RELATIONSHIP BETWEEN P300, TEMPORAL PROCESSING AND AUDITORY WORKING MEMORY IN CHILDREN WITH DYSLEXIA

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This Dissertation is submitted as part fulfillment
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CERTIFICATE

This is to certify that this dissertation entitled **“Relationship between P300, temporal processing and auditory working memory in children with dyslexia”** is a bonafide work in part fulfillment for the Degree of Master of Science in Audiology of the student with Registration No. 14AUD027. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

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DECLARATION

This dissertation entitled **“Relationship between P300, temporal processing and auditory working memory in children with dyslexia”** is the result of my own study under the guidance of Dr. Prawin Kumar, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other University for the award of any Diploma or Degree.

Mysore,

May, 2016 Register No. 14AUD027

DEDICATED TO
MUMMY, PAPA,
TARUN
&
PRAWIN SIR

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Abstract

Present study aimed to find out the relationship between P300, temporal processing and auditory working memory in children with dyslexia and typically developing children (TDC). There were total 34 children in the age range of 8-12 years considered for the study. Out of 34 children, 17 children with dyslexia served as clinical group and 17 age matched TDC served as control group. P300 was recorded with pair of stimuli i.e. /500/ as infrequent stimulus and /2000/ as frequent stimulus. Behavioral measures assessed were tests of temporal processing (GDT and FDT) and test for auditory working memory (digit span test) for both groups. In TDC, P300 was traceable in 94% children where as among children with dyslexia it was traceable in only 58% children. Descriptive statistics shows better waveform morphology among TDC in comparison to children with dyslexia. Further, Man-Whitney U test was done which showed statistically significant difference for amplitude of P300 between two groups at 0.05 level. Similarly, Man-Whitney U test showed statistically significant difference between both groups for GDT, FDT and digit span test at 0.05 level. Correlation analysis showed statistically significant relationship between latency and amplitude of P300 and behavioral measures (GDT, FDT & digit span test). The combination of both electrophysiological and behavioral measures of temporal processing and auditory working memory will probably help in early detection and intervention of auditory based processing deficit in children with dyslexia.

Chapter 1

Introduction

“Dyslexia may be defined as the specific learning disability that is neurological in origin characterized by a difficulty with accurate reading fluency and poor decoding and spelling, resulting from a deficit in the phonological component of language” (Lyon et al., 2003). A group of dyslexic children concurrently associated with other disorders like (central) auditory processing disorder, cognition deficit, language deficit, attention deficit and hyperactivity disorder. There is a dearth of information on the incidence and prevalence of auditory processing disorder among children with dyslexia. Chermak in 2001 estimated that 2 to 3 % of children have auditory processing disorder, with a 2:1 ratio between boys and girls. Similar findings reported in India by (Muthuselvi & Yathiraj, 2009) who found auditory processing disorder having prevalence of 3.2% in school-aged children. Some of the population in whom auditory processing may be affected include children with learning disorder (Chermak, 1997), specific language impairment (Lang, Eerola, Korpilahti, Holopainen, Solo & Aaltonen, 1995), aphasics (Divenyi & Robinson, 1989) and children with history of otitis media (Bellis, 2011).

“Central auditory processing refers to the perceptual processing of auditory information in the central nervous system. It includes auditory mechanisms like sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition; including temporal integration, temporal discrimination (e.g. Temporal gap detection), temporal ordering, and temporal masking; auditory performance in competing acoustic signal (including dichotic listening); and auditory performance with degraded acoustic signal"(ASHA, 1996; Bellis, 2011; Chermak, 1997). (Central) auditory processing disorder [(C)APD] can be confirmed by poor performance in one or more skill mentioned above like auditory attention, discrimination, auditory memory and temporal processing. Behavioral tests of central auditory function are used widely to assess a variety of auditory processing skills such as selective listening, binaural integration, binaural separation, and temporal sequencing (Musiek & Gurekink, 1980).

The central auditory processing of an individual can be accessed either through behavioral tests or electrophysiological tests. The behavioral and electrophysiological test has been useful in uncovering the important aspects of the neural basis of central auditory dysfunction. Despite of several researches there are controversies about the findings of behavioral tests of central auditory processing disorder (Heath & Hogben, 2004; Wilson, Bell, & Koslowski, 2003). This can be due to reduced specificity and sensitivity as well as could be because of technical factors such as electronic soundtrack and playback techniques, variability innate in the tests (Keith, Rudy, Donahue, & Katbamna, 1989) and heterogeneity within the population with central auditory processing disorders (Willeford, 1985). Further, it could be because young children may not be able to comprehend behavioral testing due to a restricted capacity to meet the language, memory and/or attention demands of the existing tests (Musiek, Chermak, & Weihing, 2007)

Electrophysiological studies have revealed physiological deficits in children with learning disorders (Regaçone, Gução, Giacheti, Romero, & Frizzo, 2014) and dyslexia

(Blomert & Mitterer, 2004; Leppänen & Lyytinen, 1997; Oliveira, Murphy, & Schochat, 2013). Such deficits result in brain cognitive dysfunction linked to selective attention, working memory or language processing. Electrophysiological measures like speech-evoked ABR have been used to inspect temporal processing deficits in children having language bases learning disorders. Researchers have found that children having learning based disorder exhibit abnormal speech evoked brainstem (Banai, Nicol, Zecker, & Kraus, 2005; King, Warrier, Hayes, & Kraus, 2002; Song, Banai, Russo, & Kraus, 2006). The majority of electrophysiological test has been carried out in children with learning disability are to assess the auditory processing at the cortical level. Auditory long latency responses are the most frequently used tests among the cortical potentials to assess cortical region. It is comprised of the N1 and P2 evoked potentials and the P300 response. Even though there are many non-auditory contributors to the P300, there is an evidence that shows lesions in the auditory regions of the cortex affects the P300 in both latency and amplitude measures (Knight, Scabini, Woods, & Clayworth, 1989). Most of the study reported a prolonged latency (Arehole, 1995; Guruprasad, 1999; Jirsa & Clontz, 1990); and reduced amplitude in children’s with dyslexia (Dawson, Finley, Phillips, & Lewy, 1989; Jirsa and Clontz, 1990; Mason & Mellor, 1984); Research on MMN has indicated reduced amplitude (Lang et al., 1995; Leppänen & Lyytinen, 1997), reduction of the area of MMN and reduced duration (Kraus, McGee, Carrell, Zecker, Nicol & Koch 1996) in children with learning disorder. Adults with central auditory processing disorder showed considerably longer P300 latency when compared with normal hearing individuals with competing noise conditions (Krishnamurti, 2001). Jirsa and Clontz,

(1990) did a study and showed significant differences among children with central auditory processing disorder and a control group in the latency and amplitude of the P300. P300 auditory event related potentials can be used to assess higher order processing in individuals with central auditory processing disorders more successfully (Jirsa & Clontz, 1990). It is recorded using an oddball paradigm and can be used to evaluate auditory perceptual skill relating to attention and discrimination (Hood, 1996). It reflects mainly the thalamus and the cortex activity; these structures are responsible for sound discrimination, integration and attention.

1.1 Need for the study

The behavioral tests have been widely accepted to be the test of choice; however processing deficit may be co-morbid with a number of pathologies that prevent the administration of behavioral tests. Hence, an attempt is required to check the equivalency of electrophysiological tests like P300 in the evaluation of children's with dyslexia and central auditory processing disorders. P300 reflects mainly the thalamus and the cortex activity; these structures involve sound discrimination, integration and attention. According to literature, children with dyslexia present poor performance in the behavioral tests of central auditory processing, longer reaction time and increased latency for P300 (Cohen-Mimran, 2006). However, there is a sporadic existence of literature in this regard. Hence further research is needed in this area to probe for difficulties faced by the children with dyslexia. An attempt is also needed to find out the responses obtained from central auditory function tests (Gap detection test, and pitch discrimination test), working memory (auditory digit span) and electrophysiological test (P300) are related or independent in children with dyslexia.

The electrophysiological measures like P300 complement the diagnosis of school going children with auditory processing disorder. The findings of the study may suggest anatomical or functional flaws in the children with dyslexia. This study may provide the opportunity for a through treatment planning, for an auditory linguistic training and improvement of auditory skills. The study will provide significant supplementary measures on the functioning and processing of the information of the auditory system.

The detection and early intervention of auditory based processing deficit in children with dyslexia is important to reduce the impact on academic and social life in this population. More investment in research in this area is needed to investigate more accurate information on the functioning of the auditory pathway in this population and carry out further investigation of the auditory processing in the children with dyslexia.

1.2 Aim of the study:

The aim of the study is to compare the performance of children with dyslexia and typically developing children using P300, test of temporal processing and auditory working memory.

1.3 Objective of the study

The objectives of the study are:

- To compare the performance of children with dyslexia and typically developing children in behavioral tests of temporal processing (Gap detection test, and frequency discrimination test).

- To compare the performance of children with dyslexia and typically developing children in auditory working memory (auditory digit span).
- To compare the P300 responses in children with dyslexia and typically developing children.
- To investigate the relationship between P300 responses, auditory working memory and behavioral tests of temporal processing in children with dyslexia.

1.4 Hypothesis

The null hypothesis is assumed for the present study indicating:

- There is no difference in the performance of children with dyslexia and typically developing children in behavioral tests of temporal processing.
- There is no difference in the performance of children with dyslexia and typically developing children in auditory working memory.
- There is no difference in the P300 responses in children with dyslexia and typically developing children.
- There is no relationship between P300 responses, auditory working memory and behavioral tests of temporal processing in children with dyslexia and typically developing children.

