BRAINSTEM CORRELATES OF AUDITORY TEMPORAL PROCESSING IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT

Vijay Karun

Register No. 11AUD030

A Dissertation Submitted in Part Fulfilment of the Degree of

Masters of Science (Audiology)

University of Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI

MYSORE 570 006

May 2013

Certificate

This is to certify that this dissertation entitled **"Brainstem Correlates of Auditory Temporal Processing in Children with Specific Language Impairment"** is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student with Registration No. 11AUD030. 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.

Mysore,

May 2013

Dr. S. R. Savithri

Director

All India Institute of Speech and Hearing

Manasagangothri,

Mysore - 570006

Certificate

This is to certify that this dissertation entitled **"Brainstem Correlates of Auditory Temporal Processing in Children with Specific Language Impairment"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any other Diploma or Degree.

Mysore,

May, 2013

Mr. Sujeet Kumar Sinha

Guide

Lecturer of Audiology

Department of Audiology

All India Institute of Speech and Hearing

Manasagangothri,

Mysore - 570006

Declaration

This dissertation entitled **"Brainstem Correlates of Auditory Temporal Processing in Children with Specific Language Impairment"** is the result of my own study under the guidance of Mr Sujeet Kumar Sinha, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore, **Register No:** 11AUD030

May, 2013

Acknowledgements

First of all, I thank God for blessing me and giving me the strength to conquer my fears and move on in a bid to pursue my goals.

Words are not enough to thank my guide, ***Mr Sujeet Kumar Sinha****, for his wonderful patience. I express my sincere & heartfelt gratitude to my guide. Sir, I thank u for rendering me constant support and guidance throughout & I sincerely thank you for having trust & confidence on me. Your words and your guidance will remain with me throughout my life.*

My sincere thanks to ***Dr. S.R. Savithri****, Director, AIISH for permitting me to carry out this dissertation.*

I am also thankful to ***Dr. Animesh Barman****, H.O.D Department of Audiology, for allowing me to carry out this research. I'm also grateful to the faculty of the Department of Audiology for imparting their knowledge and valuable suggestions which helped in bringing this dissertation to its present form.*

Dearest Mom and Dad, how does one thank their own parents? If I were to start listing out all the things which you've done for me, I'd be occupied till eternity. Anyways all that I want to say is Thank You soooo much for all the love that you've always bestowed upon me.

I would also like to take the opportunity to thank my dearest and most lovable di, who is always by my side. Love u….

I would like to thank ***Usha mam, Kishore sir & Jitin sir*** *f or helping me at the time of data collection.*

Nike sir, *my heartfelt thanks to you for helping me with your valuable guidance and suggestion constantly and helping me.*

Thanks to all the ***library staffs****, who have helped in searching and issuing books and other study materials.*

I thank all the ***subjects*** *of this study for their participation, without which the work would not have been done.*

Ratul *and* ***Abhishek****, the two chambers of my heart; you guys have added real worth to my living and have definitely made life happier and easier.*

Bhaiya & Bhabhi *you always keep on motivating me, supporting me and were behind me to finish the things quickly thanks a billion for being with me.*

Chhotu *you were always there on your toes for helping me in each perspective of my journey in AIISH…Love you lots.*

Prajeesh & Santu *the way you helped me in AIISH no- one had ever. I will be thankful to you. Have a great life ahead.*

Thanks to all my lovely classmates, ***Saha, Hrudanand, Vivek, Sandeep,Srinath, Suresh, Nandan, Hijas, Sudhanshu, Shrishti ,Prerna, Vinni, Yashu, Gagna, Bharthidasan, Avinash, Sachidanand, Nisha, Nandu, Rajkishore, Suresh, & Sreelakshmi*** *for making my days wonderful both on-campus and off-campus.*

I'd also like to thank my sweet juniors Mangal, Vibhu, Alok & Anoop for having lent a helping hand whenever I needed.

Table of Contents

CHAPTER-1

Introduction

Language helps to acquire and use complex systems for communication. Language also acts as a resource that enables us to make meaning of the world we live in and function successfully within it. Language is interconnected with aspects of form, content, and use. Meaning is well maintained when these aspects are operated effectively (Bloom & Lahey, 1978).

When learning the mother tongue, an infant must first acquire the phonemic categories of the ambient language. The acquisition of native language phonemes takes place rapidly during the first 12 months of life, during which infants learn to gradually tune into the relevant features of their mother tongue (Werker & Tees, 1984; Kuhl, 2000). This acquisition process generally requires relatively accurate perceptual capacity and most children show excellent speech discrimination from a very early age (Aslin, Pisoni, Hennessy, & Perey, 1981; Kuhl & Miller, 1982; Werker & Tees, 1984). Successful spoken language comprehension also involves processing of rapid sequential information encoded in the fast-fading auditory signal. Failures in this task may indicate problems in language learning.

Children with Specific Language Impairment (SLI) have difficulty in expression or comprehension regardless of normal cognitive development and peripheral hearing. SLI is a selective failure to develop language at a normal rate, occurring in the absence of cognitive, neurological, sensory deficit, and psychiatric disorders, and in spite of adequate social and educational opportunities for learning languages (American psychiatric association, 1994 [DSM-IV]), Bishop, 1992; Leonard, 1998; Tomblin et al., 1997).

In children with SLI, several auditory deficits such as auditory temporal deficits (Tallal & Piercy, 1973), problem in discrimination of CV syllables (Tallal & Piercy, 1974), significantly poor in backward masking effect where a brief tone (target) is followed by a masking noise (Wright et al., 1997). Even, electrophysiological studies utilizing cortical potentials have also indicated poorer temporal processing in children with specific language impairment. Children with SLI perform poorly on a rapid auditory sequencing task as it is evident by reduced N1 amplitude in children with SLI (Neville, Coffey, Holcomb & Tallal, 1993).

Temporal refers to time-related aspects of the acoustic signal. Temporal processing is critical to a wide variety of everyday listening tasks, including speech perception and perception of music (Hirsh, 1959). Temporal processing is one of the functions necessary for the discrimination of subtle cues such as voicing and discrimination of similar words. Auditory temporal processing is not a unitary construct and the temporal phenomena present in acoustic stimuli manifest themselves in different ways depending on the task (Green, 1984) and is also based on the relevant timescales and the presumed underlying neural mechanisms. According to Klein (2002), temporal processing deficits could involve a hierarchy of temporal information-processing functions ranging from the perception and identification of stimuli to individualizing and perceiving multiple stimuli presented in the correct sequences.

One way to assess the temporal processing electrophysiological is to study the stimulus complexity by examining the effects of stimulus rate on speech evoked auditory brainstem responses (Krizman, Skoe & Kraus, 2010, Garvita, 2012). Recently Speech evoked auditory brainstem responses (SABR) measures have been introduced as a means to study the brainstem encoding of speech sounds (Russo, Nicol, Mussacchia& Kraus, 2004; Banai, Nicol, Zecker & Kraus, 2005; Sinha & Basavaraj, 2010a; Sinha & Basavaraj, 2010b).

Speech evoked ABR contains two types of responses: Transient responses and the sustained responses. Additionally it is possible to get the information about encoding of fundamental frequency and its harmonics at the brainstem level. The generators of speech evoked involves multiple of structures at the brainstem level including the higher brainstem (inferior colliculus) (Worden & Marsh, 1968; Moushegian, Rupert & Stillman, 1973).

Speech evoked ABR holds its importance in the diagnosis of various pathologies. Speech evoked ABR has been evidenced to diagnose children with Learning disability (Banai et al., 2005; Cunningham, Nicol, Zecker, Bradlow & Kraus, 2001; Hayes, 2003; King, Warrier, Hayes & Kraus, 2002; Russo, Nicol, Zecker, Hayes & Kraus, 2005; Wible, Nicol & Kraus, 2004; Wible, Nicol & Kraus, 2005), individuals with sensorineural hearing loss (Ananthanarayan & Pyler, 2001), children with poor readers skills (Hornickel, Skoe, Nicol, Zecker & Kraus, 2009), children with autistic spectrum disorder (Russo, Nicol, Trommer, Zecker& Kraus, 2009), aging (Vander, Kathy, Burns & Kristen, 2011) and speech-in-noise perception problems in older adults (Anderson, Parbery- Clark, Yi & Kraus, 2011).

Need of the study

1. Speech is a complex signal and it has spectral and amplitude modulations over a period of time. Speech perception deficits could occur if there is any deficit in encoding of these spectral and amplitude modulations. The click-evoked ABR is a gross measure of time-locked neural activity in response to stimulus onset. However, the frequency-following response (FFR) is a steady state AEP is sensitive to sustained features (Worden & Marsh, 1968). Thus there is a need to study speech evoked ABR.

2. The processing of speech sounds is potentially more "meaningful" than the processing of any non-speech sound. Speech-evoked ABR recordings may have diagnostic and clinical management implications to help screen or identify patients with abnormal speech processing or perhaps those with auditory processing disorders (Khaladkar, Kartik, & Vanaja, 2005).

3. In children it is difficult to get the behavioral response. Speech evoked ABR is an electrophysiological test which does not require the cooperation from the client and gives the information about the brainstem coding of speech sound. By increasing the repetition rate of the stimuli during the recording of Speech evoked ABR, the auditory temporal processing can be checked.

4. Electrophysiological studies utilizing the cortical potentials & behavioral studies have reported an auditory temporal deficit in children with SLI (Neville, Coffey, Holcomb, & Tallal, 1993). However there is a dearth of information on auditory temporal processing at the brainstem level.

Objectives of the study

1. To investigate the interactions between auditory temporal processing and stimulus complexity by examining the effects of stimulus rate on speech evoked ABR in normal hearing children and children with specific language impairment.

2. To check whether the stimulus rate affects the encoding of the onset of the response or the sustained portion of the response in children with language impairment.

CHAPTER-2

Review of Literature

The neural encoding of sound instigates in the auditory nerve fibres and travels to the auditory brainstem. Brainstem responses to simple stimuli like clicks and tones are commonly used in clinical practice to evaluate the integrity of auditory pathway (Moller, 1999; Starr and Don, 1988). Some people cannot perceive speech well, even after normal peripheral hearing. Previous studies have shown that it happens because of the disruption of neural timing at the cortex which turns to impaired auditory perceptual (Kraus et al., 1996; Nagarajan et al., 1999; Tonnquist-Uhlen, 1996; Wible et al., 2002).

Furthermore, abnormal electrophysiological responses to speech syllables at the brainstem level have been associated with a wide spectrum of diagnosed learning problems (King et al., 2002). These abnormalities comprise a temporally delayed response to the onset of a consonant and deficient spectral representation of harmonic aspects of the speech signal. Speech brain stem responses are more useful for clinical applications. It is a sensitive biological marker of maturation (Anderson et al. 2010; Johnson et al. 2008a; Burns et al. 2009) as well auditory training (Russo et al. 2005; Song et al. 2008). It is also highly replicable during testing and reliably measured under passive conditions with the help of a small number of electrodes (Russo et al. 2004, 2005). It provides information about the biological basis of hearing and language disorders.

SPECIFIC LANGUAGE IMPAIRMENT

The ability to speak distinguishes human beings from other species. Language helps human beings to communicate their needs along with sharing their complex thoughts and emotions. Infants are born with a capacity to acquire language. About (Grimm, 2003; Leonard, 1998, Fromm et al., 1998) reported that around 6-8% of all elementary school children exhibit difficulty in learning their native language appropriately. AFASIC, (1989) stated that approximately half a million children between the age range of 3 to 16 years have speech and language impairments in spite of no hearing loss, mental handicap or emotional disorders. Tomblin (1996) reported that incidence is higher for boys than girls.

Typically, SLI is defined in terms of segregation criteria: Grimm (2003) has stated that children without any form neurological, psychiatric impairments, physical or sensation impairments, but with normal hearing sensitivity, vision, and a nonverbal (performance) IQ above 85. Child fails to acquire language with no apparent reason. Typically it is assumed that children with SLI have normal social use of language and non-verbal communication. If there is any deficit it is manifested in secondary moments of the structural language.

AUDITORY PROCESSING IN SLI

Behavioral tasks:

Auditory processing disorder (APD) and specific language impairment (SLI) are developmental communication disorders (Jerger, 2009; Leonard, 1998). The criterion to classify children under SLI includes having normal hearing sensitivity but still performing poor on listening tasks, deficits in skills related to auditory perception like discrimination, pattern recognition, temporal integration and ordering, dichotic listening, and the perception of degraded stimuli (ASHA, 2005). The various associated problems reported in children with SLI include spelling, reading, and receptive and expressive language (ASHA, 2005; Dawes et al., 2008).

CAPD might occur as a comorbid problem in children with reading and/or language related issues. Few authors believe that difficulty in processing of auditory signals eventually leads to reading and language disorders. Based on the extent of processing deficits of auditory signals in children the comorbidity can vary from issues in speech perception in noise to dyslexia/SLI (Ayotte et. al. 2002).

The incidence of behavioral auditory processing deficits in 30–40% of learning disabled (LD) individuals (Tallal, 1980; Reed, 1989; McAnally and Stein, 1996; Wright et al., 1997; Ahissar et al., 2000; Ramus et al., 2003; Banai and Ahissar, 2004). Though the incidence of SLI as such is not revealed much, the chances of SLI children having auditory processing deficit is quite high. At the same time the results of non-auditory tasks in 5-15 children with SLI showed normal performance compare to normal emphasizing the possible high incidence of auditory deficits in children with SLI (Rosen, van der Lely, Adlard, & Manganari, 2000).

Dlouha, Novak and Vokral (2007) administered various tests for central auditory processing disorders in a group of normal children and children with specific language impairment. These tests included dichotic CV and dichotic digit test. The authors reported that the children with SLI performed poor on these tests compared to the normal children. The authors concluded that there is a relationship between the deficit in speech language perception and central auditory processing disorder in children with SLI.

