Hartnegg, 2004). Hall and Grose, (1994) found that the peripheral mechanism responsible for encoding temporal aspects of the acoustic signal appeared to be well developed in young listeners. However, the ability of the central nervous system to extract and process temporal cues appear to improve as a function of age. Shinn et al., (2009) also reported that temporal resolution improves as children mature.

However, this is not in agreement with the some of the previous studies wherein there was no developmental trend was seen in GDT with increase in age. Shivaprakash and Manjula (2003) found no significant difference between the age groups from 7 years to adults on GDT. These differences between results can be attributed to the procedural differences, the stimulus parameters variations and less number of participants considered in their study.

4.3. Comparison of newly established data (using MLP) with the previous data (CD presentation)

Second objective of the present study was to compare the developed GDT norms with the previous established norms (Shivaprakash & Manjula, 2009). For this purpose, one sample Wilcoxon signed rank test was used to compare the means of two studies. The results indicated that there was a significant difference between the two normatives established ($p<0.05$) as shown in Table 4.3.

Table 4.3

The mean and SD of GDT in two age groups between the two normative procedures (CD presentation & MLP)

GDT	7-7.11 years		8-8.11 years	
	Mean (msec)	**S.D**	**Mean (msec)**	**S.D**
MLP (Present study)	5.69 ** N=120 Ears	0.49	4.85** N=120 Ears	0.50
CD presentation*	4.05 N=20 Ears	0.75	4.0 N=20 Ears	0.72

****** Significant difference (p<0.05)

*****The mean and S.D taken from the previous study by Shivaprakash S and Manjula,2003 titled Gap Detection Test – Development of Norms

This statistical difference in the normative data between two studies could be attributed to the procedural differences in estimating GDT. 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 which 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.

There are no studies in the literature that compares the gap detection thresholds in children using different psychoacoustic procedures especially in children. This was the first study that attempted to provide the normative data in children aged 7-9 years using mlp toolbox.

4.4 Validity of the developed norms

The GDT was assessed on another group of participants who were not included in the actual study to obtain normative on gap detection threshold for both the age groups (7-7.11 years & 8-8.11 years). 12 children that is 6 children (12 ears) from each age group (10%) were selected and the test was administered. The mean thresholds obtained in this groups were compared with the mean thresholds for that particular age group.

The result showed that the gap detection threshold obtained by children considered for assessing validity are similar to the normative mean thresholds obtained and are within +/- 1 SD. This result shows that the gap detection threshold obtained through MLP procedure has good validity.

Table 4.4

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

Age Group	Mean (msec)	SD
7 to 7.11 Years (N=120)	5.69	0.49
7 to 7.11 Years * (N=12)	6.22*	0.53*
8 to 8.11 Years (N=120)	4.85	0.50
8 to 8.11 Years * (N=12)	5.08*	0.47*

*Significant difference ($p<0.05$)

Chapter 5

Summary and Conclusion

Temporal resolution is the one of the important central auditory processing function which involves fine segregation of temporal events over a period of time. Gap detection test is the most commonly used test of assessing temporal resolution which provides the information on individual's temporal skills on a single threshold estimation in a clinical setting.

The present study aimed to develop normative, of GDT using MLP toolbox implemented in MATLAB in children in the age range of 7-9 years. A total of 120 children were considered for the study consisting of 60 children from each age group (7-7.11 years & 8-8.11 years). All participants had normal hearing sensitivity and had passed in auditory processing checklist (SCAP). The GDT was obtained for both the age groups across the right and left ears (N=120 ears). Further the study also compared the norms of the present study with the previously established data (using CD presentation).

The results of the study showed that:

i. The mean GDT obtained for each ear separately showed no significant differences indicating that there is no ear differences evident in gap detection test.
ii. The mean GDT obtained between the age groups by taking the combined mean of right and left ear revealed a significant difference between the age

groups ($p<0.05$). This finding of the study revealed that there is a developmental trend in GDT that is being observed.

iii. The combined mean GDT obtained using MLP was compared with the mean GDT obtained using CD presentation across the age groups and results revealed a significant difference between the two procedures. These finding could be attributed to the procedural differences in the two study.

iv. Validation of the developed GDT norms was done with 12 additional participants from each group and it was inferred that the norms developed in the present study was valid.

5.1. Clinical implications and Highlights of the Study

From the present study, the normative obtained using MLP can be used as a valuable diagnostic tool in assessing temporal resolution in a time efficient and reliable manner especially in a clinical setting. It is easy and quick to administer for the clinician and to interpret the results. The procedure involves estimation of the threshold within few trials which helps in sustaining the interest of the child especially when assessed in a CAPD test battery approach. Also, the normative data serve as a baseline for management of CAPD and as a training module for intervention.

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APPENDIX 1

Screening checklist for central auditory processing (SCAP)

Yathiraj and Mascarenhas (2003)

All India Institute of Speech and hearing

Manasagangothri, 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	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		

APPENDIX 2

Screenshot of MLP toolbox implemented in MATLAB