Chapter 2

Review of Literature

Dyslexia can be concurrently associated with other disorders like (central) auditory processing disorder, cognition deficit, language deficit, attention deficit and hyperactivity disorder. “Central auditory processing is defined as the perceptual processing of auditory information in the central nervous system and the neurobiological activity that underlies processing” (ASHA, 2005). Temporal processing and auditory working memory deficits are one of the sub-types. The "Report of the Consensus Conference on the Diagnosis of Auditory Processing Disorders in School-Aged Children" included recommendations for a test battery providing the necessary information for the differential diagnosis of (central) auditory processing disorder [(C)APD]. The recommendations included behavioral tests and electrophysiological tests, and a detailed case history. A measure of temporal gap detection was among the behavioral tests recommended to examine auditory temporal resolution. Auditory temporal processing can be measured using a variety of approaches, including gap detection test and frequency discrimination test. Children with Learning disability demonstrate abnormal temporal resolution abilities based on Gap detection procedure (Hautus, Setchell, Waldie, & Kirk, 2003). Tests of temporal processing involves adequate amount of auditory working memory. The decrease in score on this measure may not point out the lesion site but helps in the differential diagnosis and baseline to start the intervention. The literature on temporal processing and auditory working memory deficits in dyslexia can be broadly divided into behavioral and electrophysiological aspects. P300 can be used effectively to evaluate higher order processing in children’s with central auditory processing disorders (Jirsa & Clontz, 1990). An oddball paradigm is used to record the P300 and can be used to assess auditory perceptual skill involving attention and discrimination (Waechter, 2013). P300 mainly reflects the thalamus and the cortex activity; these structures are responsible for sound discrimination, integration and attention.

2.1 P300 in typically developing children

The recording of P300 highly depends on the subject status. The age, state of arousal and subject’s attention affects the P300 recording. Goodin, Squires, Henderson, and Starr, 1978 did a study on auditory evoked potentials and recorded LLR and P300 on 47 subjects of age range 6 to 76 years. Evaluation of effects of maturation and aging on the evoked (N1 and P2) and event-related (N2 and P3) components were analyzed. To see the effect of age on the event-related components the children (less than 15 years of age) and adults the subjects were separated into two populations for analysis. For adults there were increase in the latency and decrease in amplitude of each component of LLR and P300 with increasing age. In addition, the rate of the age-related increase in latency was relative to the latency of the component. For children, the latencies of the LLR and P300 decreased with age. In contrast to the adult data, age affected the scalp distributions of the stimulus-evoked components differently than the event-related components. These results suggest an aging process is reflected in the auditory evoked potential which is not the simple inverse of maturational processes.

Polich, Howard, and Starr in 1985 recorded P300 using an auditory “oddball” paradigm from a sample of young (5 to 15 years) and older (20 to 86 years) individuals.

Distinct P3a and P3b subcomponents of the P300 were seen within individuals and across trial blocks. The results shows age affected P300 latency in a similar fashion for both subcomponents with latency increasing about 65 ms between 20 and 70 years. P300 latency variability was also found with advancing age. The results correlated with previous age-related ERP changes and extended them to the P3a and P3b subcomponents.

There is relatively less normative data on the P300 response in children. Passive P300 can be used with infants and young children. From 6 years to late adolescence, P300 amplitude increases, latency reduces, morphology improves (Squires & Hecox, 1983). The relation between age from 6 years up to 15 years and latency is defined by an average change in P300 latency as a function of age of approximately 19 ms/year (Bandhu, Shankar, Tandon, & Madan, 2011; Nash & Fernandez, 1996). In a study done by Pearce, Crowell, Tokioka, and Pacheco in 1989 investigated the developmental changes in P3 latency from childhood to adolescence. Event-related potentials evoked by auditory stimuli were recorded from 35 normal children ranging from 5 and 13 years. Regression analyses showed considerable age trends in the auditory P3 latency. Latencies decreased at a faster rate (Cz: 20.34 ms/year; Pz: 19.27 ms/year) from childhood to adolescence, suggesting an increased competence in processing information as children mature. Another study done by Wada, Nanbu, Koshino, Shimada, and Hashimoto in 1996 showed that amplitude of P300 decreases and amplitude increases during the transition from alert awake state to drowsiness and then to sleep stage I

Sugg and Polich in 1995 did a study were auditory stimulus intensity 45, 60, 75, dBSPL respectively and standard/target frequency 250/500 and 1000/2000 Hz were changed systematically to assess their effects on the P300 event-related brain potential. For the target stimuli, increase in intensity produced reliable increase in P3 amplitude and decrease in peak latency. P3 latency at the lowest intensity level was slightly longer for the low frequency situation. For the standard stimuli, increase in intensity produced reliable P3 amplitude, low frequency stimuli resulted in smaller components than high frequency stimuli, and numerous interactions with the electrode factor were obtained. As the intensity increased the P3 latency decreased, and low frequency tones produced longer latencies than high frequency tones. The N1, P2, and N2 components from both stimulus types generally were affected in the same manner: intensity increases producing larger amplitudes and shorter latencies, with some effects of tone frequency also observed. The findings suggest that auditory stimulus parameters contribute to both P3 amplitude and latency measures in important ways.

P300 can be evoked by using a wide verity of stimulus using oddball paradigm. Stimulus such as click, tone burst and different type of speech signals are used to elicit the response. Lew, Slimp, Price, Massagli, and Robinson in 1999 did a study were twenty-two normal adults (11 males and 11 females; age range, 18-60 years) were tested for both speech-evoked and tone-evoked P300 responses. Speech-evoked P300 responses had significantly larger amplitudes (mean, 12.1 μV) than the tone-evoked responses (mean, 5.9 μV). To conclude the recording of P300 is highly dependent on subject’s status. The age, state of arousal and subject attention affects the P300 recording. Aging affects the P300 latency and amplitude but it is not a simple inverse of maturational process. Studies have shown that there is average decrease of latency between 6 years to

15 years. The decrease in latency is faster from childhood to adolescence. P300 response has larger amplitude and shorter latency with conscious and focused attention to rare signal.

2.2 P300 in children with dyslexia

Event related potentials (ERP) like late latency response and P300 provide prognosis and assessment of Specific Learning Disabilities and, primarily, dyslexia. Electrophysiology is a technique that assesses how long it takes the brain to process stimuli that activate its cognitive functions and how this processing is affected. ERPs represent the synchronized activation of electrical fields linked with the activity of large populations of neurons. This activity volume conducts to the scalp surface, and is configured in such a way that their individual electrical fields summate to yield a dipolar field (a field with positive and negative charges). ERPs reflect changes in the brain's electrical activity in response to a discrete stimulus or event. They are normally collected after the presentation of repeated stimuli. In general, electrical activity recording occurs at about 100 ms or more before stimulus presentation and continues over a period of 500-2,000 ms after its termination.

Auditory long latency responses are the most frequently used test among the cortical potentials to assess cortical region. It is comprised of the N1 and P2 evoked potentials and the P300 response. Although there are non-auditory contributors to the P300, there is evidence that lesions in the auditory regions of the cortex compromise the P300 in both latency and amplitude (Knight et al., 1989; Musiek, Baran, & Pinheiro, 1992). Most of the study reported a prolonged latency (Arehole, 1995; Guruprasad, 1999;

Jirsa & Clontz, 1990) and reduced amplitude in children’s with dyslexia (Dawson et al., 1989; Jirsa & Clontz, 1990; Mason & Mellor, 1984). If the P300 wave is small and delayed, there is evidence of a deficit in the cognitive processing (Hall et al., 2006). P300, cognitive or endogenous potential is associated to mental function of perception and represents the physiological phenomena related to auditory attention, discrimination, integration and memory (Kraus et al., 1996). Electrophysiological studies have shown physiological deficits in children with learning disorders (Regaçone et al., 2014) and dyslexia (Bonte & Blomert, 2004; Oliveira et al., 2013). Such deficits result in brain cognitive dysfunction linked to selective attention, working memory or language processing. In general, they observed delayed values of the components in dyslexic children’s group compared with children without dyslexia.

Holcomb, Ackerman, and Dykman in 1985 did a study in which ERPs were recorded from four groups of children: reading disabled, attention deficit disorder with and without hyperactivity, and normal controls. Subjects were asked to press a button to a low probability nonsense syllable and ignored all other events. The amplitudes of several late ERP components and the latency of the P3 component were examined. The overall amplitude of P3 was considerably smaller in all clinical groups than in controls, but the difference in P3 amplitude between targets and non targets was lesser only in the two attention deficit groups. Reading disabled children had smaller P3 and Pc components to words than to symbols, while controls had equivalent values. P3 latency was significantly longer in the three clinical groups than in controls, but only the attention deficit groups showed an increase in P3 latency across blocks of the task.

Jirsa and Clontz in 1990 did a study to compare children with auditory processing disorders to normal group children and found that there was a considerable latency increase for P3 component in processing disordered group. Since P3 latency is directly related to speed of information processing (Mullis, Holcomb, Diner, & Dykman, 1985) difficulties in this area would be reflected increase in P300 latencies. Fosker and Thierry in 2004 studied attention shifts towards phonological information as indexed by event-related potentials (ERPs) in normal readers and dyslexic adults. Participants performed a lexical decision task on spoken stimuli of which 80% started with a standard phoneme and 20% with a deviant phoneme. A P300 modulation was predicted for deviants in control adults, indicating that the phonological change had been detected. A mild and right-lateralized P300 was observed for deviant stimuli in controls, but was absent in dyslexic adults. Result suggested that dyslexic adults fail to make shifts of attention to phonological cues in the same way that normal adult readers do.