Vandewalle, Boets, Ghesquiere and Zink (2012) investigated auditory temporal processing task, speech perception task in a group of normal children and children with specific language impairment. The authors also tried to correlate between these auditory processing task and speech perception skills and oral language and literacy skills in children with SLI. The authors reported that children with SLI performed poorer that normal children on speech perception task and not on the auditory temporal processing task. The authors concluded that speech perception ability in children with SLI is more associated with the development of literacy skills and less with oral language ability.

In order to discriminate tones based on the duration, children with SLI required longer inter stimulus interval compared to normal control group (Lowe and Campbell, 1965). Tallal and Piercy (1973) reported that a inter stimulus interval (ISI) required for children with SLI was 300 msec. However, the performance significantly required when the ISI is reduced. But up to 8ms the control group maintained higher performance. The temporal sequencing test also showed similar performance in control group. However, they concluded that the prominent issue might be lying in discrimination rather than in sequencing.

Miller, Kail, Leonard and Tomblin (2001) evaluated the reaction time for a range of auditory tasks in a group of normal children and children with specific language impairment. The task included both linguistic and nonlinguistic tasks. The authors reported that children with SLI perform poorly in the entire auditory task for both the linguistic and nonlinguistic stimuli compared to the normal children. The authors concluded that children with SLI have slower reaction time compared to the normal children on auditory tasks.

Shortening the absolute duration of the tonal signal results in difficulty in discrimination among children with SLI. The performance of the children with SLI was significantly reduced when the absolute duration of the signal was reduced from 250ms to 75ms (Tallal & Piercy, 1973). Hence they concluded that children with SLI have basic problem with temporal processing of transient signals leading to difficulty in speech perception.

The children with SLI also show difficulty in perceiving formant transition. Tallal and Piercy (1974) conducted a research with discrimination of /b/ from /d/ by making a continuum from /b/ to /d/ by changing formant transition. Children with SLI showed significant difficulty in this discrimination task since it was basically related to transient temporal changes. However they performed better when the transition was made slower. Hence, this suggests that deficits in auditory processing is related to transient signals which may leading to a language deficit which is supported by studies of temporal processing in children with language disorders (Tallal and Piercy, 1974).

Wright et. al. (1997) investigated the degree of masking obtained for a variety of temporal and spectral relationships between a noise masker and a short probe tone. For simultaneous masking and forward masking the thresholds shown by children with SLI was similar to that seen normal hearing children, however in backward masking performance was very poor. The performance had a difference of 40 dB with normal showing less masking effect relatively. The difficult of children with SLI in frequency discrimination can also pop up as a deficit in discrimination of transition (McArthur & Bishop, 2004).

The poor formant discrimination in children with SLI is restricted to isolated second formant discrimination but that is not shown up in the natural speech (Rosen & Manganari, 2001). Auditory deficits certainly are more common in SLI groups than in controls, but far from universal. As Bishop et. al. (1999) has pointed out, an auditory deficit is neither necessary nor sufficient to cause SLI/SRD. The controversy lays in the fact those individuals with normal literacy and language skills do show temporal deficit. Similarly many children with SLI also show normal temporal processing. Hence they supported the conclusion that APD is occurring as a comorbid condition among children with SLI.

Wong, Ciocca & Yung (2009) evaluated 14 children with SLI and compared these children with age matched and vocabulary matched children. The task given was discrimination of fundamental frequency patterns for the three groups. The authors reported that the children with SLI performed poorly on discrimination task than the age matched group but not the vocabulary matched group. The authors concluded that for children with SLI have deficits in processing of fundamental frequency.

However, there are also studies which report no difference in the auditory task between normal children and children with specific language impairment. Montgomery (1999) evaluated the lexical mapping of auditory word recognition in group of normal children and children with specific language impairment on a forward gating task in which both the groups listened to successive temporal chunks of familiar monosyllabic words. Montgomery (1999) reported that the normal children and children with specific language impairment do not differ in the lexical mapping of auditory task.

Hill, Hogben and Bishop (2005) evaluated frequency discrimination task over a longitudinal period. The authors reported that at the first time of evaluation children with SLI had poor frequency discrimination capability compared to the normal children. At the second time of evaluation the frequency discrimination ability of children with SLI had improved, however, again it was poorer compared to the normal children. However, there was a greater variability in the response of the children with SLI. Few children with SLI performed poorer compared to the other few children and hence there was a group differences.

Electrophysiological tasks

Not only the behavioral task indicates an auditory processing deficit in children with SLI but also the electrophysiological task indicates an auditory problem in children with SLI. Jirsa and Clontz (1990) reported a prolongation of N1 and P2 latency elicited by 1000 Hz and 2000 Hz pure tones in a group of SLI children compared to the normal children. Neville, Coffrey, Holcomb, and Tallal (1993) also reported increased N1-latencies over the right hemisphere in children with SLI compared to the normal children. Several other studies have also reported an increase in N1 latency in children with SLI compared to the normal children (Tonnquist-Uhlen, 1996; Lincoln, Courchesne, Harms, and Allen, 1995).

McArthur and Bishop (2004) used a 700 Hz tone as deviant, a 600 Hz tone as standard with 16 controls (mean age 14.5 years) and 16 SLI to elicit an N1-P2-N2 complex as well as to examine the frequency discrimination. They authors found that N1 and P2 were absent in the SLI with poor reading skills whereas abnormalities were detected in children with SLI with normal reading skills. The authors concluded that frequency discrimination may be impaired in the majority of SLI children.

Korpilahti and Lang (1994) used three odd ball paradigms with younger children with SLI to record MMN. The MMN in normal children with SLI was elicited with frequency discrimination and duration discrimination. The authors reported that across the group there was a difference in term of amplitude of MMN for frequency discrimination, but not for duration discrimination. Hence, the Frequency discrimination might help in detecting subtle problems compared to duration changes in MMN.

As the age increases the latency of MMN reported to be shortens, however which is not reported among children with SLI. Holopainen et al. (1997) conducted a frequency discrimination task in 14 control children and 10 SLI children. The analyses of MMN from different surface electrode positions were compared. At electrode F4 there was a significant difference across groups in term of amplitude but the latencies were similar to the control group. The location on scalp where maximum potential obtained was frontal-right area in control group, but it was at central location for children with SLI. They concluded the results by referring the difference between groups to maturation.

Holopainen et al. (1998) examined 12 children with SLI, 13 children with language impairment due to mental retardation and a control group consisting of 10 normally developed children. The two groups of children with disorder showed reduced amplitude of MMN. The topographical distribution showed differences between all groups: the MMN was more centrally located in the SLI group, and more to the right and central hemisphere in the control group. The difference in topography may be attributed to maturational effects especially when comparing with earlier studies (Holopainen et al. 1997, 1998). They inferred that frequency discrimination deficit may be an indicator of linguistic deficits in children with SLI.

The performance of dyslexic/SLI children varies depending upon the type of problems they have. Lachmann, Berti, Kujala, and Schroger (2005) reported that frequency discrimination deficit was shown by a subgroup of dyslexic children who were poor on word reading whereas such a difference did not existed among children who had difficulty with non-word treading. The difference between dyslexic and normal probably attributes to the difficulty with frequency discrimination or poor memory capacity to store and compare the later presented stimuli in case of discrimination tasks and MMN. Such differences are shown only for those stimuli which were lower in frequency as well as the difference are less than 50 Hz. This probably suggests that neural phase locking might be the factor affecting in children with SLI and contributing to the so called auditory and/or linguistic deficits in them.

It has been reported that children who having learning problem, they cannot discriminate rapid acoustic changes that are occur in speech. Kraus, McGee, Carrell, Zecker, Nicol & Koch (1986), did a study of normal and the children with learning problems, impaired behavioral discrimination of a rapid speech changes (/da/ vs /ga/) was correlated with diminished magnitude of the MMN measures. They concluded that the ability of the children with learning problems to discriminate another rapid speech changes, also was reflected in the neurophysiology. Results indicate that children's discrimination deficits originate in the auditory pathway before conscious perception for the children with learning disability.

In a study by Basu, Krishnan & Weber-Fox (2010) reported a temporal processing deficit in children with specific language impairment utilising frequency following responses recorded with different pure tone stimuli. Basu et. al. (2010) reported that the phase locking was reduced in children with specific language impairment at higher repetition rate suggesting of a auditory temporal defects in these children. The authors conclude that there is a disruption in the temporal pattern of phase-locked neural activity necessary to encode rapid frequency change and an increased susceptibility to desynchronizing factors related to faster rates of stimulus presentation in children with SLI.

Speech Evoked Auditory Brainstem Responses

Speech ABR is a valid and reliable electrophysiological test to find out the integrity of the neural transmission of the speech sound at the brainstem. Brainstem responses provide direct information about how the acoustic feature of a speech syllable like /da/ is encoded by the auditory system. The brainstem response to a speech syllable can be divided into transient and sustained portions, it also known as the onset response and the frequency-following response (FFR). These features are present in /da/ sound and it also intact in the brainstem structure (Boston & Moller, 1985).

Onset responses (peaks V, A) are transient, with peak durations lasting tenths of millisecond. Within the FFR having separate peaks, it corresponds to the periodic peaks in the stimulus waveform. Later portions are representing the offset of the onset burst or the onset of voicing (wave C) and the offset of the stimulus (wave O). Frequency following response (FFR, waves D, E, and F) comes from the harmonic portion of the speech stimulus. The period difference between the response peaks D, E, F resembles to the wavelength of the Fundamental frequency (F0). A Fourier analysis of this portion of the response confirms a spectral peak at the frequency of F0 and also a spectral peak at first formant frequency (F1) (Johnson, Nicol & Kraus, 2005; Galbraith, Arbagey, Branski & Comerci, Rector, 1995; Russo, Nicol, Musacchia & Kraus, 2004).

Clinical Utility of Speech ABR

Hearing loss

Transient response and the FFR are affected in SNHL. Player and Ananthnarayanan (2001) evaluated the FFR encoding of three synthetic stop consonants, /ba/, /da/, /ga/, in normal- hearing and hearing impaired listeners with mild to moderate cochlear loss. They reported that the FFR related phase locked activity faithfully followed the second formant transition in the normal. Whereas, in contrast, FFR from the hearing impaired listeners did not follow the formant transition presented in the stimuli. However, in cochlear hearing loss subject the identification performance of stop consonant was reduced because of degradation in the encoding of the second formant.

There are reports that suggest that the transient part of the speech evoked ABR is affected in SNHL subjects. Khaladkar, Karthik & Vanaja (2005) recorded speech ABR on 20 ears with mild to moderate SNHL. Two different stimuli were used to evoke ABR- an acoustic click and burst portion of syllable /t/. They reported that latency of the wave V for the click stimulus was within normal limit, whereas speech burst ABR showed deviant results in SNHL cases for the same measures. It suggests that speech ABR helps in isolate normal speech processing from abnormal processing. Further, as the degree of SNHL increases, the coding of speech parameters are more affected at the brainstem.

Sumesh and Barman (2010) inspected the effect of cochlear HL on brainstem responses to speech. They took the 20 normal and 22 individuals between the age range of 16-50 years whose hearing Loss was between 26-55 dB HL. Clinical groups were divided into mild and moderate HL. They concluded that all latency, amplitude, and spectral parameters showed significant difference across the groups. Amplitude reduced and latency prolonged with an increase in degree in hearing loss. The author concluded from this finding to difficulty in coding temporal fine structure by cochlear hearing loss groups.

Learning disability

It has been reported that peaks of A, C & F is delayed in the learning problem children (Cynthia King, Nina Kraus, et.al. 2001). There was a significant difference in latency of peaks A, C & F between the normal and the learning problem children. These findings indicate that onset synchrony of auditory brainstem neurons differs between normal children and some children with learning impairments. Furthermore, children with delayed onset responses to a speech stimulus also have delays in the brainstem FFR.

It has been reported that there is significantly prolonged wave V latencies with the learning problem children in the presence of noise (Kraus, 2001). A fast Fourier transform of the FFR revealed reduced energy in certain frequency bands (250-750 Hz) in the learning problem children compared to normal. Correlations between the stimulus and response waveforms in noise were significantly lower for the learning disable children. Overall, the data indicate that synchrony of auditory brainstem neurons differs between normal learning and children with learning problem.

It can make difficult to process the language at the higher level, when subcortical structure shows the abnormal representation of important features of speech sounds, reported by Wible, Nicol & Kraus., (2004). They examined under stress of rapid stimulation how the human auditory brainstem represents basic elements of speech sounds differently in children with language-based learning problems compared to normal children. They got the significantly shallower slope of wave V-Vn in learning problem children in response to the onset response of the speech sound /da/. It means wave V-Vn had longer latency and the smaller amplitude. The amplitude of the frequency following response (FFR) was reduced in LP subjects over the 229–686 Hz range (first formant of the/da/ stimulus), while activity at 114 Hz, representing the fundamental frequency of /da/, and was no different between groups.

Reading disorder

Even though it is well known that in poor reader phonological processing are affected, it is not well known that how the neural origins are responsible of phonological processing. Banai, Hornicke, Skoe, Nicol, Zecker and Kraus(2009) were first to showed, that phonological decoding, measured with a test of single-non word reading, is significantly correlated with the timing of subcortical auditory processing and also, to a lesser extent, with the robustness of subcortical representation of the harmonic content of speech, but not with pitch encoding. The connections they observe between reading and subcortical processing fall along a continuum, with poor readers at one end and good readers at the other. They did a study and on the basis of data suggest that reading skill may depend on the integrity of subcortical auditory mechanisms.

Banai et. al., (2009) observed that speech evoked ABR latencies were prolonged for the poor reader compare to good reads. The encoding of the pitch and the harmonics was affected in the poor readers compared to the good readers. The authors suggested that the reading skill may depend on the integrity of subcortical auditory mechanisms. With the idea they told that subcortical representation of the acoustic features of speech may play a role in normal reading as well as in the development of reading problem population.

Developmental plasticity

Krista, Johnson, Nicol, Zecker and Kraus (2008) recorded speech evoked ABR in group of children in the age range of 1 years to 5 years. Speech evoked ABR were analysed for both the transient as well as sustained responses. The authors reported that the click evoked ABR develops till 2 years of age whereas, speech evoked ABR in children continues to develop till 5 years of age. The authors concluded that the developmental plasticity for both the speech and non speech stimuli are different.

Ranjan (2011) recorded speech evoked ABR for /da/ in 57 children in 5 groups in the age range of 5 to 9.11 years. The authors reported that for speech ABR, no significant changes were seen for the transient and the sustained responses. The authors concluded that neural processing of temporal aspects of speech stabilizes before 5 years of age.

Speech evoked ABR in musicians

Work on music evoked ABR has included a bowed cello note (Musacchia, Sams, Skoe & Kraus, 2007; Musacchia, Strait & Kraus, 2008), a five- note melody (Skoe &

Kraus,2009), as well as consonant and dissonant two- tone intervals synthesized from an electric piano (Lee, Skoe, Kraus & Ashely, 2009) and tone complexes (Greenberg, Marsh, Brown & Smith, 1987; Bidelman & Krishnan, 2009).

Studies show that potential evoked from primarily brainstem structures are enhanced in musicians, compare to non- musicians. Specifically musicians have more robust representation of pitch periodicity and faster neural timing to sound onset when listening to and viewing a speaker. Musacchia et al. (2008) recorded speech ABR responses to /da/ stimulus and cortical evoked response in musician and non-musician subjects and reported that brainstem response periodicity was related to early cortical response timing across all subjects, and this relationship was stronger in musicians. The author concluded that the neural representation of pitch, timing and timber cues, and cortical response timing are shaped in a coordinated manner, and indicate corticofugal modulation of subcortical afferent circuitry.

Several studies have found that the quality of subcortical speech and sound encoding is significantly greater in musically trained individuals (Musacchia et al., 2007; Wong, Soke, Russo, Dees & Kraus, 2007; lee et. al., 2009; Parbery-Clark, Soke & Kraus, 2009; Strait, Soke, Kraus & Ashley, 2009). It has been reported that music provides the first biological evidence for musician perceptual advantage for speech in noise as evidence by speech evoked ABR. Parbery-Clark et. al. (2009) compared subcortical neurophysiological response to speech in quite & noise in a group of highly trained musicians and non-musician controls. The authors reported that the musician found to have a more robust subcortical representation of the acoustic stimulus in the presence of noise and they demonstrated faster neural timing, enhanced representation of speech harmonics, and less degraded response morphology in noise.

Wong et. al. (2007) examined the FFR in musically trained and untrained individuals and the native English speakers unfamiliar with mandarins listened passively to the mandarin syllable /mi/ (pronounced “me”) with three different lexical tones. The salient findings were that quality of F0 tracking was superior in musically trained individuals.

Speech evoked ABR in Older population

Vander, Kathey, Burns, & Kristen (2011) recorded speech-evoked ABRs using a synthetic 40-mesc /da/ stimulus in normal hearing younger adults and older adults. Results suggested age – related differences in neural processing of speech at the brainstem level, with significant delayed in the timing of the offset portion of the speech ABR in older listeners compares with their younger counterparts, also significant reductions in amplitude of the speech ABR at the onset. These results are consistent with a reduction in a neural synchrony in older adults to transient components of both speech and non-speech sounds. However, sustained components of the speech ABR which follows the harmonics components of the syllable showed the group differences but were not significant after adjusting for peripheral hearing loss.

Anderson, Parbery-Clark, Yi & Kraus (2011) investigated a neural basis of speech-in-noise perception in older adults (28 adults, age 60 -73 yrs.), speech- evoked auditory brainstem responses were recorded in quiet and in background noise. The authors reported that in the quite condition, the poorer speech-in-noise group had reduced neural representation of the fundamental frequency and in the noise condition; greater disruption was seen, reflecting reduction in neural synchrony. Thus, the older adults with poorer SIN perception demonstrate impairment in the subcortical representation of speech.

Speech evoked ABR in children with Autism

Russo et. al. (2008) investigated the subcortical representation of prosodic speech in children with autistic spectrum disorder. They recorded brainstem response of speech syllables /ya/ with descending and ascending pitch contours and a click stimulus. They observed that some children on the autism spectrum show deficient pitch tracking compared with typically developing normal children. There was no significant difference in terms of latency or the amplitude of ABR evoked by click stimulus. Thus the authors concluded that speech evoked ABR may have clinical implications for diagnostic and remediation strategies in a subset of children with autistic spectrum disorder.

Russo, Nicol, Trimmer, Zecker, & Kraus (2009) measured brainstem response to syllable /da/ in quiet and in background noise in children with autistic spectrum disorder who had normal intelligence and hearing. Children with autistic spectrum disorder exhibit deficits in both the transient response and sustain responses despite normal click-evoked brainstem. Children with autistic spectrum disorder also show reduced magnitude and fidelity of speech-evoked responses and inordinate degradation of responses by background noise in comparison to typically developing controls. The authors suggested that the speech-evoked brainstem response may serve as a clinical tool to assess auditory processing in children with autistic spectrum disorder.

In summary, substantial body of work has been established that the temporal processing is affected in children with SLI. There are so many studies related to behavioral and electrophysiological findings that help in diagnosis of children with SLI. However there is dearth of information on speech coding at the brainstem in children with specific language impairment.

Also, how the auditory temporal processing is affected at the brainstem in these children is not known. Hence, this study was undertaken to study these two aspects in children with specific language impairment.

CHAPTER-3

Method

The present study was conducted with an aim of investigating the interaction between auditory temporal processing and stimulus complexity by examining the effects of the stimulus rate on speech evoked ABR in normal hearing children and children with specific language impairment (SLI).

Participants

Participant in the study were divided into two groups:

1. Experimental Group: The group was comprised of 11 males and 4 females in the age range of 4-12 years with a mean age of 6.79 years. Total number of ear tested was 30. All 15 children were diagnosed as specific language impairment (SLI).
2. Control Group: 14 aged matched normal hearing children were taken. Their age range was 4-12 years and mean age was 7.16 years. Total number of ear tested was 30.

Participants Selection Criteria

Participant selection criteria for control group:

1. All the participants had normal hearing thresholds as evidenced by air conduction thresholds of less than or equal to 15 dB HL in the octave frequency range of 250 Hz to 8000 Hz and bone conduction thresholds of less than or equal to 15 dB HL in the octave frequency range of 250 Hz to 4000 Hz.

2. All the participants had normal middle ear functioning as evidenced by tympanometry and reflexometry results.
3. Participants did not have any history of otological or neurological problems.
4. Participant did not have any evidence of retrocochlear pathology. This was confirmed with auditory brainstem responses.
5. All the participants passed the screening checklist for auditory processing (SCAP) questionnaires.

Participant selection criteria for the experimental groups:

1. The behavioral thresholds of the participants were ≤ 15dBHL for Air conduction and Bone conduction bilaterally based on pure tone audiometry across 250Hz, 500 Hz, 1 KHz, 2 KHz, 4 KHz, & 8 KHz for air conduction and 250 Hz, 500Hz, 1000 Hz, 2000 Hz & 4000 Hz for bone conduction.
2. All the participants had ‘A’ type tympanogram and acoustic reflex thresholds within normal limits across 500 Hz, 1000 Hz, and 2000 Hz in both the ear.
3. Participants didn’t have any history or presence of other otological or neurological problems.
4. Subjects did not report any illness on the day of testing.
5. All the participants were diagnosed as specific language impairment with the help of a Speech Language Pathologist.

Instrumentation

Following equipment's was used for the study:

1) Pure Tone Audiometer

A two channel OB922 audiometer with TDH-39 head housed in MX-41/ AR ear cushions and a bone vibrator (Radio ear B-71) was used to obtain pure tone threshold at different frequencies for both air conduction and bone conduction.

2) Immittance meter

A calibrated automatic Immittance meter with a visual display (Grason - Stadler GSI-TS) was used with the 226 Hz probe tone to carry out tympanometry and reflexometry.

3) Evoked potential system

An evoked potential system (Biologic Navigator Pro EP) with biological insert was used to record both click evoked and speech evoked ABR.

Test Stimulus for speech ABR:

The test stimulus which was used for speech evoked ABR in the present study is a synthesized /da/ syllable. The stimulus is available in evoked potential system with the BioMARK protocol. The /da/ stimulus is a 40ms synthesized speech syllable produced using KLATT synthesizer (Klatt, 1980). This stimulus simultaneously contains broad spectral and fast temporal information characteristics of stop consonants, and spectrally rich formant transitions between the consonant and the steady-state vowel. Although the steady-state portion is not present, the stimulus is still perceived as being a consonant-vowel syllable. The fundamental frequency (F0) linearly rises from 103 to 125 Hz with voicing beginning at 5ms and an onset noise burst during the first 10ms. The first formant (F1) rises from 220 to 720 Hz, while the second formant (F2) decreases from 1700 to 1240 Hz over the duration of the stimulus. The third formant (F3) falls slightly from 2580 to 2500 Hz, while the fourth (F4) and fifth formants (F5) remain constant at 3600 and 4500 Hz, respectively. Figure 3.1 shows both the time and spectral domain of the stimulus used in the present study.

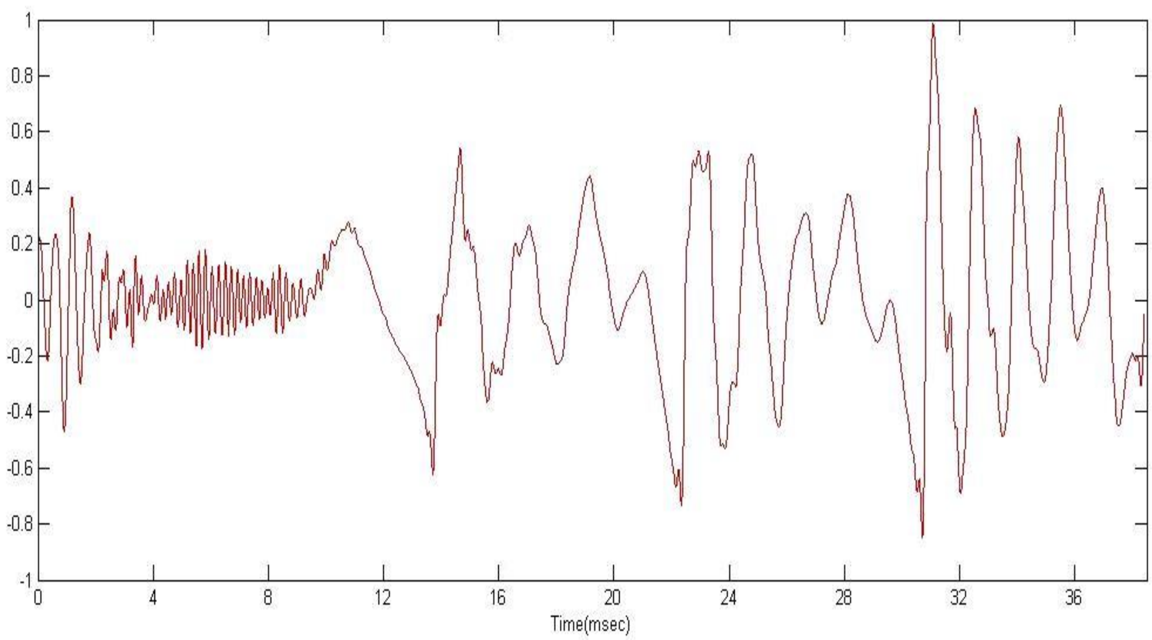

Figure - 3.1 Waveform of speech stimulus /da/.

TEST ENVIRONMENT

All the test evaluation and recording were carried out in a sound treated room. The noise level was within the permissible levels as recommended by ANSI-S.3 (1991).

PROCEDURE

1)Pure tone audiometry

Behavioral air conduction and bone conduction thresholds were tracked using modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Air conduction thresholds were obtained from 250Hz to 8 KHz and bone conduction thresholds were obtained from 250Hz to 4 KHz. Participants who had thresholds within 15 dB HL underwent further assessment.

2) Tympanometry

Tympanometry was done to rule out pathology of middle ear using 226Hz probe tone. Immittance test was carried out by sweeping the pressure from +200 to -400 dapa. In reflexometry both ipsilateral and contralateral acoustic reflexes thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000Hz frequencies.

3) Screening checklist for auditory processing

The SCAP developed by Yathiraj and Mascarenhas, (2004) was administered to all the control grouped children. The SCAP was administered to rule out any auditory processing problem. This checklist contained of 12 questions. Subjects who passed the checklist have kept in control group.

4). Psychological evaluation

Participants from both the groups were sent for a psychological evaluation to check the intelligent quotient. Children with normal intelligent quotient were enrolled for the studies.

5) *Click evoked ABR*

Click evoked ABR was recorded from all the participants. The participants for whom the click evoked ABR were enrolled for the study. Click evoked ABR was recorded at 90 dB nHL with a repetition rate of 11.1/sec. The responses were analysed in 10 msec time window was band pass filtered between 100 Hz to 3000 Hz.

6) Speech evoked ABR recording

Participants were instructed to sit comfortably on a reclining chair and relax during the testing. Electrodes were placed on the sites with conduction paste and secured with skin tape. It was insured that each electrode impedance is within <5 k Ω and inter electrode impedance is within <2 k Ω. Impedance for each electrode was also checked during testing. They were instructed to close their eyes during the testing to avoid any artifacts. Speech evoked ABR was recorded twice to ensure the reproducibility of the waveforms. The recording protocol for speech evoked ABR is given in table-1

Table 3.1

Parameters for recording speech evoked ABR

	Speech evoked ABR
Stimulus	CV syllable /da/
Duration	40 ms
Intensity	80 dB SPL
Filter settings	100 to 3000 Hz
Rate	6.9/s, 10.9/s & 15.4/s
No of sweeps	2000
Transducer	Biologic Insert ear phone
Polarity	Alternating
Time window	64 msec which included a pre stimulus time of 10 msec
Electrode montage	Non-inverting electrode: Forehead Inverting electrode: Test ear Mastoid. Ground electrode: Non test ear mastoid.

Analysis of speech evoked ABR:

The electrophysiological brainstem responses to speech sound are a complex waveform. This includes onset peaks as well as sustained elements that comprise the FFR. The representative waveform of speech evoked ABR is shown in figure.