Oliveira et al., in 2013 compared the performance of children with dyslexia and a control group in behavioral tests of (Central) Auditory Processing and Long Latency Auditory Evoked Potentials (P300). 22 individuals with dyslexia (study group) and 16 individuals with typical development (control group) were included in the study. All individuals underwent behavioral and electrophysiological assessment of (Central) Auditory Processing like Frequency Pattern Test, Dichotic Digit Test, Speech-in-Noise Test, and P300. The findings revealed that individuals with dyslexia present temporal auditory processing and figure-ground alterations, which was evidenced by behavioral auditory processing tests. There was no significant difference between the performances of both groups for the P300 test. Maciejewska, Wiskirska-Woźnica, Świdziński, and Michalak in 2013 assessed auditory evoked potentials (MMN and P300) in children with dyslexia. The results showed that Mismatch negativity (MMN) and P300 waves were significantly more frequent in the healthy children (control group) than in children with dyslexia. The P300 wave was present in all subjects from the control group and the MMN wave in 92% of them. Latencies of complex ERPs in children with dyslexia were greater than latencies in children in the control group. MMN and P300 maturation (change with age) was observed only for the control group. A wide range of MMN and P300 responses was observed across children with dyslexia. To conclude auditory late latency response like P300 are most frequently used test among the cortical potential to assess cortical regions. It is comprised of N1 and P2 evoked potentials and the P300 response. Although there are non auditory contributions to P300, there is evidence that lesions in the auditory region of the cortex compromise the P300 in both latency and amplitude. Studies have shown prolonged latencies and reduced amplitude in children with dyslexia.

2.3 Temporal processing and auditory working memory in typically developing children

“Temporal refers to the 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). In speech perception temporal processing is one of the essential components in the discrimination of cues like voicing and the discrimination of the similar words. Auditory temporal resolution can be measured using a variety of approaches, including gap detection or its reciprocal process, fusion detection (Formby & Muir, 1988). The gap detection paradigm typically involves the presentation of two relatively long sounds, a leading and a trailing sound, with a brief silent period or gap between them (Phillips, 2011). Gap detection tasks generally require subjects to listen to stimuli presented with varying inter-stimulus intervals and indicate when they detect the presence of the gap. The gap detection threshold represents the smallest silent interval in a stimulus that a listener can detect (Lister, Besing, & Koehnke, 2002). In click fusion tasks, normal subjects can resolve that two clicks have been presented with inter stimulus interval as low as 2-3 ms (Albert & Bear, 1974; Auerbach, Allard, Naeser, Alexander, & Albert, 1982; Hirsh & Sherrick , 1961). In order to notice the gap between two auditory stimuli, normal adults need thresholds of around 5 to 16 ms (depending on the frequency of the stimulus) (Werner, Marean, Halpin, Spetner, & Gillenwater, 1992).

Hirsh in 1959 studied the outcome of inter stimulus interval (ISI) on perception of temporal order. Using a variety of acoustic stimuli, he determined that an ISI of only 2 ms is required for normal listening to perceive 2 sounds instead of one. However, this ISI should be raised to 17 ms to say which of the 2 stimuli came first with 75% of accuracy. Hence there are 3 sub-processes which are involved in the task like detecting gaps, ordering or patterning the stimuli and temporal masking. Hirsh concluded that if a person requires more than 15 to 20 ms ISI then one can suspect deficit in temporal processing and look for anatomical and physiological correlates of such a judgment.

Shivprakash and Manjula in 2003 developed the normative data for gap detection test in children of age range 7-12 years. The subjects were asked to discriminate gap, which was embedded in one of the 3 noise bursts. The stimulus was presented monaurally at 40 dBSL. Results showed that children required gap of 3 to 4 ms with standard deviation of 1 ms to detect it. Further, it was seen that there was no improvement in GDT after 7 years. This study also suggests that normal hearing individuals start performing like adults on gap detection by the age of 6-7 years.

Shinn, Chermak, and Musiek in 2009 did a study to determine the viability of the Gap in noise test in the pediatric population. The study involved 72 participant separated into six groups of normal children ranging from 7 to 18 years of age. Results showed that there was no statistically significant difference in GIN thresholds among age groups. The conclusion made from the study was GIN can be in both pediatric and adult populations for the assessment of temporal resolution. Similar study was carried out by Perez and Pereira in 2010 to examine temporal resolution using the Gap in Noise test in children in order to establish criteria of normal development. 92 children, with ages of 11 and 12 years, with no evidences of otologic, and/or neurologic, and/or cognitive disorders, as well as with no history of learning difficulties or school failure participated in the study. Results showed that the average gap thresholds was 5.05 ms, and the average percentage correct answers was 71.70%. The researchers found no significant statistical variation between the responses by age (11 and 12 years), by ear (right and left), by gender (male and female). However when they compared the tests, it was observed that the 1st test showed a higher percentage of identifications of gap compared to 2^{nd} test.

Auditory working memory is defined as an ability to repeat a series of items in the correct order as well as total number of items presented auditory. Here difficulty of a task goes on increasing as the number of items to be recalled increases. The decrease in the scores on this measure may not point out the lesion site but will definitely give us the baseline to start with the intervention for this measure. Study done by Polich, Ladish and Burns, 1990 studied the normal variation in memory span and P300. A simple auditory task was employed in which subjects indicated with a finger movement when a randomly occurring target tone (high pitch) was presented in a series of standard (low pitch) tones. Memory capacity was assessed with forward and reverse digit spans. The results showed that P300 latency decreased with age, and P300 amplitude tended to become larger with age. Digit span were also curvilinear to P300 values. Multiple regression analysis indicated that changes in age and memory span both predicted significant changes in P300 latency and amplitude. To conclude temporal processing plays very important role in everyday listening task, including speech perception and music. Gap detection test and frequency discrimination tests helps in assessing the temporal processing ability of the children. Studies have shown that children require gap of 3 to 4 ms to detect it. The gap detection ability improves till 7 years of age. The literature also suggests that the normal hearing individuals start performing adult like in gap detection by the age of 7 years. Auditory working memory tests like digit span may not point out lesion site but helps in assessment of baseline for intervention and differential diagnosis.

2.4 Temporal processing and auditory working memory in children with dyslexia

McCroskey and Kidder in 1980 did a study using two tones having duration of 17-msec, and inter stimulus interval ranging 0 to 40 ms, researchers found that both a reading-disabled and a learning-disabled group of 9-year-olds required longer inter stimulus interval than did normal's to separate the tones. The result showed reading-disabled children were affected by intensity, but not frequency. (Haggerty and Stamm, 1978) used a click fusion task, but rather than presenting the two clicks in sequence to both ears, they presented them either to both ears at once, or with one ear leading. Results showed that learning-disabled group required a longer ISI to separate clicks than did the controls (1.67 ms vs. 1.29 ms). Utilizing a temporal integration task, Stanley and Hall, (1973) presented two parts of a stimulus with 20-msec duration with varying ISIs. Dyslexics required longer ISIs to separate the two stimulus than did the normal readers (mean ISI of 140 vs. 102 ms), and to identify the stimuli, dyslexics needed 327 ms, whereas normal readers took 182 ms.

According to Tallal in 1980 dyslexics are impaired in comparison with younger controls when they were asked to say whether two tones are presented in rapid succession, at ISIs of 8-305 ms, were similar or different. At ISIs of 428 ms, dyslexics performed better compared to controls. Despite the fact that results have shown that disabled readers made more errors in a temporal order judgment task than in the same-different judgment task. Dyslexics have been found to be impaired when complex stimulus was given to match. Poor readers of 7 to 10 years were observed to be poorer than good readers on same-different judgments for sets of synthesized consonant-vowel syllables (ba/da) from a phoneme continuum (Reed, 1989). Reed used the pairs of vowel and pairs of consonant-vowel stimuli with a duration of 250 ms and with pairs of pure tones with a duration of 75 ms (as in the Tallal, 1980) and presented to the subjects the task was to perform a temporal order judgment with ISIs varying from 10 to 400 ms.

Results suggested that reading disabled group was impaired compared to controls as ISIs reduced for pairs of tones and pairs of consonant-vowel syllables.

Study done by Oliveira et al in 2013 suggested that individuals with dyslexia show temporal auditory processing and figure-ground alterations, which was evidenced by using behavioral auditory processing tests. The newly developed test by Musiek, 2003 Gaps-In-Noise (GIN) has provided a fresh diagnostic tool for the finding of temporal resolution deficits. Earlier reports show that the GIN is comparatively a sensitive tool for the diagnosis of central auditory processing disorder in adult populations. Hautus et al. in 2003 reported atypical temporal resolution (i.e., high GDTs) in children (ages 6–9 years) with learning disabilities/dyslexia compared to age-matched controls. In contrast, the older children showed normal GDTs, suggesting either developmental maturation or positive effects of their treatment programs. Zaidan and Baran, 2013 did a study to find if the gaps-in-noise test could differentiate children with dyslexia and phonological awareness deficits from a group of children with normal reading skills. Sixty one children between the ages of 8.1 and 9.11 year, separated into two groups: children with dyslexia and significant phonological deficits (Group I); normal-reading peers with age-appropriate phonological skills (Group II). Results indicated that Children in Group I showed longer gap detection (GD) thresholds and lower gap identification scores than did the children in Group II. Conclusion made through the study was an auditory temporal processing deficit should be considered in children presenting with dyslexia and phonological processing disorders.

Dias, Jutras, Acrani, and Pereira in 2012 did a study to evaluate the auditory temporal resolution ability in children with central auditory processing disorders, 131 participants with central auditory processing disorder and 94 with normal auditory processing were included in the study. The random gap detection test was administered to the participants. Results showed that there was a significant difference in children with and without central auditory processing disorder. Also, 48% of children with central auditory processing disorder were not able to finish the random gap detection test and the percentage decreased as a function of age. The highest percentage (86%) was found in the 5–6 year-old children. Researchers suggested based on the results that random gap detection test should not be administered to children younger than 7 years old because other reduced capacities might influence their performance.