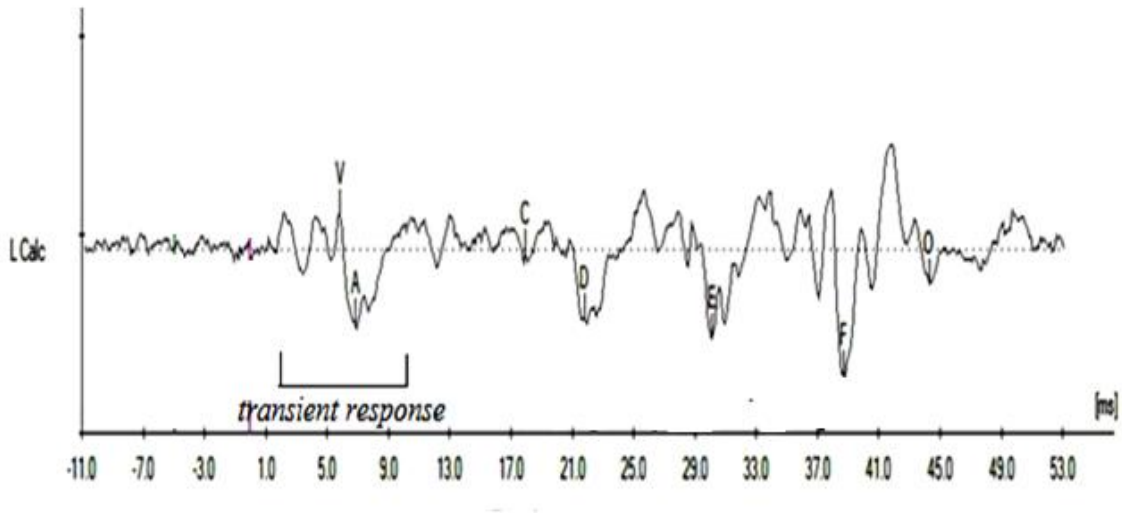

Figure-3.2 A representative waveform of the speech evoked ABR.

a. *Transient responses*

Wave V latency was marked. To analyses wave V the peak which had highest amplitude within 10 ms of the recorded waveform were considered as wave V.

b. *Pitch*

The sustained FFR portion which occurs immediately after the onset responses was subjected to FFT and it represents the FFT for the sustained portion. FFT was performed to obtain information regarding spectral characteristics of the FFR- frequency and amplitude of the spectral peaks. Average spectral amplitude was calculated for a range encompassing the fundamental frequency (F0), 103-120Hz. FFT was performed on all speech evoked potential using a custom made program run in MATLAB. The peak amplitude corresponding to F0 was also calculated using a custom made file in the MATLAB platform. The frequency analysis was done from 11.4 to 40.6 msec. The sustained portion of the response (FFR) was passes through 103-120Hz band pass fourth order Butterworth filters in order to obtain the energy at F0. The Fourier analysis was performed on the filtered signal. A subject's response was required to above the noise floor in order to include in the analysis. This was performed by comparing the spectral magnitude of pre stimulus period to that of the response. If the quotient of the magnitude of F0 frequency component of FFR divided by the stimulus period was >1, the response was deemed to the above the noise floor.

c. *Harmonics*

The harmonics measure is a composite of the average spectral energy from two frequency bands: first formant (F1) 220 to 720 Hz, high frequency (HF) 721- 1154 Hz. F1 includes the harmonics of the stimulus that make up the most prominent frequencies of the first formant range in the analysis time of 11.4 to 40.6 msec. the HF range is composed of harmonics between the first and second formants (F1 and F2, respectively). For ease of reading, the high frequency band will be called as F2 throughout the dissertation. The sustained portion of the response (FFR) was through 200 to 720 band pass fourth order Butterworth filters in the order to obtain the energy at F1. Because higher formants are above the phase locking limits of the brainstem, no higher frequency range were included. The figure shows maximum amplitude in the FO region i.e. around 103 to 125Hz. There is also some amount of energy in the F1 region i.e. from 220 to 720Hz.

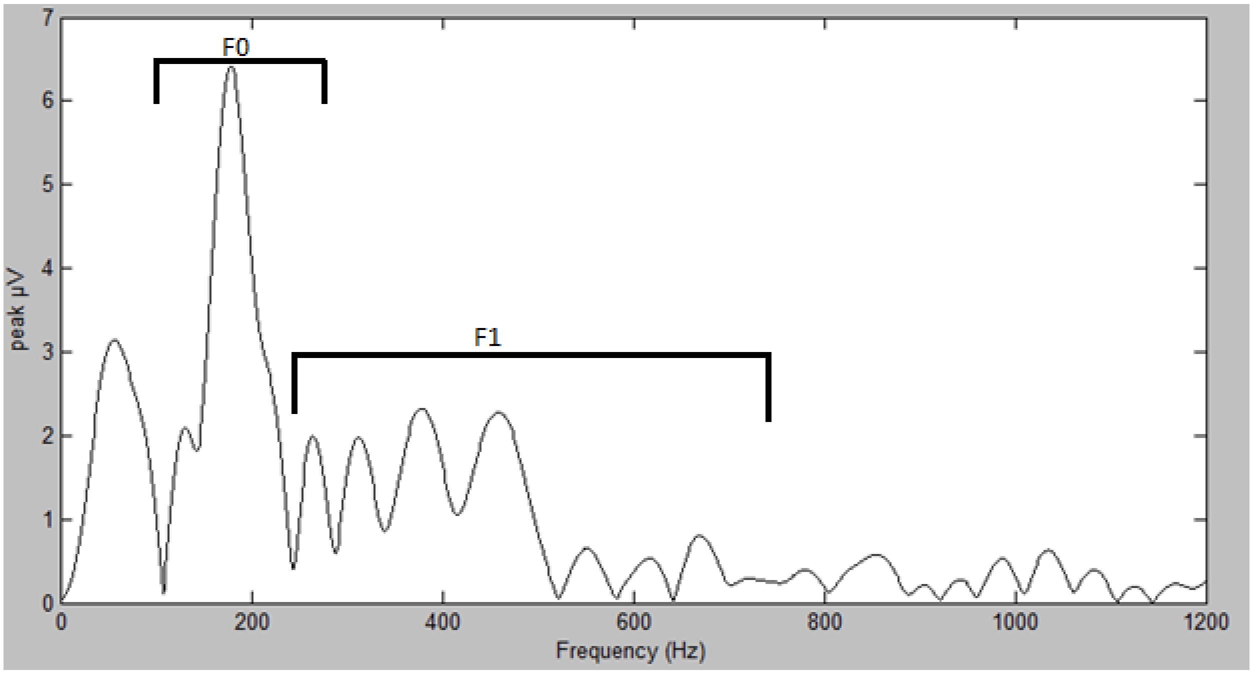

Figure-3.3 FFT representing the energies at fundamental and its harmonics.

Statistical Analysis

All the data was analyzed through SPSS version 16.0 version. Following statistical analysis was done for the data:

1. Descriptive statistics was done to find out the mean and standard deviation for the wave V latency and amplitude of fundamental frequency and the first formant frequency and second formant frequency.
2. Repeated measure ANOVA (2 groups X 3 repetition rate) was done to see the overall effect of groups and repetition rate on speech evoked ABR.
3. Boneferroni pairwise test comparison was done to see the overall group differences for the repetition rate if the repeated measure ANOVA showed a significant main effect for repetition rate.

4. One way ANOVA was done to see the effect of repetition rate on different parameters within each group separately.
5. If the repeated measure ANOVA showed a significant main effect for the groups and independent ‘t’ test was done to the see the differences between the two parameters between the two groups.

CHAPTER-4

Results

The aim of the study was to investigate the interactions between auditory temporal processing and stimulus complexity by examining the effects of stimulus rate on speech evoked ABR in normal hearing children and children with specific language impairment. To achieve the aim, a group of children with normal hearing and another group of children diagnosed with specific language impairment were taken. Speech evoked ABR was recorded for both the groups using /da/ syllable. Latency of wave V and amplitude of F0, F1 & F2 parameters were taken for the comparison among the groups.

Wave V latency

Total 30 ears were tested for SLI and 28 ears for the normal subjects. In the SLI subjects wave V was present in 24 ears out of 30 ears, in rest 6 ears the speech evoked ABR was absent. Wave V was also present in 28 ears of the normal subjects, but only 24 ear data was considered and data of 4 ears (2 subjects) was discarded because of post-aurical muscle artifacts present in those subjects. The latency of wave V was analyzed for the speech evoked ABR for three different repetition rates (6.9/sec, 10.9/sec, &15.4/s). Figure 4.1 shows syllable /da/ evoked ABR waveform at the three repetition rates obtained from one of the SLI group and the normal group.

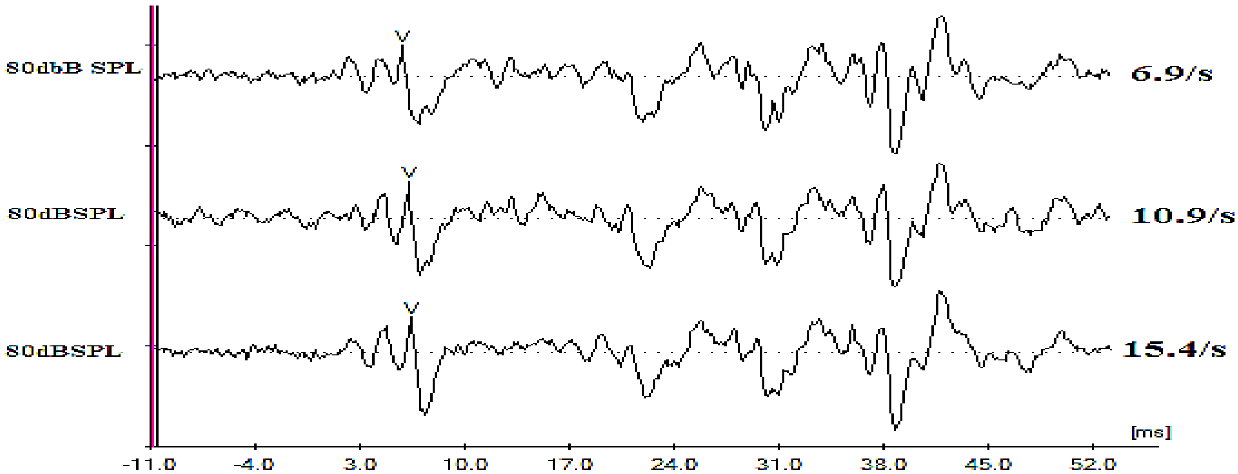

Figure 4.1 Sample waveform of speech evoked ABR- transient waveform at three repetition rate obtained from one SLI group individual.

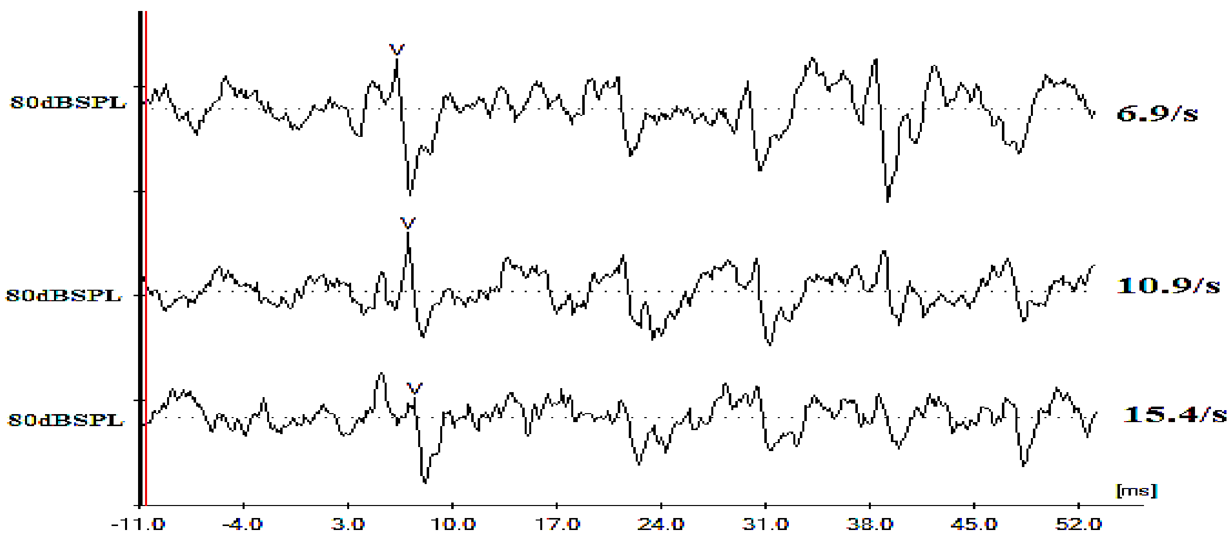

Figure 4.2 Sample waveform of speech evoked ABR- transient waveform at three repetition rate obtained from one normal group individual.

As it can be seen in the figure 4.1 and 4.2 that there is an increase in latency of the peak V of speech evoked transient response with the increase in repetition rate for both the normal and children with specific language impairment.

Descriptive statistics was done to find out the mean and standard deviation for wave V latency for both the groups. Table-4.1 shows the mean and standard deviation of wave V latency elicited for three repetition rate for both the groups.

Table 4.1

Mean and standard deviation (SD) of wave V latency recorded using /da/ stimulus in all the three repetition rate for both the groups

	Wave V latency					
Repetition Rate →	6.9/s		10.9/s		15.4/s	
Groups ↓	Mean latency(msec)	SD	Mean latency(msec)	SD	Mean latency(msec)	SD
Normal children	6.34	0.17	6.63	0.22	6.86	0.30
children with SLI	6.31	0.92	6.52	0.90	6.95	0.82

It can be seen from the table 4.1 that as the repetition rate increased, there is an increase in the mean latency of the wave V of speech evoked transient response for both the normal as well children with specific language impairment. The same can be seen in figure 4.3

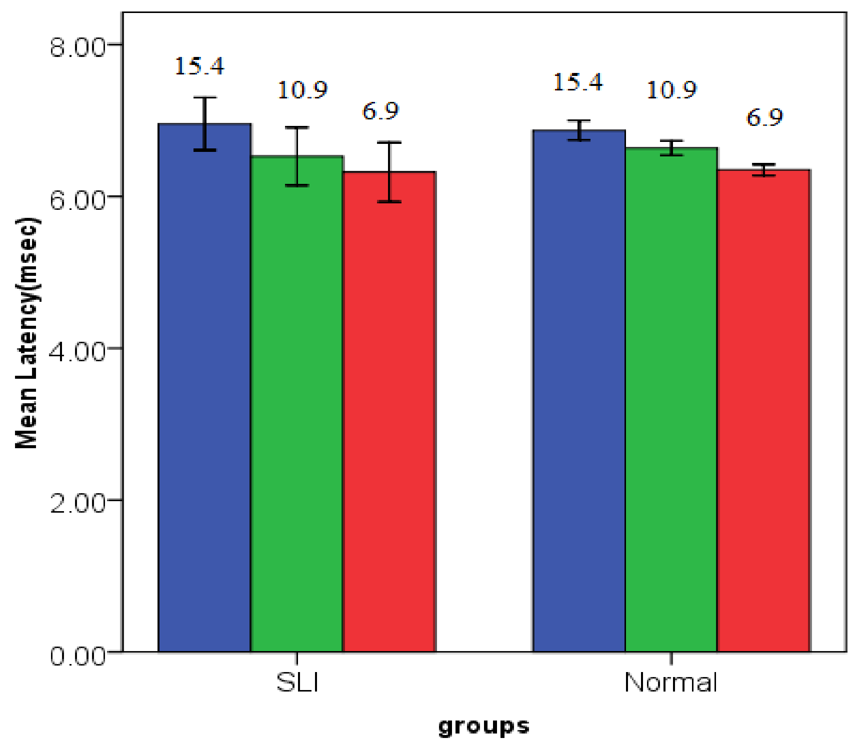

Figure 4.3 Latency of speech evoked transient V peak latency for three repetition rate across the two groups.

Overall effect of groups and repetition rate on speech evoked transient response

As the repetition rate and groups affected the wave V latency, a repeated measure ANOVA (2 groups X 3 repetition rate) was administered to see the significant main effect of group and repetition rate and also significant interaction across the variables on wave V latency. Repeated measure ANOVA analysis revealed a significant main effect between the repetition rates [F (2, 92) =45.25, p<0.05]. But repeated measure ANOVA failed to show a significant main effect between the groups [F (2, 92) =1.25, p>0.05] and also failed to show significant interaction between groups and conditions [F (1, 46)

=0.01, p>0.05]. A Bonefferoni pairwise comparison test was done for the three repetition rate and the results of the Bonefferoni test are given below in table 4.2

Table 4.2

Bonferroni pairwise comparison test results for the /da/ evoked wave V latency across the three repetition rate

Repetition rate	10.9/s	15.4/s
6.9/s	**p<0.05**	**p<0.05**
10.9/s		**p<0.05**

Effect of repetition rate on transient response of speech evoked ABR within each group

As the repetition rate showed a significant main effect, a one way analysis of variance (one way ANOVA) was done to see the repetition rate effect for the wave V latency elicited by /da/ stimulus in all the three repetition rate for the two groups separately. One way ANOVA analysis revealed a significant effect of repetition rate on wave V latency for the normal group [F(2,69)=28.07, p<0.05], also it showed a significant effect of repetition rate on wave V latency for children with specific language impairment [F(2,69)=3.21, p<0.05]. Bonefferoni pairwise comparison was done to understand the different repetition rate effect for wave V latency elicited by /da/ stimulus and the results are given below in table 4.3

Table 4.3

Bonferroni pairwise comparison test results for the /da/ evoked wave V latency across the three repetition rates for normal and the SLI group.

Group	Repetition rate	10.9/s	15.4/s
Normal children	6.9/s	**p<0.05**	**p<0.05**
	10.9/s		**p<0.05**
Childern with SLI	6.9/s	p>0.05	**p<0.05**
	10.9/s		p>0.05

It can be seen from table 4.3 that for the normal group the wave V latency for 6.9/sec repetition rate was significantly different from 10.9/sec and 15.4/sec repetition rate, whereas for the children with SLI group the wave V latency elicited for 6.9/sec repetition rate was significantly different from 15.4/sec repetition rate only.

Amplitude of F0

Descriptive statistics was done to find out the mean and standard deviation for F0 (103 to125 Hz) amplitude for both the groups. Table-4.4 shows the mean and standard deviation of the amplitude of F0 elicited for three repetition rate for both the groups.

Table 4.4

Mean and standard deviation (SD) of F0 amplitude recorded using /da/ stimulus in the entire three repetition rate for both the groups

	Amplitude of F0					
Repetition Rate →	6.9/s		10.9/s		15.4/s	
Groups ↓	Mean amplitude(µv)	SD	Mean amplitude(µv)	SD	Mean amplitude(µv)	SD
Normal children	7.45	5.71	6.79	3.26	5.47	2.56
children with SLI	5.31	3.84	4.54	2.70	4.48	2.68

It can be seen from the table 4.4 that as the repetition rate increased, there is a decrease in the mean amplitude of the F0 of speech evoked transient response for both the normal as well children with specific language impairment. The same can be seen in figure 4.4

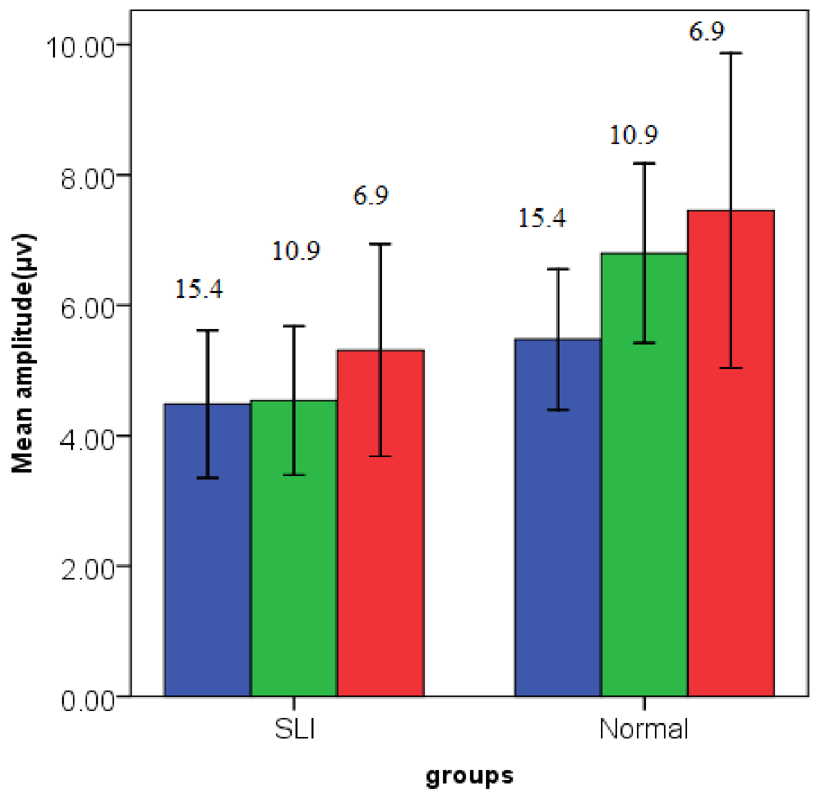

Figure 4.4 Amplitude of F0 for three repetition rate across the two groups.

Overall effect of groups and repetition rate on amplitude of F0

As the repetition rate and groups affected the amplitude of F0, a repeated measure ANOVA (2 groups X 3 repetition rates) was administered to see the significant main effect of group and repetition rate and also significant interaction across the variables on amplitude of F0. Repeated measure ANOVA analysis revealed a significant main effect between the repetition rates [$F(2,92)=3.39$, $p<0.05$], between groups [$F(2,92)=0.84$, $p<0.05$] and also show a significant interaction between groups and conditions [$F(1,46)=4.53$, $p<0.05$].

Table 4.5

Bonferroni pairwise comparison test results for the /da/ evoked fundamental frequency across the three repetition rates

Repetition rate	10.9/s	15.4/s
6.9/s	$p>0.05$	$p>0.05$
10.9/s		$p>0.05$

Although, the Repeated measure ANOVA showed a significant main effect of repetition rate on amplitude of fundamental frequency, the Boneferroni Pairwise test failed to show the significant difference at 0.05 levels, however the Boneferroni pairwise comparison showed a significant difference between 6.9/sec repetition rate and 15.4 repetition rate at 0.1 significance level.

Group differences for the encoding of Fundamental Frequency

As the group showed a significant main effect and also the group and repetition rate showed a significant interaction among variables, an independent t-test was done to understand this group differences. The results of the independent t-test are given in table below

Table 4.6

t-test results for group comparison

Repetition rate	t-value	df	Significance level
6.9	1.52	46	0.19
10.9	2.61	46	**0.01**
15.4	1.31	46	0.13

It can be seen from Table 4.6 that the two groups differed only at 10.9 repetition rate for the encoding of fundamental frequency in speech evoked ABR.

Effect of repetition rate on amplitude of F0 within each group

As the repetition rate showed a significant main effect, a one way analysis of variance (one way ANOVA) was done to see the repetition rate effect for the amplitude of F0 elicited by /da/ stimulus in all the three repetition rate for the two groups separately. One way ANOVA analysis revealed no significant effect of repetition rate on amplitude of F0 for the normal group [$F(2,69)=1.46$, $p>0.05$], also it showed no significant effect of repetition rate on amplitude of F0 for children with specific language impairment [$F(2,69)=0.52$, $p>0.05$]. Further a Post hoc comparison test was not done here, as one way did not show a main effect for encoding of F0 in normal children and children with SLI.

Amplitude of F1

Descriptive statistics was done to find out the mean and standard deviation for F1 (220 to 720 Hz) amplitude for both the groups. Table-4.7 shows the mean and standard deviation of the amplitude of F1 elicited for three repetition rate for both the groups.

Table 4.7

Mean and standard deviation (SD) of F1 amplitude recorded using /da/ stimulus in all the three repetition rate for both the groups

Repetition Rate →	Amplitude of F1					
	6.9/s		10.9/s		15.4/s	
Groups ↓	Mean amplitude(µv)	SD	Mean amplitude(µv)	SD	Mean amplitude(µv)	SD
Normal children	0.92	0.34	0.76	0.29	0.72	0.25
children with SLI	0.71	0.31	0.59	0.25	0.65	0.30

It can be seen from the table 4.7 that as the repetition rate increased, there is a decrease in the mean amplitude of the F1of speech evoked transient response for both the normal as well children with specific language impairment. The same can be seen in figure 4.5

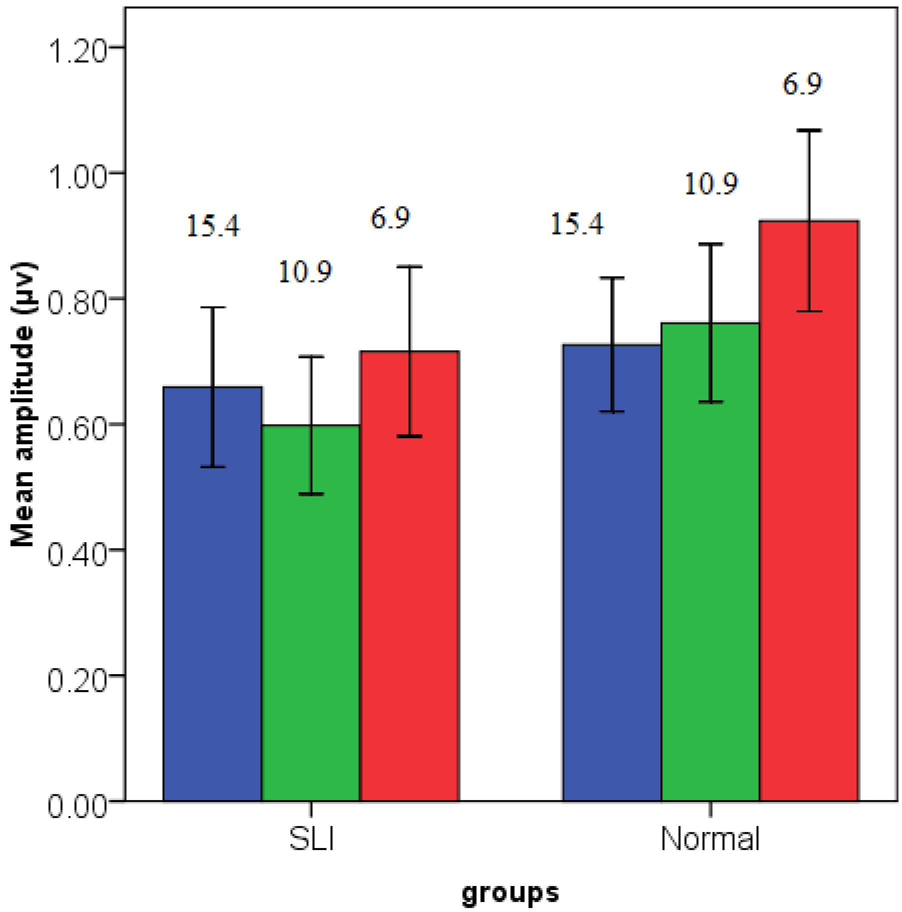

Figure 4.5 Amplitude of F1 for three repetition rate across the two groups.