Research has shown that dyslexic individuals perform poor in auditory frequency discrimination (FD) task. Halliday in 2006 did a study to evaluate the FD thresholds of 28 children with dyslexia and 28 age-matched controls aged 6–13, on a task that minimized strain on short-term memory. To explore the mechanisms involved in potential FD deficits, FD thresholds were measured at 1 kHz and 6 kHz. The temporal cues were presented at 1 kHz and it was absent at 6 kHz The dyslexic group showed significantly higher FD thresholds than controls in both the 1 kHz and 6 kHz conditions. The findings of the study suggested that children with dyslexia have poor FD. Another study done by Baldweg, Richardon, Watkins, Foale, and Gruzelier in 1999 used mismatch negativity (MMN) and pitch discrimination. Subjects were asked to perform a visual distracter task. MMN responses to graded changes in tone frequency or tone duration were recorded in

10 dyslexic and matched control subjects. MMN recordings showed that dyslexic children showed abnormal response when there were changes in tone frequency but not to changes in tone duration. Furthermore, the pitch discrimination and MMN deficit was associated with the degree of impairment in phonological skills, as reflected in reading errors of regular words and non words. The study concluded that it is possible that in dyslexic children may exhibit a persistent sensory insufficiency in monitoring the frequency of incoming sound which may impair the feedback control necessary for the normal development of phonological skills.

Hill, Hogben, and Bishop in 2005 did a study on 10 children with SLI and 12 control children first tested 42 months previously. At 1st time, the children with SLI had significantly high FD thresholds compared to the matched controls. At 2nd time, the thresholds of both groups had improved, but the children with SLI still showed poorer FD thresholds compared to the control group. To assess temporal resolution, auditory backward masking was measured and it was found that most of the children with SLI performed similarly as the controls. The results showed greater variability among the children with SLI compared to controls on the FD task. These studies show considerable heterogeneity in auditory function among children with SLI and suggest that assessment of frequency discrimination is important in this population. Similar study done by France et al in 2002 investigated whether frequency discrimination is affected in dyslexics, two interval same-different paradigm and a variant with six A-stimuli per trial were used. Frequency was varied around 500 Hz and inter-stimulus interval (ISI) ranged between 0 ms and 1,000 ms. Under two interval same-different paradigm, dyslexics had larger just noticeable differences (JNDs) compared to controls. Dyslexic and control JNDs were equal at shorter ISIs under six A-stimuli per trial but dyslexics became poorer than controls at longer ISIs. Signal detection analysis suggests that both sensory variance and trace variance are poor in dyslexics than in controls.

Hill, Bailey, Griffiths, and Snowling in 1999 did a study to evaluate auditory sensitivity dyslexics and matched control listeners. The first experiment assessed frequency discrimination and frequency modulation detection thresholds at both 1 and 6 kHz. Results showed that thresholds were poor for the dyslexic group, but the differences were not statistically reliable. The second experiment assessed the binaural masking level difference for a 200 Hz pure tone in noise. Thresholds did not differ significantly between the two groups. The results from this study provided minute support for the hypothesis that dyslexic listeners are impaired in their skill to process information in the temporal fine structure of auditory stimuli.

Auditory working memory is defined as an ability to repeat a series of items in the correct order as well as total number of items presented auditory. There is considerable evidence that individuals with dyslexia have an impaired verbal working memory (Banai et al., 2005)(Banai et al., 2005). Cohen-Mimran and Sapir in 2007 studied the degree to which reading disabilities in young adults are linked to deficits in specific aspects of temporary storage of verbal information, explicitly, memory span and the central executive component of working memory. Individuals with and without reading disability were tested with the digit span test and revised part of the word memory test of the Token Test (WMTT). The results of the study showed overall poorer performance of the reading disability group on memory tests. (De Jong & Van Joolingen, 1998; Plaza, Cohen, & Chevrie-Muller, 2001; Siegel & Ryan, 1989)

Swanson and Jerman in 2007 did a longitudinal study of 3 years and figured out whether subgroups of children with reading disabilities, with arithmetic deficits, with both reading and arithmetic deficits, and low verbal IQ readers and skilled readers varied in working memory (WM) and short-term memory (STM) growth. A battery of different test of memory and reading measures was administered on 84 children (11–17 years of age) across three testing's having a 1 year gap in between. The results showed that skilled readers exhibited higher working memory growth estimates than the reading disabilities groups.

Wang and Gathercole in 2013 did a study on children with reading difficulties to explore the origin of the reported problems in working memory. Verbal and visuospatial simple and complex span tasks, digit span and reaction times tasks were performed individually and in combination. The task was administered on forty six children having single word reading difficulties and forty five typically developing children matched for age and nonverbal skill. The results showed that children with reading difficulties had pervasive deficits in the simple and complex span tasks and had poorer abilities to organize two cognitive demanding tasks. These results show that working memory problems in children with reading difficulties may reveal a core deficit in the central executive.

According to Temple in 1989 dyscalculia is a impairment of number processing. Temple did a study and found that when reading and writing Arabic numbers the syntactic part of the number is processed precisely but lexical processing results in inaccurate digit selection. When reading Arabic numbers the distribution of lexical items into syntactic frames is particularly deprived for digits in the unit position. Lexical distribution is unaltered by stimulus length. Despite reduced short term memory, word reading is not impaired apart from for the reading of numeral words for which there is a category specific deficit. Reading errors to numeral words are more frequent than to Arabic numbers but the nature of the errors is comparable. This reading deficit coexists with good phonological reading skills.

Geary and Hoard in 2001 did a study on the number counting, and arithmetic competencies on children with learning disability. The study showed that the major features of learning disability in arithmetic and most dyscalculia's are difficulty in the procedural features associated with the solving of complex arithmetic problems and difficulties in remembering fundamental arithmetic facts. The procedural deficits and one form of retrieval deficit emerge to be connected with functioning of the prefrontal cortex, while a second form of retrieval deficit appears to be associated with the functioning of the left parieto-occipito-temporal areas and numerous subcortical structures.

Tressoldi, Rosati, and Lucangeli in 2007 did a study to examine the degree to which some characteristics of dyscalculia which may be common to dyslexia. Two children with dyslexia only, two with dyscalculia only, and three more children with co morbidity of dyslexia and dyscalculia were chosen for the study. All participants were assessed with a standardized comprehensive battery of arithmetical, reading, and cognitive tests. Researchers observed that a clinical impairment in mental and written calculations, arithmetical facts retrieval, number comparison, number alignment, and identification of arithmetical signs seen with a normal reading capacity and autonomously with the short-term verbal memory deficit. The study concluded that these results add convergent support to the evidence mostly obtained from group comparisons that the more idiosyncratic characteristics of dyscalculia are functionally autonomous to dyslexia.

Schuchardt, Maehler, and Hasselhorn in 2008 did a study to inspect working memory functioning in children with specific developmental disorders of academic skills. Ninety seven 2nd to 4th graders with a minimum IQ of 80 are compared using a 2 x 2 factorial (dyscalculia vs. no dyscalculia; dyslexia vs. no dyslexia) design. Children with dyscalculia exhibited deficits in visual-spatial memory; children with dyslexia exhibited deficits in phonological and central executive functioning. Although children with both reading and arithmetic disorders are consistently performed poor compared to all other groups, there is no significant relation between the factors dyscalculia and dyslexia.

Landerl, Fussenegger, Moll, and Willburger in 2009 did a study to test the hypothesis that dyslexia and dyscalculia are mainly linked with cognitive deficits namely phonological deficit and a deficit in the number module respectively. Phonological awareness, phonological and visual–spatial short-term and working memory, naming speed, and basic number processing skills were assessed on four groups of 8 to 10 year old children including 42 control, 21 dyslexic, 20 dyscalculia, and 26 dyslexic/dyscalculia. A phonological deficit was found for both dyslexic groups, irrespective of additional arithmetic deficits, but not for the dyscalculia-only group. In contrast, deficits in processing of symbolic and non symbolic magnitudes were seen in both groups of dyscalculia children, irrespective of additional reading difficulties, but not in the dyslexia-only group. Cognitive deficits in the co morbid dyslexia/dyscalculia group were additive; that is they resulted from the combination of two learning disorders. These findings advocated that dyslexia and dyscalculia have distinguishable cognitive profiles, namely a phonological deficit in the case of dyslexia and a deficient number module in the case of dyscalculia.

Landerl, Bevan, and Butterworth in 2004 did a study on 31 children aged 8 to 9 year selected having dyscalculia, reading difficulties or both, were compared to controls on a range of basic number processing tasks. Children with dyscalculia only had poor performance on the tasks despite high-average performance on tests of IQ, vocabulary and working memory tasks. Children with reading disability were slightly impaired only on tasks that involved articulation, while children with both disorders exhibited a pattern of numerical disability similar to that of the dyscalculia group, with no special features resulting on their reading or language deficits. Researchers concluded that dyscalculia is the result of specific disabilities in basic numerical processing, rather than the outcome of deficits in other cognitive abilities. To conclude the literature suggested that individual with dyslexia show temporal auditory processing alterations which was evidenced by using behavioral auditory processing tests. Children with dyslexia showed longer (poorer) gap detection threshold. Similarly for frequency discrimination and auditory working memory literature suggested that children with dyslexia perform poorer compared to typically developing children.

Chapter 3

Method

The present study was undertaken to investigate the existence of a possible association between behavioral tests of temporal processing, auditory working memory and P300 in children with dyslexia. To fulfill the above aim, the below mentioned method was adopted.