Overall effect of groups and repetition rate on amplitude of F1

As the repetition rate and groups affected the amplitude of F1, a repeated measure ANOVA (2 group's X 3repitition rate) was administered to see the significant main effect of group and repetition rate and also significant interaction across the variables on amplitude of F1. Repeated measure ANOVA analysis revealed a significant main effect between the repetition rates [F (2, 92) =9.67, p<0.05]. But repeated measure ANOVA failed to show a significant main effect between the groups but reached to a significance level [F(2,92)=3.76, p=0.05] and also failed to show significant interaction between groups and conditions [F(1,46)=2.08, p>0.05]. A post hoc test was administered for repetition rate to see the group wise differences. The results of the Boneferroni post hoc test are given below in table 4.8

Table 4.8

Bonferroni pairwise comparison test results for the /da/ evoked encoding of F0 across the three repetition rates

Repetition rate	10.9/s	15.4/s
6.9/s	p>0.05	**p<0.05**
10.9/s		**p<0.05**

Effect of repetition rate on amplitude of F1 within each group

As the repetition rate showed a significant main effect, a one way analysis of variance (one way ANOVA) was done to see the repetition rate effect for the amplitude of F1elicited by /da/ stimulus in all the three repetition rate for the two groups separately. One way ANOVA analysis revealed no significant effect of repetition rate on amplitude of F1 for the normal group, but reached to a significance level [F(2,69)=2.96, p=0.05], also it showed no significant effect of repetition rate on amplitude of F1 for children with specific language impairment [F(2,69)=0.96, p>0.05]. As on Repeated measure ANOVA F1 reached to significance level, Bonefferoni pairwise comparison was done to understand the different repetition rate effect for F1 amplitude elicited by /da/ stimulus.

Table 4.9

Bonferroni pairwise comparison test results for the /da/ evoked F1 amplitude across the three repetition rates for normal and the SLI group.

Group	Repetition rate	10.9/s	15.4/s
Normal children	6.9/s	p>0.05	p>0.05
	10.9/s		p>0.05
Children with SLI	6.9/s	p>0.05	p>0.05
	10.9/s		p>0.05

It can be seen that Bonefferoni pairwise comparison test did not reveal any significant difference for both the groups at any repetition rate at 0.05 significance level, but it showed a significant difference between 6.9/sec repetition rate and 15.4/sec repetition rate for normal group at 0.1 significance level.

Group differences for the encoding of First formant frequency

As the group reached to a significance level in repeated measure ANOVA, an independent t-test was done to understand this group differences. The results of the independent t-test are given in table below

Table 4.10

t-test results for group comparison

Repetition rate	t-value	df	Significance level
6.9	2.18	46	**0.03**
10.9	2.02	46	**0.04**
15.4	0.84	46	0.40

It can be seen from table 4.10 that the two groups differed at 6.9 /sec and 10.9/sec repetition rate for the encoding of first formant frequency in speech evoked ABR.

Amplitude of F2

Descriptive statistics was done to find out the mean and standard deviation for F2 (1700 to 1240 Hz) amplitude for both the groups. Table-4.8 shows the mean and standard deviation of the amplitude of F2 elicited for three repetition rate for both the groups.

Table 4.11

Mean and standard deviation (SD) of F2 amplitude recorded using /da/ stimulus in all the three repetition rate for both the groups

	Amplitude of F2					
Repetition Rate →	6.9/s		10.9/s		15.4/s	
Groups ↓	Mean amplitude(µv)	SD	Mean amplitude(µv)	SD	Mean amplitude(µv)	SD
Normal children	0.39	0.12	0.35	0.10	0.33	0.11
children with SLI	0.36	0.14	0.30	0.11	0.30	0.15

It can be seen from the table 4.11 that as the repetition rate increased, there is an increase in the mean amplitude of the F2 of speech evoked transient response for both the normal as well children with specific language impairment. The same can be seen in figure 4.6

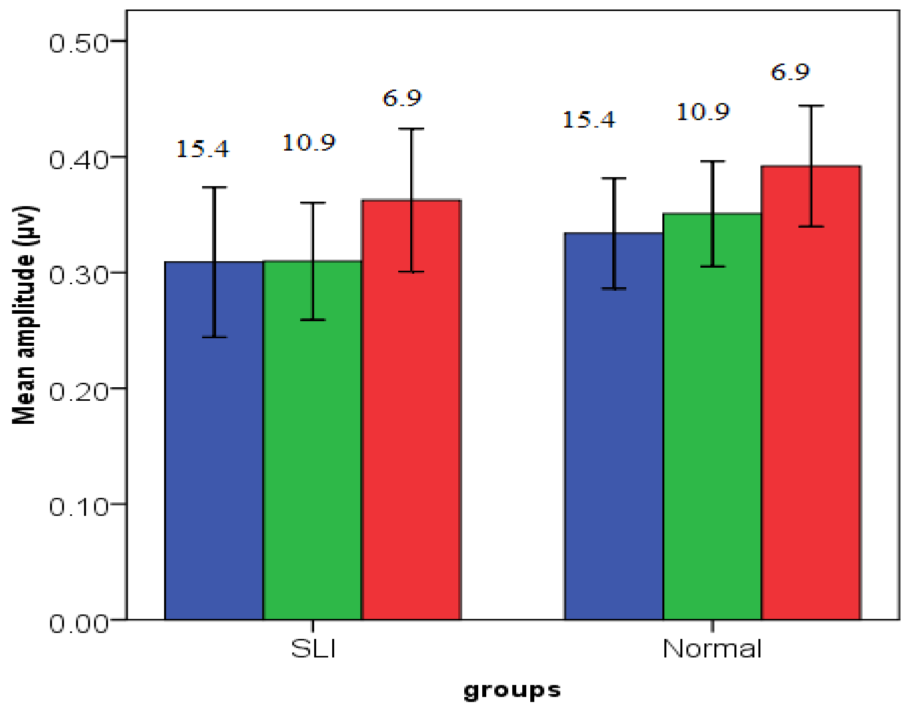

Figure 4.6 Amplitude of F2 for three repetition rate across the two groups.

Overall effect of groups and repetition rate on amplitude of F2

As the repetition rate and groups affected the amplitude of F2, a repeated measure ANOVA (2 groups X 3 repetition rate) was administered to see the significant main effect of group and repetition rate and also significant interaction across the variables on amplitude of F2. Repeated measure ANOVA analysis revealed a significant main effect between the repetition rates [F (2, 92) =5.93, p<0.05]. But repeated measure ANOVA failed to show a significant main effect between the groups [F (2, 92) =0.11, p>0.05] and also failed to show significant interaction between groups and conditions [F (1, 46)

=1.04, p>0.05]. As Repeated measure ANOVA showed a significant main effect for the repetition rate, Bonefferoni pairwise comparison was done to understand the different repetition rate effect for F2 amplitude elicited by /da/ stimulus.

Table 4.12

Bonferroni pairwise comparison test results for the /da/ evoked F2 amplitude across the three repetition rates

Repetition rate	10.9/s	15.4/s
6.9/s	$p>0.05$	**$p<0.05$**
10.9/s		**$p<0.05$**

Effect of repetition rate on amplitude of F2 within each group

As the repetition rate showed a significant main effect, a one way analysis of variance (one way ANOVA) was done to see the repetition rate effect for the amplitude of F2elicited by /da/ stimulus in all the three repetition rate for the two groups separately. One way ANOVA analysis revealed no significant effect of repetition rate on amplitude of F2 for the normal group [$F(2, 69) = 1.62$, $p>0.05$], also it showed no significant effect of repetition rate on amplitude of F2 for children with specific language impairment [$F(2, 69) = 1.14$, $p>0.05$]. As the one way ANOVA did not show any significant effect of repetition rate on amplitude of F2 for normal children or the children with SLI, further statistics were not done.

To summaries the results, the speech evoked ABR was absent in 7 participants with specific language impairment at all the repetition rates. In rest of the participants, the repetition rate affected the wave V latency within each group; however, there were no group differences for wave V latency at any repetition rate. Also, the encoding of fundamental frequency, first formant frequency and second formant frequency was not affected by the repetition rate within and across each group.

CHAPTER-5

Discussion

The present study was conducted with an aim of studying the brainstem correlates of the auditory temporal processing in the normal children and children with specific language impairment. This was done by recording speech evoked ABR at different repetition rates.

Effect of repetition rate on transient responses of speech evoked ABR

Total 30 ears were tested for SLI and 28 ears for the normal subjects. In the SLI subjects wave V was present in 24 ears out of 30 ears, in rest 6 ears the speech evoked ABR was absent. Wave V was also present in 28 ears of the normal subjects, but only 24 ear data was considered and data of 4 ears (2 subjects) was discarded because of post-aurical muscle artifacts present in those subjects.

Auditory brainstem responses to speech stimulus was absent in three subjects (6 ears) with specific language impairment inspite of a normal click ABR. Auditory brainstem responses using speech stimulus has been found to be superior to click stimulus in evaluating the children with learning problems. Several studies have reported that children who have abnormal speech evoked ABR they have poor speech perception (Wible, Nicol & Kraus, 2004; Goncalves et al., (2011)

The difference in the result obtained for the children with specific language impairment could be due to stimulus differences. The click stimulus contain a broad range of frequencies, speech is more spectrally shaped. In addition, the onset of the /da/ stimulus occurs more gradually relative to the instantaneous rise time of the click. Finally, brainstem activity can be experience dependent (Tzounopoulos & Kraus, 2009), i.e. the latency effects of the two stimuli may be due to the greater exposure to and use of speech sounds.

Although the acoustic differences discussed above may be partially responsible for the findings in this study, it is important to know that human beings are exposed to speech stimulus in the environment and not the click stimulus. Particularly relevant is that brainstem encoding of sound has been shown to be shaped by lifelong linguistic and musical experience (Krishnan et al., 2004, 2005; Musacchia et al., 2007; Wong et al., 2007). That is, brainstem activity evoked by Mandarin tones and music is enhanced in musicians and speakers of tonal languages relative to non-musicians and non-native speakers. Additionally, short-term training has been shown to lead to changes in speech-evoked brainstem responses (Russo et al., 2005; Song et al., 2008). Also the reversed speech is processed differently at the brainstem level compared to the forward speech (Sinha & Basavaraj, 2010), indicating a differential processing of a forward and reversed speech at the brainstem. Moreover, recent animal work has also shown that experience can lead to large-scale reorganization of the inferior colliculus tonotopic organisation (Yu et al., 2007) and that experience dependent pruning of synaptic inputs is important for the maturation of the functional inhibition in brainstem nuclei (Magnusson et al., 2005).

Apart from the three subjects with SLI in rest of the participants, repetition rate affected the latency of wave V for each of the group, however when latency of wave V was compared between the normal children and children with SLI there was no difference for wave V latency at any of the repetition rate.

With respect to the onset response of the speech evoked ABR, several authors have reported an increase in the onset response with the increase in repetition rate of the stimuli in adults (Krizman, Skoe & Kraus, 2010) and in children (Ranjan, 2011, Mehta & Singh, 2012). The increase in latency of wave V of click ABR and wave V and A of speech evoked ABR due to increase in the repetition rate might be due to cumulative neural fatigue and adaptation, and incomplete recovery involving hair-cell-cochlear nerve junction and also subsequent synaptic transmission. Latency shifts seen with increase in rate in normals may also be due to a change in cochlear receptor functions (Don et al., 1977), the refractory period of individual nerve fibers resulting in a desynchronization of the response that most affects the encoding of the faster elements of the stimulus (Hall, 1992; Jacobson, Murray & Deppe, 1987), decrease in synaptic efficiency (Pratt & Sohmer, 1976) due to which conduction rate decreases and there is an increase in latency. The effect of rate would be additive as the synapses increases from wave I to wave V (Hall, 1992).

However there were no group differences between children with specific language impairment and normal children. In a previous study Filippini Befi-Lopes and Schochat (2012) also reported no differences in speech evoked ABR between normal children and children with specific language impairment. In another study by Rocha-Muniz, Befi-Lopes and Schochat (2012) reported a significant delay of wave V latency in a group of children with specific language impairment. Some other studies have also indicated a delay in the latency of wave V of speech evoked ABR in a group of children with learning disorder and autism (Russo et al. 2004; Song, Banai & Kraus, 2008), which indicate that these children might have neural synchrony deficits, however in the present study no differences could be observed between the two groups indicating that children with SLI did not have any synchrony problems. Whereas, in three subjects the speech evoked ABR was absent in rest of the participants it was present indicating that there may *a hetrogenous group of children with SLI* (Rocha-Muniz, Befi-Lopes & Schochat, 2012). Hence, the responses were absent in only few subjects whereas other few participants it was normal. Banai et al. (2007) have also reported that not all children with same spectrum disorder (viz learning problems) exhibit problem in speech evoked ABR. This may explain why the speech evoked ABR was present normally in subjects with SLI.

The wave V latency did not vary even at the higher repetition rates indicating that the temporal processing may be intact in children with SLI. Several studies on a behavioural paradigm have reported no auditory processing deficits in children with SLI (Montgomery, 1999; Vandewalle, Boets, Ghesquiere & Zink (2012). Also Vendewalle et al. (2012) reported that children with SLI although they might differ from normal children on speech perception task they do not differ in the auditory temporal processing task. Also, few studies have reported an auditory temporal processing deficit in children with SLI (Lowe and Campbell, 1965; Tallal & Piercy, 1973). The equivocal findings in the literature could be due to the hetrogenity of the problems in children with specific language impairment.

Effect of repetition rate on sustained response

Repetition rate did not affect the amplitude of fundamental frequency, First formant frequency and second formant frequency within each group. When amplitude of fundamental frequency was compared across the group it showed a significant difference only at 10.9 repetition rate. Also, amplitude of first formant frequency across the two groups it showed a significant difference at 6.9 and 10.9 repetition rates but not at 15.4 *repetition rate. Also, when amplitude of fundamental frequency was compared across the group it did not show a significant difference at any repetition rate.*

Krizman et al., (2010) reported a significant rate effect on the higher harmonics (in the frequency range of 750-1100 Hz) and not on the coding of F0 and F1. In the present study also there was no significant effect of repetition rate on encoding of F0, F1 and F2. Previous studies by Garvita (2012) reported a significant effect of repetition rate on encoding of F0, F1 and F2 in a group of normal hearing adults, whereas Ranjan (2011) did not find s significant effect of repetition rate on encoding of F0 and F1. Thus, there is an equivocal findings regarding the effect of repetition rate on sustained portion of the speech evoked ABR. Thus, this mechanism needs to be further explored.