3.1 Participants

The study included two groups, i.e. clinical and a control group. Seventeen children with dyslexia (clinical group) and 17 age matched typically developing children (control group) in the age range of 8-12 years participated in the study. The diagnosis of dyslexia was made by qualified Speech Language Pathologist/Clinical Psychologist.

3.2 Subject selection criteria

3.2.1. *Group I: Clinical group (children with dyslexia)*

Inclusion criteria for clinical group included were bilateral hearing sensitivity less than or equal to 15 dBHL. Speech recognition thresholds were within ± 12 dB of PTA and speech identification scores were above 90% in both the ears in quiet condition along with uncomfortable loudness level greater than 100 dBHL. All participants’ had normal middle ear functioning with 'A' type tympanograms and acoustic reflexes present at least at 500 Hz and 1 kHz in both the ears. Otoacoustic Emissions indicated normal outer hair cells functioning bilaterally. Based on structured case history, they were referred to be having no history or presence of any other neurological deficits, or complaint of giddiness or balance problem. All the participants in the group had no other associated problems during the recording.

Participants were chosen based on convenient sampling and all of them belong to English medium school. They were then assessed using Screening checklist for auditory processing (SCAP) developed by Yathiraj & Mascarenhas, 2002 and 'Screening test for auditory processing' (STAP) developed by Yathiraj & Maggu, 2012 indicating presence/absence of auditory processing disorder. They were also assessed using Modified Mini Mental State Examination (MMMSE) by Passi (2005) indicating presence/ absence of cognitive deficit.

3.2.2. *Group II: Control group (typically developing children)*

Inclusion criteria used remained similar to the clinical group, along with matched age and gender considered for the control group. Normal hearing sensitivity was found out in all the participants with no other otological complaints. No history or complaint of any speech and language problem was taken into consideration. Early reading skills, standardized and adapted for Indian children by Loomba (1995) were used to rule out any reading disorders. SCAP and STAP were administered along with Modified Mini Mental State Examination (MMSE) to rule out auditory processing disorder and cognitive deficit.

3.3 Instrumentation

A calibrated diagnostic audiometer, GSI-61 (Grason-Stadler Incorporation, USA) with Telephonics TDH-50 supra aural headphone was used for estimating the air conduction thresholds. Radio ear B-71 bone vibrator was used for bone conduction threshold. For assessing middle ear, calibrated middle ear analyzer, GSI tympstar

(Grason-Stadler Incorporation, USA) was used for tympanometry and reflexometry. Then ILO 292 DPEcho port system (Otodynamics Inc., UK) was used to assess transient evoked otoacoustic emissions. P300 recording was done using the Intelligent Hearing System (version 4.3.02) (Intelligent Hearing System, Florida, USA), with ER-3A Insert ear phone (Etymotic Research, Inc., Elk Grove Village, IL, USA). A personal computer (PC), Intel i3 processor with MATLab software was used to play the test items for behavioral testing (gap detection test and frequency discrimination test) and adobe audition version 3 was used to play stimulus for auditory digit span.

3.3 Test Environment

All the behavioral as well as electrophysiological tests were done in acoustically treated rooms with permissible noise level as per ANSI, 1999 standards. The testing rooms were well illuminated and air conditioned for the comfort of the experimenter as well as participant

3.4 Procedure

The testing was carried out in two phases. The first phase included complete hearing screening along with ERS, SCAP, STAP and MMMSE. The second phase consisted of behavioral tests of temporal processing (Gap detection test and frequency discrimination test), test of auditory working memory (Digit span) and P300 was recorded.

3.4.1. *Phase I: Hearing screening, ERS, SCAP, STAP and MMMSE*

As an initial procedure, otoscopic examination was carried out to rule out external ear and tympanic membrane pathologies. A detailed case history was taken before the commencement of the routine audiological assessment. Pure-tone thresholds were obtained using modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959) at octave frequencies between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction. Speech identification scores were obtained using phonetically balanced words in Kannada given by Vandana & Yathiraj, 1998.The stimulus was presented at 40 dB SL (with reference to PTA i.e. average thresholds obtained at 500 Hz, 1000 Hz & 2000 Hz) in quiet. Immittance audiometry was carried out with a probe tone frequency of 226 Hz. Ipsilateral and contralateral acoustic reflex thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. A significant change of admittance value of at least 0.03 ml was considered as presence of acoustic reflexes. Transient-evoked otoacoustic emissions (TEOAE) were obtained for 260 nonlinear click stimuli. The foam tip was properly positioned in the external auditory canal to get a flat frequency spectrum across the frequency. The overall TEOAEs amplitude of 6 dBSPL above the noise floor with a reproducibility >80% was considered as the presence of TEOAEs (Dijk, Wit, & Segenhout, 1989).

Early reading skills, standardized and adapted for Indian children by Loomba (1995) was administered which include sections of alphabet testing, visual and auditory discrimination test, phoneme and grapheme correspondence, structural analysis, close and oral reading tests. Screening checklist of auditory processing (SCAP) developed by Yathiraj & Mascarenhas, 2002 was administered which consisted of twelve questions. The screening was done as ‘Yes’ or ‘No’. Each answer was marked ‘Yes’ carried one point and ‘No’ carried zero point. Children who scored less than 50% (<6/12) were considered (Pass SCAP) for the study.

STAP was administered which consisted of four subsections (Speech-in-Noise, Dichotic CV, Gap detection, and Auditory memory). The CD of the test contained a 1 kHz calibration tone, overall instruction to the test, instructions for each subsection prior to the commencement of the stimuli for each subsection, and the stimuli for each subsection. As the stimuli for each ear were recorded on the two different tracks, evaluation of the two ears could be done without any manipulation once the test commenced, cutoff criteria were provided for each subsection to decide whether a child was ‘at-risk’ or not at risk for the APD. Children were considered ‘at-risk’ for APD if they were referred on one or more subsection of STAP test.

Modified mini mental state examination (MMSC) developed by Passi in 2005 was administered to assess the cognitive functioning of the children, which consist of questions related to orientation, attention and concentration, registration and sensory perception and recall and language. Jain and Passi defined a cutoff point for cognitive deficit of two standard deviations below the mean. The maximum score for all sections was 37 and children who scored less than 30 were suspected with cognitive deficit and excluded from the study. Seventeen subjects from each group who passed all the criteria mentioned above were selected for the study. All subjects were informed about the purpose of the study and their consent for the participation in the study was taken from their parents.

3.4.2. *Phase II: Tests of temporal processing, auditory working memory and P300*

The following behavioral and electrophysiological tests were used to assess temporal processing, auditory memory and auditory discrimination for both experimental and control group.

Gap detection threshold

The Gap detection threshold was measured using “mlp” tool box which implements a maximum likelihood procedure in MatLab software. The maximum likelihood procedure uses a large number of candidate psychometric functions and after each trial calculates the probability (or likelihood) of obtaining the listener's response to all of the stimuli that have been presented given each psychometric function (Grassi & Soranzo, 2009). The participants’ ability to detect temporal gap was assessed which was embedded in the center of a 750 ms broadband noise (Harris, Eckert, Ahlstrom & Dubno, 2010). The noise was designed to have a 0.5 ms cosine ramp at the beginning and the end of the gap. This broadband noise was used for the GDT as its spectrum does not change with the insertion of the gap (Moore & Moore, 2003). A silence of standard duration was placed at its temporal center. The variable had variable gap duration and the length of its gap was changed as function of the subject performance.

Frequency Discrimination test

For Frequency discrimination task, three-interval, two-alternative forced choice AXB procedure was used to estimate threshold using MATLab software. Every trial had a successive presentation of 250 ms sinusoidal tones separated with ISIs of 300 ms through a headset. Onset and offset of tones were gated on and off with two 10-ms raised cosine ramps. Three tones were presented in each trial. The first tone (A) was a 1000 Hz standard, the third tone (B) was the same frequency (i.e., 1000 Hz) plus some frequency difference, and the middle tone (X) matched the frequency of either the first tone or the third tone on a random basis. Participants had to indicate which of the tone in each pair was higher in frequency. The initial stimulus difference was 30 Hz and was modified using a parameter estimation by sequential testing procedure (Taylor & Creelman, 1967). This procedure presents large frequency differences that initially are easily discriminable. The frequency differences are systematically reduced in a stepwise protocol, and the task becomes more and more difficult until an error is made. After an error is made, the frequency difference is increased to make discrimination easier (a reversal). Step size is then progressively reduced again, until a threshold level is reached. The maximum step size used in the measurements was 8 Hz, and the minimum step size was 0.1 Hz. Testing was conducted in an acoustically treated room. The child was seated in front of a computer screen and required to identify whether the middle sound was the same as the first sound or the last sound. They indicated their choice by pressing the appropriate button on a keypad. Training was given to all children to familiarize them with the task.

Auditory digit span test

Auditory working memory was assessed using auditory digit span for the forward phase. In this task cluster of digits were presented in random order with the increasing level of difficulty. The numbers were recorded from one to nine and six lists were presented with increasing level of difficulty with level 1 being easiest and level 6 being the toughest. Level 1 had three digits while the level 6 had eight digits, which were presented randomly. The participants were asked to repeat the numbers in the same order for forward digit span test. Auditory working memory capacity was calculated as the total number of digits the child successfully recalled.