Also, in the present study the repetition rate affected the wave V latency for both the groups but not the sustained responses, suggesting that there could be two mechanisms for encoding of transient and sustained responses at the brainstem level. Akhoun et al. (2008) reported that with a decrement in stimulus intensity, the latency of sustained responses are decreased more than onset responses, also, when speech evoked ABR is presented in noise the effect of noise on wave V is more compared to the sustained responses (Russo et al. 2004; Russo et al. 2005). Thus, a differential effect of repetition rate could have been because of a different neural mechanism for onset response and a different neural mechanism for sustained responses.

There were no significant differences in the encoding of F0, F1 and F2 between the normal children and children with SLI at any repetition rate. There are equivocal findings in the literature regarding the encoding of F0, F1 and F2 in children with SLI. Filippini, et al. (2012) reported that there was no significant difference in encoding of

F0, F1 and F2 between normal children and children with SLI with speech evoked ABR recorded at 10.9 repetition rate, whereas, Rocha-Muniz et al. (2012) reported a significant difference between the two groups for the encoding of F0, F1 and F2 for speech evoked ABR recorded at 10.9 repetition rate. The equivocal findings in the literature could be attributed to the hetrogenity of this group. Also, even at higher repetition rate there was no significant difference indicating that the auditory temporal processing was not affected in these children. Vendewalle et al. (2012) reported that children with SLI although they might differ from normal children on speech perception task they do not differ in the auditory temporal processing task. Also, few studies have reported an auditory temporal processing deficit in children with SLI (Lowe and Campbell, 1965; Tallal & Piercy, 1973). Thus, the amplitude of F0, F1 and F2 were significantly not different between the two groups.

CHAPTER-6

Summary and Conclusion

Specific language impairment (SLI) is a developmental disorder involving language delays (vocabulary, grammar, phonology) that are out of line with a child's other abilities (non-verbal IQ) and have no obvious cause such as another developmental disorder, acquired brain injury or severe environmental deprivation (Bishop, 1992; Leonard, 1998; Tomblin et al., 1997). SLI has an estimated prevalence of 6-7% in school children (Scerri et. al., 2011). In a group of children with specific language impairment it has been reported they have several auditory deficits such as auditory temporal deficits (Tallal & Piercy, 1973), problem in discrimination of CV syllables (Tallal & Piercy, 1974), significantly poor in backward masking effect where a brief tone (target) is followed by a masking noise (Wright et al., 1997).

The primary aim of the present study was to investigate the interactions between auditory temporal processing and stimulus complexity by examining the effects of stimulus rate on speech evoked ABR in normal hearing children and children with specific language impairment.

To achieve the aim, two groups of participants were taken for the study. First group of participants included 15 subjects in the age range of 4-12 years diagnosed as specific language impairment and second group included 14 age matched participants with normal hearing. These participants did not have any otological, neurological or psychological problems at the time of testing.

First the routine audiological evaluations such as puretone audiometry, Immittance evaluations, click evoked ABR was administered to all the participants in both the groups. Later Speech evoked ABR was recorded at 80 dB SPL at three repetition rates. Speech evoked ABR was recorded using /da/ speech syllables. For recording the Speech evoked ABR the non inverting electrode was placed on the Forehead, Inverting electrode was placed on the test ear mastoid and ground electrode was placed on non test ear mastoid. Responses were recorded for 64 msec including the pre stimulus time window. Total 2000 stimulus was averaged and responses were band pass filtered from 100 Hz to 3000 Hz.

Latency of wave V evoked by speech syllable /da/ were analysed for both the groups. Additionally an objective analysis using the MATLAB software was done for knowing the encoding of fundamental frequency, first formant frequency and second formant frequency for both the groups.

Results of the study revealed:

1. Total 30 ears were tested for SLI and 28 ears for the normal subjects. In the SLI subjects wave V was present in 24 ears out of 30 ears, in rest 6 ears the speech evoked ABR was absent. Wave V was also present in 28 ears of the normal subjects, but only 24 ear data was considered and data of 4 ears (2 subjects) was discarded because of post-aurical muscle artifacts present in those subjects.
2. Repetition rate affected the latency of wave V for each of the group, however when latency of wave V was compared between the normal children and children with SLI there was no difference for wave V latency at any of the repetition rate.

3. Repetition rate did not affect the amplitude of fundamental frequency within each group. When amplitude of fundamental frequency was compared across the group it showed a significant difference only at 10.9 repetition rate.
4. Repetition rate did not affect the amplitude of first formant frequency within each group. When amplitude of first formant frequency was compared across the group it showed a significant difference at 6.9 and 10.9 repetition rate but not at 15.4 repetition rate.
5. Repetition rate did not affect the amplitude of second formant frequency within each group. When amplitude of second formant frequency was compared across the group it did not show a significant difference at any repetition rate.

Conclusions

The major finding of this study is that there was no significant difference between the normal group and the children with SLI for speech evoked ABR at any repetition rate. However, in a small group of 3 subjects with SLI the speech evoked ABR was absent in spite of a click ABR present normally. This suggests that in a group of children with SLI there might be a problem in encoding of the speech stimuli at the brainstem level. Thus, Speech evoked ABR can be utilised to know the encoding of speech stimuli at the brainstem in children with SLI.

Implications of the study

1. Study can be utilized to know the pattern of speech encoding at the brainstem level in children with SLI.
2. The results of this study can be utilized to design a training programme for the rehabilitation of the children with specific language impairment.

REFERENCES

AFASIC (1989). Breaking Down The Communication Barrier, London: AFASIC.

Ahissar, M., Protopapas, A., Reid, M., &Merzenich, M. M. (2000). Auditory processing for clinical practice.parallel reading abilities in adults. *Proceedings of the National Academy of Science of the United States of America, 97*, 6832–6837.

Akhoun, I.,Gallego, S., Moulin, A., Menard, M., Veuillet, E., Berger-Vachon, C., Collet, L., & Thaivan, H. (2008). The temporal relationship between speech auditory brainstem responses and the acoustic pattern of the phoneme /ba/ in normal-hearing adults. *Clinical Nurophysiolgy, 119,* 922-933.

American National Standards Institute. (1991). M*aximum permissible ambient noise levels for audiometric test rooms*.(ANSI S3.1-1991). New York: American National Standards Institute.

American Psychatric Association (1995). Diagnostic and statistical manual of mental disorders (4th ed., rev). Wash-ington, DC: Author.

American Speech Language Hearing Association (ASHA). (2005). (Central) auditory processing disorders, *1 – 20*.

Ananthananryan, A. K., & Pyler, P. N. (2001). Human frequency- following responses: representation of second formant transitions in normal-hearing and hearing-impaired listeners. *Journal of the American Academy of Audiology, 12*, 523-533.

Anderson, S., Parbery, C. A., Yi, H., & Kraus, N. (2011). A Neural basis of speech-in-noise in older adults. *Ear and Hearing, 32*, 10-15.

Anderson, S., Skoe, E., Chandrasekaran, B., & Kraus, N. (2010). Neural timing is linked to speech perception in noise. *Journal of Neuroscience, 30,* 4922–4926.

ANSI/ASA S3.1-1999 (R2008). American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test rooms.

Arbagey, P.W., Galbraith, G. C., Branski, R., Comerci, N., & Reactor, P. M. (1995). Intelligible speech encoded in the human brain stem frequency- following response. *Neuroreport, 27,* 2363-2367.

Aslin, R. N., Pisoni, D. B., Hennessy, B. L., & Perey, A. J. (1981). Discrimination of voice onset time by human infants: new findings and implications for the effects of early experience. *Child Development*, *52*, 1135-1145.

Ayotte, J., Peretz, I., & Hyde, K. (2002). A group study of adults afflicted with a music-specific disorder. *Brain, 125,* 238 – 251.

Banai, K., & Ahissar, M. (2004). Poor frequency discrimination probes dyslexics with particularly impaired working memory. *Audiology and Neurotology, 9,* 328–340.

Banai, K., Abrams, D., & Kraus, N. (2007). Sensory-based learning disability: Insights from brainstem processing of speech sounds. *International Journal of Audiology, 46*, 524–32.

Banai, K., Hornickel, J., Skoe, E., Nicol, T., Zecker, S., & Kraus, N. (2009).Reading and subcortical auditory function. *Cerebral Cortex, 19*, 2699 –2707.

Banai, K., Nicol, T., Zecker, S. G., & Kraus, N. (2005). Brainstem timing: Implications for cortical processing and literacy. *Journal of Neuroscience, 25,* 9850–9857.

Basu, M., Krishnan, A., & Weber-Fox, C. (2010). Brainstem correlates of temporal auditory processing in children with specific language impairment. *Developmental Science, 13,* 77-91.

Bidelman, G., & Krishnan, K. (2009). Neural Correlates of Consonance, Dissonance, and the Hierarchy of Musical Pitch in the Human Brainstem. *Journal of Neuroscience, 29*, 13165–13171.

Bishop, D. M., & Adams, C. (1992). Comprehension problems in children with specific language impairment: Literal and inferential meaning. *Journal of Speech and Hearing Research, 35,* 119-129.

Bishop, D., Carlyon, R., Deeks, J., & Bishop, S. (1999). Auditory temporal processing impairment: Neither necessary nor sufficient for causing language impairment in children. *Journal of Speech, Language, and Hearing Research, 42,* 1295-1310.

Boston, J. R., & Moller, A. R. (1985). Brainstem auditory-evoked potentials. 2nd edn. In: CRC Press. .

Burns, J. G., Saravanan, A., & Rodd, F. H. (2009). Rearing environment affects the brain size of guppies: lab- reared guppies have smaller brains than wild-caught guppies. *Ethology, 115*, 122-133

Carhart, R., & Jerger, J. F. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders, 24*, 330-345.

Cunningham, J., Nicol, T., Zecker, S. G., Bradlow, A., & Kraus, N. (2001). Neurobiologic responses to speech in noise in children with learning impairment: deficits and strategies for improvement. *Clinical Neurophysiology, 112,* 758–767.

Cynthia, K., McGee, T., Tremblay, K., Nicol, T. G., Cunningham, J., & Kraus, N. (2001). Long-term habituation of the speech-elicited mismatch negativity. *Psychophysiology,* 38, 653-658.

Dawes, P., Bishop, D. V. M., Sirimanna, T., & Bamiou, D. E. (2008). Profile and aetiology of children with Auditory Processing Disorder (APD). *International Journal of Pediatric Otorhinolaryngology*, *72*, 440-465.

Dlouha, O., Novak, A., & Vokral, J. (2007). Central auditory processing disorder (CAPD) in children with specific language impairment (SLI): Central auditory tests. *International Journal of Pediatric Otorhinolaryngology*, *71*, 903-907.

Don, M., Allen, A. R., Starr, A. (1977). Effect of click rate on the latency of auditory brain stem responses in humans. *Annals of Otology, Rhinology, and Laryngology*, *86*, 186– 195.

Flippini, R., Befi-lopes, D. M., & Schochat, E. (2012). Efficacy of auditory training using the auditory brainstem response to complex sounds: auditory processing disorder and specific language impairment. *International Association of Logopedics and Phonetics, 64*, 217-226.

Fromm, D., Holland, A., & Frattali, C. (1998). Communicative abilities in daily living – CADL2. Austin TX: Pro-Ed.

Galbraith, G., Arbagey, P., Branski, R., Comerci, N., & Rector, P. (1995). Intelligible speech encoded in the human brain stem frequency-following response. *NeuroReport, 6,* 2363-2367.

Garvita, M. (2012). Stimulus rate and subcortical auditory processing of speech: comparison between younger and older adults. Unpublished Masters dissertation. University of Mysore.

Goncalves, I. C., Wertzner, H. F., Samelli, A. G., & Matas, C. G. (2011). Speech and non-speech processing in children with phonological disorders: an electrophysiological study. *Clinics, 66,* 293-298.

Green, D. M. (1984). Temporal factors in psychoacoustics. In A. Michelsen (Ed.).Time resolution in auditory systems (128-140). Berlin: Springer-Verlag.

Greenberg, S., Marsh, J. T., Brown, W. S., & Smith, J. C. (1987). Neural temporal coding of low pitch.Human frequency following responses to complex tones. *Hearing Research, 25,* 91-114.

Grimm, K., Justic, L.M., Kaderavek, J., Bowles, R. (2003). Language impairment, parent-child shared reading, and phonological awareness a feasibility study. *Topics in Early Childhood Spatial Education Fall, 25,* 143-156.

Hall, J. W. (1992). *Handbook of Auditory evoked Responses.* Boston: Allyn & Bacon.

Hayes, E., Warrier, C. M., Nicol, T., Zecker, S. G., & Kraus, N. (2003). Neural plasticity following auditory training in children with learning problems. *Clinical Neurophysiology, 114*, 673- 684.

Hill, P. R., Hoqben, J. H., & Bishop, D. M. (2005). Auditory frequency discrimination in children with specific language impairment: a longitudinal study. *Journal of Speech, Language and Hearing*, *48*, 1136-1146.

Hirsh, I. (1959). Auditory perception of temporal order. *Journal of the Acoustical Society of America*, *31*, 759-767.

Holopainen, I. E., Korpilahti, P., Juottonen, K., Lang, H., & Sillanpaa, M. (1998). Abnormal frequency mismatch negativity in mentally retarded children and in children with developmental dysphasia. *Journal of Child Neurology*, *13*, 178-183.

Holopainen, I. E., Korpilahti, P., Juottonen, K., Lang, H., & Sillanpaa, M. (1997). Attenuated auditory event-related potential (mismatch negativity) in children with developmental dysphasia. *Neuropediatrics, 28*, 253-256.

Hornickel, J., Skoe, E., Nicol, T., Zecker, S., & Kraus, N. (2009b). Subcortical differentiation of voiced stop consonants: Relationships to reading and speech in noise perception. *Proceedings of the National Academy of Sciences, USA, 106*, 13022-13027.

Jacobson, J. T., Murray, T. J., & Deppe, U. (1987). The effects of ABR stimulus repetition rate in multiple sclerosis. *Ear and Hearing, 8*, 115-20.

Jerger, J. (2009). On the diagnosis of auditory processing disorder (APD). *Journal of the American Academy of Audiology, 20*, 161.

Jirsa, R. E., & Clontz, K. B. (1990). Long latency auditory event-related potentials from children with auditory processing disorders. *Ear and Hearing, 11*, 222–232.

Johnson, K. L, Nicol, T., Zecker, S. G., Bradlow, A. R., Skoe, E., & Kraus, N. (2008). Brainstem encoding of voiced consonant-vowel stop syllables. *Clinical Neurophysiology, 119*, 2623–2635.

Johnson, K. L., Nicol, T., & Kraus, N. (2005). The brainstem response to speech: a biological marker. *Ear and Hearing, 26*, 424-433.

Khaladkar, A., Kartik, N., & Vanaja, C. S. (2005). Speech burst and click evoked ABR. *Audiology Online*.

King, C., Warrier, C. M., Hayes, E., & Kraus, N. (2002). Deficits in the brainstem pathway of speech sounds in children with learning problems. *Neuroscience Letters, 319*, 111-115.

Klatt, D. (1980). Software for cascade/parallel formant synthesizer. *Journal of Acoustical Society of America, 67*, 971–975.

Klein, R. M. (2002). Observations on the temporal correlates of reading failure. *An Interdisiplinary Journal, 15,* 207-232.

Korpilahti, P., & Lang, H. (1994). Auditory ERP components and mismatch negativity in dysphasic children. *Electroencephalography and Clinical Neuropsychology, 91*, 256-264.

Kraus, N. (2001). Auditory pathway encoding and neural plasticity in childrean with learning problems. *Audiology & Neurotology, 6*, 221-227.

Kraus, N., McGee, T. J., Carrell, T. D., & King, C. (1996). Auditory neurophysiologic responses and discrimination deficits in children with learning problems. *Science, 3,* 273-971.

Kraus, N., Smith, D. I., McGee, T., & Stein, L. (1986). Development of the MLR in humans corresponds closely to an animal model. *International Congress on Auditory Evoked Potentials, New York City*.

Krishnan, A., Xu, Y., Gandour, J.T., Cariani, P.A. (2004). Human frequency-following response: representation of pitch contours in Chinese tones. *Hearing Research, 12*, 189.

Krishnan, A., Xu, Y., Gandour,J., & Cariani, P. (2005). Encoding of pitch in the human brainstem is sensitive to language experience. *Brain Research. Cognitive Brain Research, 25,* 161-168.

Krista, L. J., Nicol, T. G., Zecker, S. G., Bradlow, A., Skoe, E., & Kraus, N. (2008). Brainstem encoding of voiced consonant-vowel stop syllables. *Clinical Neurophysiology, 119,* 2623-2635.

Krizman, J., Skoe, E., & Kraus, N. (2010). Stimulus rate and subcortical auditory processing of speech. *Audiology & Neurotology, 15,* 332-342.

Kuhl, P.K. (2000). A new view of language acquisition. *Proceedings of the National Academy of Sciences, 97*, 11850-11857.

Kuhl, P. K., & Miller, J. D. (1982). Discrimination of auditory target dimensions in the presence or absence of variation in a secondary dimension by infants. *Perception and Psychophysics, 31*, 279-292.

Lachmann, T., Berti, S., Kujala, T., & Schroger, E. (2005). Diagnostic subgroups of developmental dyslexia have different deficits in neural processing of tones and phonemes. *International Journal of Psychophysiology, 56,* 105-120.

Lee, K. M., Skoe, E., Kraus, N. & Ashley, R. (2009). Selective subcortical enhancement of musical intervals in musicians. *Journal of Neuroscience, 29,* 5832–5840.

Leonard, L. (1998). Children with specific language impairment. Cambridge, Mass: MIT Press.

Lincoln, A. J., Courchesne, E., harms, L., & Allen, M. (1995). Sensory modulation of auditory stimuli in children with autism and receptive developmental language disorder: Event relative brain potential evidence. *Journal of Autism and Developmental Disorders, 25,* 521-539.

Lowe, A. D., & Campbell, R. A. (1965). Temporal Discrimination in Aphasoid and Normal Children. *Journal of Speech and Hearing Research, 8,* 313-314.

Magnusson, A. K., Kapfer, C., Grothe, B. & Koch, U. (2005). Maturation of glycinergic inhibition in the gerbil medial superior olive after hearing onset. *The Journal of Physiology*, *15*, 497-512.

McAnally, K. I., & Stein, J. F. (1996). Auditory temporal coding in dyslexia. *Biological Sciences, 263,* 961–965.

McArthur, G. M., & Bishop, D. V. M. (2004). Which people with specific language impairment have auditory processing deficits? *Cognitive Neuropsychology*, *21*, 79–94.

Mehta, G., & Singh, N. k. (2012). *Stimulus rate and subcortical auditory processing of speech in children with learning disability*. Poster presentation at 44th ISHACON, Hyderabad.

Miller, C. A., Kail, R., Leonard, L. B., & Tomblin, J. B. (2001). Speed of processing in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *44,* 416-433*.*

Moller, A. (1999). Neural mechanisms of BAEP. *Electroencephalography and Clinical Neurophysiology Supply*, *49*, 27–35.

Montgomery, J. W. (1999). Recognition of gated words by children with specific language impairment: An examination of lexical mapping. *Journal of Speech, Language, and Hearing Research, 42,* 735-743.

Moushegain, G., Rupert, A. L., & Stillman, R. D. (1973). Scalp-recorded early responses in man to frequencies in the speech range. *Electroencephalography and Clinical Neurophysiology, 35, 665-667.*

Musacchia, G., Sams, M., Skoe, E. & Kraus, N. (2007). Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. *Proceedings of the National Academy of Sciences of the United States of America*, *104*, 15894-15898.

Musacchia, G., Strait, D., & Kraus, N. (2008). Relationships between behavior, brainstem and cortical encoding of seen and heard speech in musicians and non-musicians. *Hearing Research*, *241*, 34–42.

Nagarajan, S., Mahncke, H., Salz, T., Tallal, P., Roberts, T., Merzenich, M. M. (1999). Cortical auditory signal processing in poor readers. *Proceedings of the National Academy of Science*, *96*, 6483–6488.

Neville, H. J., Coffey, S. A., Holcomb, P. J., & Tallal, P. (1993). The neurobiology of sensory and language processing in language-impaired children. *Journal of Cognitive Neuroscience, 5*, 235-253.

Parbery-Clark, A., Skoe, E., & Kraus, N. (2009). Musical experience limits the degradative effects of background noise on the neural processing of sound. *Journal of Neuroscience, 29,* 14100.

Plyler, P. N., & Ananthanarayan, A. K. (2001). Human frequency following responses: Representation of second formant transitions in normal-hearing and hearing-impaired listeners. *Journal of the American Academy of Audiology, 12,* 523–533.

Pratt, H., & Sochmer, H. (1976). Intensity and rate functions of cochlear and brainstem evoked responses to click stimuli in man. *Archives of Otorhinolaryngology, 212,* 85-93.

Ramus, F. (2003). Developmental dyslexia: Specific phonological deficit or general sensorimotor dysfunction? *Current Opinion in Neurobiology, 13,* 212–218.

Ranjan. R. (2011). Effect of stimulation rate on subcortical auditory processing in children. Unpublished Masters dissertation. University of Mysore.

Reed, M. A. (1989). Speech perception and the discrimination of brief auditory cues in reading disabled children. *Journal of Experimental Child Psychology, 48,* 270–292.

Rocha-Muniz, C. N., Befi-Lopes, D. M., & Schochat, E. (2012). Investigation of auditory processing disorder and language impairment using the speech evoked auditory brainstem response. *Hearing Research, 294,* 143-152.

Rosen, S., & Manganari, E. (2001). Is there a relationship between speech and non-speech auditory processing in children with dyslexia*? Journal of Speech Language and Hearing Research, 44*, 720–736.

Rosen, S., van der Lely, H., Adlard, A., & Manganari, E. (2000). Backward masking in children with and without language disorders. *British Journal of Audiology, 34*, 124-124.

Russo, N. M., Nicol, T. G., Zecker, S. G., Hayes, E. A., & Kraus, N. (2005). Auditory training improves neural timing in the human brainstem. *Behavioral Brain Research, 156,* 95-103.

Russo, N. M., Skoe, E., Trommer, B., Nicol, T., Zecker, S., Bradlow, A., et al. (2008). Deficient brainstem encoding of pitch in children with Autism Spectrum Disorders. *Clinical Neurophysiology. 119*, 1720–1731.

Russo, N., Nicol, T., & Trommer, B., et al. (2009). Brainstem transcription of speech is disrupted in children with autism spectrum disorders. *Developmental Science, 12,* 557–567.

Russo, N., Nicol, T., Musacchia, G., & Kraus, N. (2004). Brainstem responses to speech syllables. *Clinical Neurophysiology, 115,* 2021–2030.

Scerri, T. S., Morris, A. P., Buckinghan, L.L., Newbury, D. F., Miller, L.L., Monaco, A.P Bishop, D. V., Paracchini, S. (2011). DCDC2, KIAA0319 and CMIP are associated with reading-related traits. *Biological Psychiatry, 70*,237-245.

Sinha, S. K., & Basavaraj, V. (2010a). Lateral Asymmetry in Speech Processing at the Brainstem: Evidence from Speech Evoked ABR. *Journal of All India Institute of Speech and Hearing, 29,* 101- 109.

Sinha, S. K., & Basavaraj, V. (2010b). Speech evoked auditory brainstem responses: a new tool to study brainstem encoding of speech sounds. *Indian Journal of Otolaryngology Head & Neck Surgery, 62,* 395- 399.

Skoe, E., & Kraus, N. (2009). The effects of musical training on subcortical processing of a missing fundamental piano melody. *Society for Neuroscience. Chicago*.

Song, J. H., Skoe, E., Wong, P. C., & Kraus, N. (2008). Plasticity in the adult human auditory brainstem following short-term linguistic training. *Journal of Cognitive Neuroscience, 20,* 1892–1902.

Starr, A., & Don, M. (1988). Handbook of electroencephalography and clinical neurophysiology. 3rd edn. Elsevier, New York.

Strait, D. L., Skoe, E., Kraus, N., & Ashley, R. (2009). Musical experience and neural efficiency: effects of training on subcortical processing of vocal expressions of emotion. *European Journal of Neuroscience* 29, 661-668.

Sumesh, K., & Barman, A. (2010). Brainstem response to speech in normal hearing and cochlear hearing loss individuals. *Article based on dissertation at A.I.I.S.H, 185-199.*

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language, 9,* 182–198.

Tallal, P., & Piercy, M. (1973). Defects of non-verbal auditory perception in children with developmental aphasia. *Nature, 241*, 468–469.

Tallal, P., & Piercy, M. (1974). Developmental aphasia: Rate of auditory processing and selective impairment of consonant perception. *Neuropsychologia, 12,* 83–93.

Tomblin, J. B., records, N. L., Buckwalter, P., Zhang, X., Smith, E., & O'Brien, M. (1997). Prevalence of specific language impairment in kindergarten children. Journal *of Speech, Language, Hearing & Research, 40*, 1245-60.

Tomblin, J. B., Records, N., & Zhang, X. (1996). A system for the diagnosis of specific language impairment in kindergarten children. *Journal of Speech and Hearing Research, 39,* 1284–1294.

Tonnquist-Uhlen, I. (1996). Topography of auditory evoked cortical potentials in children with severe language impairment: the P2 and N2 components. *Scandinavian Audiology, 25*, 1- 44.

Tzounopoulos, T., Kraus, N. (2009). Learning encoding timing: mechanism of plasticity in the auditory brainstem. *Neuron, 62*, 463-469.

Vander, W., Kathy, R., Burns, & Kristen, S. (2011). Brainstem Response to Speech in younger and Older Adults. *Ear & Hearing, 32*, 168-180.

Vandewalle, E., Boets, B., Boons, T., Ghesquiere, P., & Zink, L. (2012). Auditory processing and speech perception in children with specific language impairment: relations with oral language and literacy skill. *Research in Developmental Disabilities, 33,* 635-644.

Werker, J., & Tees, R. C. (1984). Cross-language speech perception: evidence for perceptual reorganization during the first year of life. *Infant Behaviour and Development, 7*, 49-63.

Wible, B., Nicol, T., & Kraus, N. (2002). Abnormal neural encoding of repeated speech stimulus in noise in children with learning problems. *Clinical Neurophysiology, 113,* 484–94.

Wible, B., Nicol, T., & Kraus, N. (2004). Atypical brainstem representation of onset and formant structure of speech sounds in children with language-based learning problems. *Biological Psychology, 67,* 299–317.

Wible, B., Nicol, T., & Kraus, N. (2005). Correlation between brainstem and cortical auditory processes in normal and language-impaired children. *Brain, 128,* 417–423.

Wong, A. M., Ciocca, V., & Yung, S. (2009). The perception of lexical tone contrasts in cantonese children with and without specific language impairment (SLI). *Journal of Speech, Language, and Hearing Research, 52,* 1493-14509.

Wong, P. C., Skoe, E., Russo, N. M., Dees, T., & Kraus, N. (2007). Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature Neuroscience, 10,* 420–422.

Worden, F. G., & Marsh, J. T. (1968). Frequency-following neural responses evoked by sound. *Electroencephalography and Clinical Neurophysiology, 25*, 45–52.

Wright, B., Lombardino, L., King, W., Puranik, C., Leonard, C., & Merzenich, M. (1997). Deficits in auditory temporal and spectral resolution in language impaired children. *Nature*, *387*, 176-178.

Yathiraj, A., & Mascarenhas, K. (2004). Auditory profile of children with suspected auditory processing disorder. *Journal of Indian Speech and Hearing Association*, *18*, 6-14.

Yu, X., Sanes, D. H., Aristizabal, O., Wadghiri, Y. Z., & Turnbull, D. H. (2007). Large-scale reorganization of the tonotopic map in mouse auditory midbrain revealed by MRI. *Proceedings of the National Academy of Sciences, 104,* 12193-12198.