Electrophysiological Evaluation

P300 was recorded for both clinical and control group using a paired stimulus. The pair had /2000Hz/ and /500Hz/ with /2000Hz/ as frequent stimulus and /500Hz/ as the infrequent stimulus. The total duration of the stimulus was 200 ms with 30 ms rise-fall time with plateau of 140 ms. The stimulus was made with the help of Aux viewer program. The wave file was then converted to stimulus file for AEPs using the software "Stimconv" provided by the Intelligent hearing system version 4.3.02. The electrode sites were cleaned using skin preparation paste (Nuprep). The Ag-AgCl disc type of electrodes was placed on the scalp at electrode placement site with adequate amount of conduction paste. Responses were differentially recorded with each electrode having impedance ≤ 5 kΩ, with non-inverting electrode placed on the vertex (Fz, Cz, & Pz), inverting electrode placed on the nape of the neck and ground electrode placed on nasion. These electrodes were taped to prevent any dislocation of electrodes by means of surgical tape. The recording was done in an acoustically and electrically shielded room using four channels in which one was used to cancel ocular artifact evoked potentials. The subjects were instructed to relax and refrain from extraneous body movements to minimize movement artifacts. The subjects were also instructed to press response switch whenever the deviant stimulus comes to avoid the passive listening. Recording protocol for P300 is shown in table 3.1

Table 3. 1: Recording protocol for P300 recording

STIMULUS PARAMETERS	
Transducer	Insert ER- 3A
Stimulus paradigm	Oddball paradigm
Stimulus type	Tone burst (2000Hz & 500 Hz)
Intensity	70 dBHL
Duration: Tone burst	
Rise time/ Fall time	~30 ms
Plateau	~140 ms
Repetition rate	1.1/s
Stimulus probability (target)	20%
Polarity	Rarefaction
Presentation ear	Binaural
ACQUISITION PARAMETERS	
No. of sweeps	100
Amplification	25000
Analysis time	600 ms
Filter setting	HPF: 1Hz
	LPF: 30Hz
Notch filter	No
Electrode type	Disc or disposable
Electrode montage	*Non inverting :- Fz, Cz and PZ*
	Inverting : Nape of the neck
	Ground : Nasion
No. of recordings	2

**HPF = High pass filter; LPF = Low pass filter*

3.7 Statistical analysis:

The P300 peaks were given for visual inspection to two qualified Audiologist independently. Cronbach’s alpha reliability test was done to check the reliability between the two raters. Descriptive analysis was done to find out mean and standard deviation for all the parameters of P300 (latency and amplitude of Fz, Cz and Pz), tests of temporal processing (GDT & FDT) and test of auditory working memory (Digit span). Shapiro-Wilk test was done to check the normal distribution of the data. It was noticed that the data collected for latency and amplitude of P300, scores of GDT and FDT and scores of the auditory digit span were not normally distributed. Hence, non parametric test was applied for all the above measures.

The non parametric test, i.e. Man-Whitney U test was done to compare between two groups for latency and amplitude of P300, Gap detection test, frequency discrimination test and auditory digit span test (for typically developing children and children with dyslexia). Wilcoxon Signed rank test was done to compare P300 amplitudes and latency of Fz, Cz and Pz positions, tests of temporal processing and auditory working memory within the group. Further, Spearman rank correlation was done to check if there was any correlation between P300 latency as well as amplitudes at different recording sites and behavioral test of temporal processing and auditory working memory in children with dyslexia.

Chapter 4

Results

Seventeen typically developing children and children with dyslexia constituted the control and experimental group respectively. Out of 17 typically developing children, P300 was traceable in 16 (94%) children at Cz position, 14 (82 %) children at Pz position and 13 (76.5%) children at Fz position. Similarly, out of 17 children with dyslexia, P300 was traceable in 9 (58%) children at Cz, Pz and Fz position each. The above data indicate more traceable P300 at Cz position in typically developing children. However, children with dyslexia showed similar representation of P300 at different sites of recordings.

The P300 peaks were given for the visual inception by two qualified Audiologists independently. The Cronbach's alpha reliability test was performed to check the inter judge reliability. The result showed positive reliability of 0.992 which indicates that presence of responses noticed by the both the examiners matched well. After visual inspection of the waveforms, amplitudes and latency of P300 were marked and tabulated for further statistical analysis. The characteristics of waveforms obtained in typically developing children and children with dyslexia at different recording sites (Fz, Cz and Pz) are shown in figure 4:1 and 4:2. These figures show that the amplitude of P300 is higher in typically developing children, as compared to children with dyslexia irrespective of different recording sites.

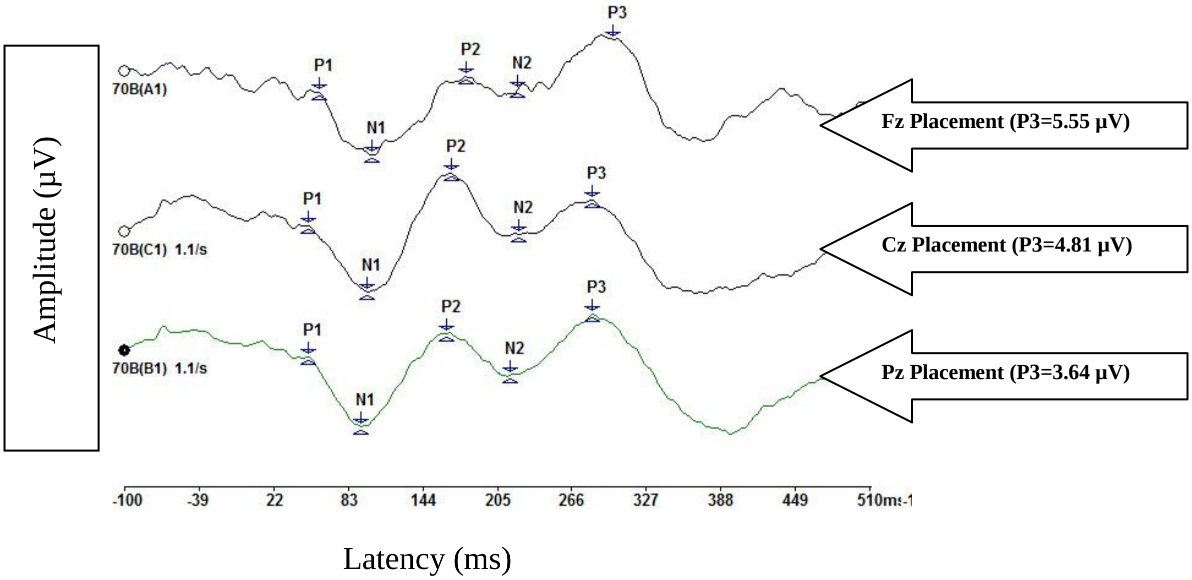

Figure 4: 1: A sample waveform of P300 in typically developing children. The X-axis represents latency of waveform; the Y- axis represents amplitude of waveform.

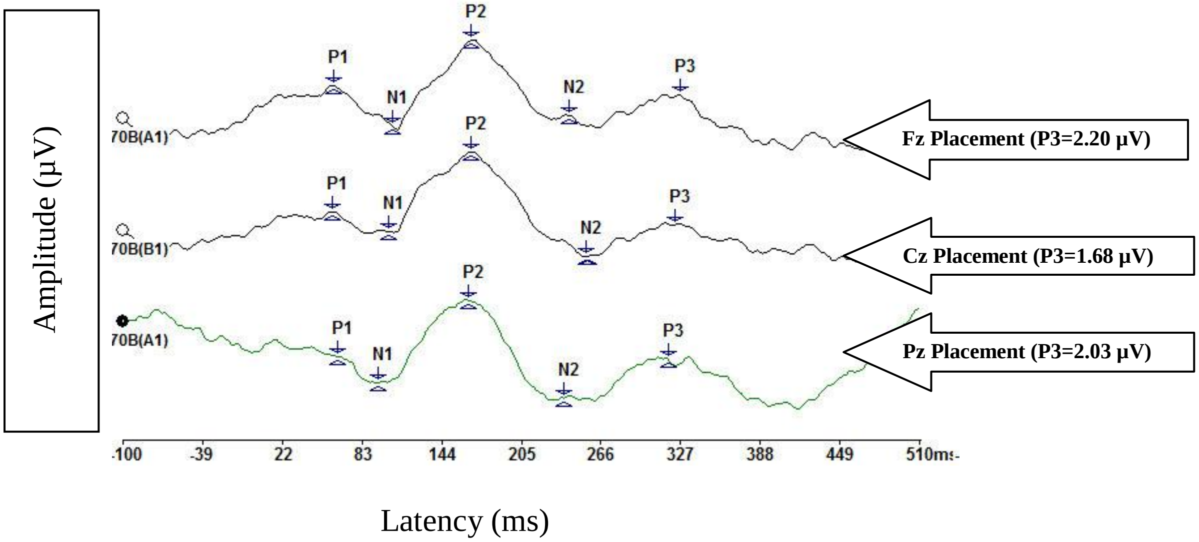

Figure 4: 2: A sample waveform of P300 in children with Dyslexia. The X-axis represents latency of waveform; the Y- axis represents amplitude of waveform.

4.1 Latency and amplitude measures of P300

As shown in table 4.1 and figure 4:3, the mean latency of P300 was lesser (better) at the Fz position in both groups. However, the Standard deviation (SD) was higher at the Pz position in both groups which indicates more variability at Pz position compared to Fz and Cz position. Though there is a difference in mean and SD at different positions of recording site, these values was not significant as per Man-Whitney U test. Man-Whitney U test shows no statistically significant difference in the latency of P300 in both the groups with |Z| value 0.876, 1.331 and 1.230 for different positions i.e. Fz, Cz and Pz respectively at 0.05 level.

Table 4. 1: Mean and standard deviation (SD) in P300 Latency (ms) in typically developing children and children with dyslexia

	Typically developing children			**Children with dyslexia**		
Recording site	N	Mean	SD	N	Mean	SD
Fz_Latency	13	296	41	9	314	33
Cz_latency	16	306	44	9	334	35
Pz_latency	14	309	48	9	333	41

Note. Fz, Cz and Pz are various recording site, according to international 10-20 system of electrode placement; N= number of subjects; SD=Standard deviation

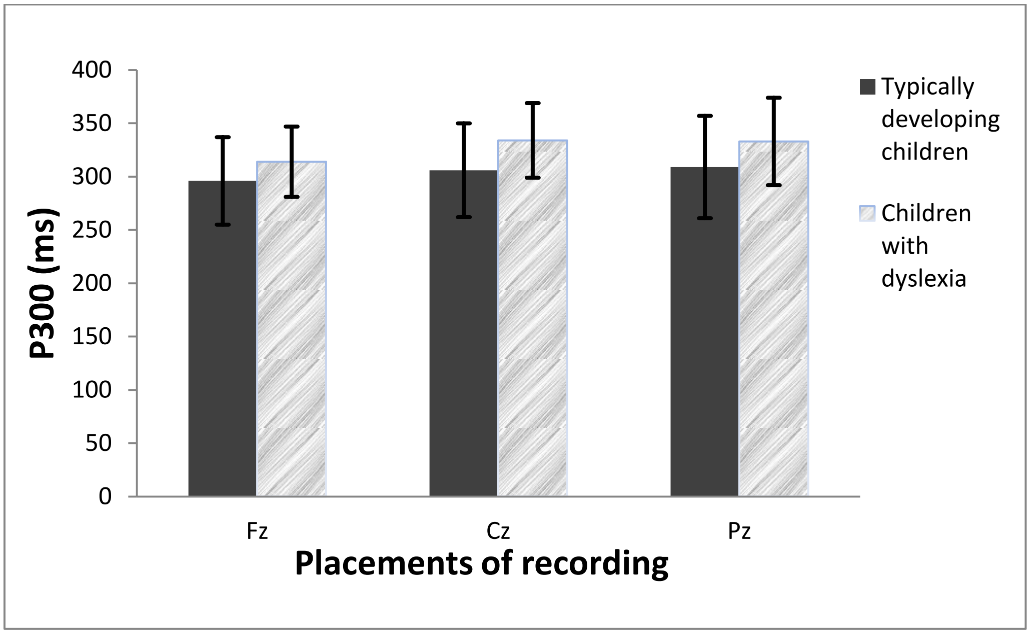

Figure 4: 3: P300 Latency (ms) in typically developing children and children with dyslexia. The x axis represents various placements of recordings and the y axis represents the latency of the waveform.

As per data in table 4.2 and figure 4:4, it is noticed that the mean amplitude of P300 is higher (better) at the Fz position in both groups compared to Cz and Pz position. Further, the SD was also lesser at the Fz position in both groups which indicate less variability in individual data at Fz position. In addition, Man-Whitney U test was done to compare the amplitude of P300 between two groups. The results showed statistically significant difference between typically developing children and children with dyslexia at Fz and Cz positions amplitude with |Z| value of 3.450 and 3.064 respectively at 0.05 levels. However, there was no statistically significant difference noticed at the Pz position with |Z| value 1.348 and at 0.05 levels. Hence, null hypothesis is rejected since there is a significant difference between two groups.

Table 4. 2: Mean and standard deviation (SD) of P300 amplitude (µV) in both groups

	Typically developing children			**Children with dyslexia**		
Recording site	N	Mean	SD	N	Mean	D
Fz_amp	13	5.55	2.00	9	2.20	1.18
Cz_amp	16	4.81	2.49	9	1.68	1.58
Pz_amp	14	3.64	2.48	9	2.03	1.50

Note. Fz, Cz and Pz are various recording site, according to international 10-20 system of electrode placement; N= number of subjects; SD=Standard deviation

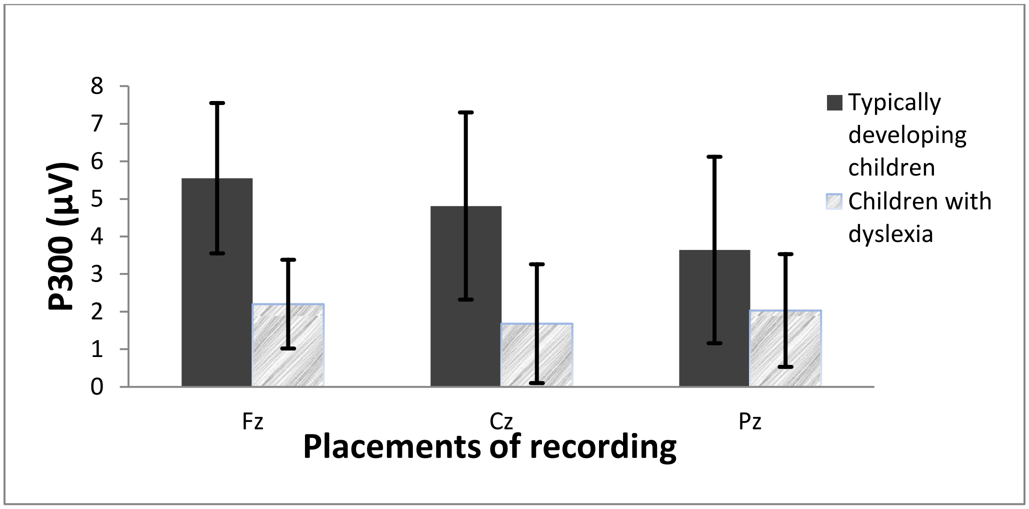

Figure 4: 4: P300 amplitude (µV) in typically developing children and children with Dyslexia. The x axis represents various placements of recordings and the y axis represents the amplitude of the waveform.

Wilcoxon signed rank test was done to compare the different sites of recording (Cz, Pz & Fz) in each group. The result shows statistically significant difference for Fz verses Pz as well as Fz verses Cz positions with |Z| value of 2.691 and 2.040 respectively at 0.05 levels in typically developing children (Table 4.3). However, no significant difference was found between Cz and Pz positions in typically developing children. In contrast, in children with dyslexia Wilcoxon signed rank test shows that there was no significant difference between amplitude of Fz verses Pz; Fz verses Cz, as well as Cz verses Pz with a |Z| value of 0.981, 1.364 and 1.364 respectively at 0.05 level (Table 4.3).

Table 4. 3: Comparison of P300 amplitude at different positions within typically developing children and children with Dyslexia

Groups	Recording sites	Fz	Cz	Pz
TDC	Fz	-	0.04*	0.00**
	Cz	0.04*	-	0.23
Children with dyslexia	*Fz*	-	*0.17*	*0.32*
	Cz	*0.17*	-	*0.17*

*Note. Fz, Cz and Pz are various recording site, according to international 10-20 system of electrode placement. *P<0.05; **p<0.01; TDC = typically developing children*

The co-morbidity of disorder like (C)APD was assessed and its effect on P300 was examined using descriptive analysis. With the help Screening checklist of auditory processing (SCAP) and Screening tests of auditory processing (STAP), 7 children out of 17 children with dyslexia were suspected with at risk of (C)APD. Further on analysis the P300 was adversely affected in children with dyslexia and at risk of (C)APD compared to dyslexia without (C)APD. P300 in dyslexia with at risk of (C)APD was present only in 2 (28.5%) out of 7 children at Fz and Pz position and 1(14.2%) at Cz position.

4.2 Gap detection test

As per data in table 4.5 and figure 4:5, the mean of gap detection threshold in children with dyslexia were higher (poorer) in comparison to typically developing children. It was almost double the value in dyslexic children compared to typically developing children. Further, the SD was also higher among dyslexic children in comparison to typically developing children, which indicates more heterogeneity among children with dyslexia. The higher GDT indicates the poor temporal resolution ability of the dyslexic children. Further, Man-Whitney U test shows statistically significant difference between typically developing children and children with dyslexia (|Z|= 4.077, P<0.05). Hence, null hypothesis is rejected since there is a significant difference between two groups.

Table 4. 4: GDT(ms) in typically developing children with dyslexia.

	Typically developing children (N=17)	Children with dyslexia. (N=17)
Mean	4.07	8.71
SD	0.53	1.56
Median	4.00	9.09

Note. N= Number of subjects; SD= Standard deviation

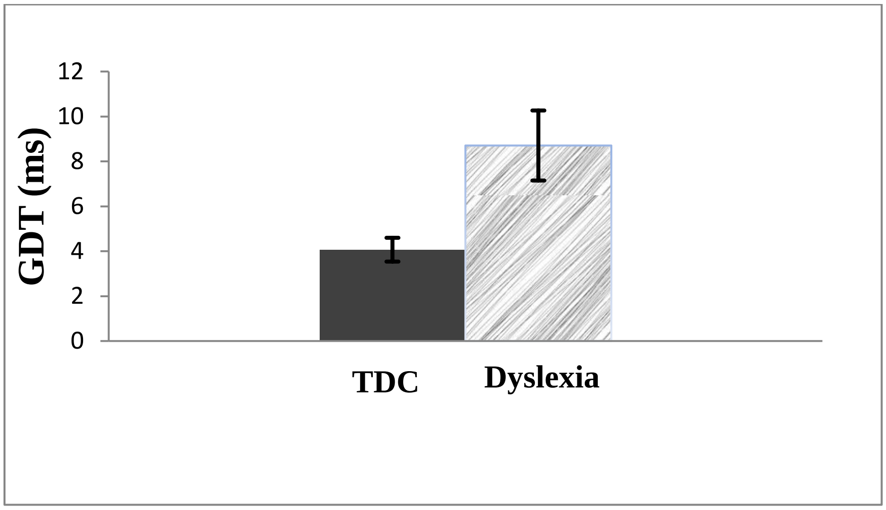

Figure 4:5**:** GDT (ms) scores in typically developing children and children with dyslexia. The X- axis represents subjects; The Y- axis represents GDT scores.

4.3 Frequency Discrimination test

The mean scores of Frequency discrimination test shows higher (poorer) scores for dyslexic children compared to typically developing children (Table 4.6). In addition, the SD was also noticed to be higher among dyslexic children compared to typically developing children. Further, Man-Whitney U test was done to compare between two groups. The result shows a statistically significant difference between typically developing children and children with dyslexia (|Z|=3.775; P<0.05). Hence, null hypothesis is rejected since there is a significant difference between two groups. Scores of Frequency discrimination test are given in table 4.6 & figure 4:6.

Table 4. 5: FDT (Hz) in typically developing children and children with dyslexia..

	Typically developing children (N=17)	Children with dyslexia (N=17)
Mean	28.95	43.18
SD	5.40	10.42
Median	28.99	42.44

Note. n= number of subjects; SD= Standard deviation

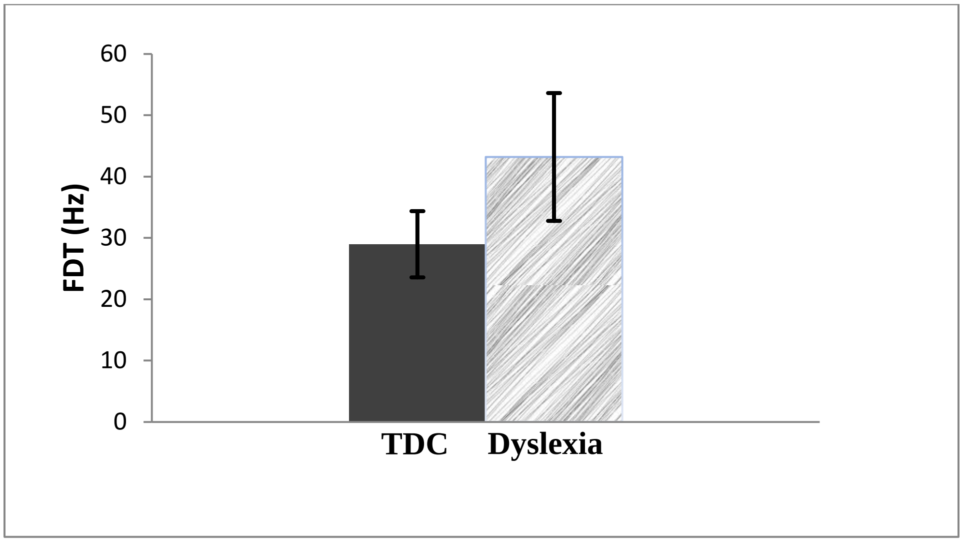

Figure 4:6: FDT (Hz) scores in typically developing children and children with dyslexia. The X- axis represents subjects; The Y- axis represents FDT scores. TDC= Typically developing children

4.4 Digit Span Test

Digit Span test of typically developing children and children with dyslexia shows dyslexic children have lower (poorer) mean scores compared to typically developing children. Further, Man-Whitney U test was done to compare the two groups. The result showed there was a statistically significant difference between two groups (|Z|=3.108, P<0.05). Hence, null hypothesis is rejected since there is a significant difference between two groups. Scores of Frequency discrimination test are given in table 4.7 and figure 4:7.

Table 4. 6: Digit span scores in typically developing children and children with dyslexia.

	Typically developing children (N=17)	Children with dyslexia (N=17)
Mean	6.47	5.53
SD	0.72	0.79
Median	7.00	6.00

N= number of subjects; SD= Standard deviation

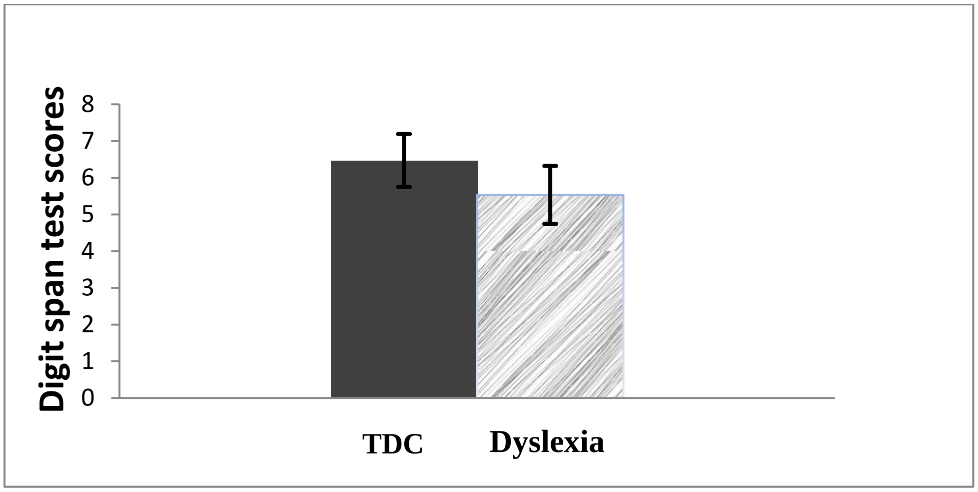

Figure 4:7: FDT (Hz) scores in typically developing children and children with dyslexia. The X- axis represents subjects; The Y- axis represents FDT scores. TDC= Typically developing children

4.5. Relationship between P300, behavioral test of temporal processing (GDT, FDT) and auditory working memory (Digit span) in children with dyslexia

Spearman rank correlation test was used to check if there is any correlation between P300 Latency and amplitude at different recording sites and behavioral test of temporal processing (GDT, FDT) and auditory working memory (Digit span) in children with dyslexia. As shown in table 4.8, there is a positive correlation between GDT and FDT with P300 latency at Cz, Pz and Fz position. However, these correlations were not statistically significant except GDT with P300 at Cz position. In addition a negative correlation was noticed for digit span with respect to P300 latency at different site of recording. This suggests that the latency of P300 was prolonged when there was an increase in scores of gap detection test and frequency discrimination test and vice-versa. Similarly, digit span was less (poorer) when latency was prolonged. In contrast, for the digit span test, there was a significant negative correlation for Pz and Cz position. Overall, it was noticed that at Cz position the correlation were statistically significant between latency of P300 and behavioral (GDT, FDT and Digit span) measures.

Similarly to check the correlation between P300 amplitude at different recording site and behavioral tests of temporal processing and auditory working memory, Spearman rank correlation test was done. As shown in table 4.9, there is a strong correlation between GDT and P300 amplitude at Cz and Pz position. The negative correlation noticed for the both GDT and FDT with respect to P300 amplitude. This suggests that the amplitude of P300 was lesser (poorer) when there was an increase in scores of gap detection test and frequency discrimination test and vice-versa. However, though there was a correlation at the Pz position of P300 with GDT and FDT, it was not statistically significant. In contrast, for the digit span test, there was a significant positive correlation for Fz and Cz and position. However statistically significant correlation was not noticed at Pz position. The positive correlation between P300 amplitude and digit span test suggest that digit span score was better (higher) when P300 amplitude was better (more). Overall, it is noticed that at Fz and Cz position, the correlation was statistically significance between amplitude of P300 and behavioral (GDT, FDT and DST) measures. Hence, null hypothesis is rejected since there is a correlation observed between P300 and behavioral measures in children with dyslexia.

Table 4. 7: Correlation scores of P300 latency, tests of temporal processing and auditory working memory

Parameters	GDT		FDT		Digit Span	
	ρ value	p value	ρ value	p value	ρ value	p value
Fz position	0.266	0.22	0.27	0.20	-0.353	0.09
Cz position	0.384	0.05*	0.46	0.01*	-0.493	0.01*
Pz position	0.331	0.12	0.19	0.37	-0.465	0.02*

**p<0.05; ρ= correlation coefficient*

Table 4. 8: Correlation scores of P300 amplitude, tests of temporal processing and auditory working memory

Parameters	GDT		FDT		Digit Span	
	ρ value	p value	ρ value	p value	ρ value	p value
Fz position	-0.704	0.00**	-0.538	0.00**	0.514	0.01*
Cz position	-0.511	0.00**	-0.546	0.00**	0.411	0.04*
Pz position	-0.241	0.26	-0.033	0.88	0.064	0.77

*p<0.05; **p<0.01; ρ= correlation coefficient

Chapter 5

Discussion

The present study aimed to compare the performance of children with dyslexia and typically developing children using P300, tests of temporal processing and auditory working memory. Gap detection test and frequency discrimination test were done to assess the temporal processing in both the groups. Auditory working memory was assessed using a digit span test. P300 was recorded with tonal stimulus and the correlation was investigated between tests of temporal processing and auditory working memory. Further, the results of the same are discussed under the following headings:

1. Findings of P300 latency and amplitude measures
2. Findings of tests of temporal processing and auditory working memory.
3. Correlation between P300, tests of temporal processing and auditory working memory.

1. Findings of P300 latency and amplitude measures

The behavioral tests have been widely accepted to be the test of choice; however processing deficit may be co-morbid with a number of pathologies that prevent the administration of behavioral tests. Hence, in the present study an attempt was made to check the equivalency of electrophysiological tests like P300 in the evaluation of children's with dyslexia. The results of the study showed that in spite of good cognitive and temporal processing skills in typically developing children, P300 was traceable only in 16 (94%) at Cz position, 14 (82 %) at Pz position and 13 (76.5%) at Fz position out of

17 typically developing children. Studies have shown that child’s inattention to the stimulus can be a reason for the infrequent occurrence of P300 waves. Moreover, studies have shown that P300 are not always present even in children with normal auditory processing (Kraus et al., 1996; Sharma et al., 2006). The study showed no statistically significant difference in P300 latency which can be due to high variability in the latency of the individual subject. This finding contradicts the studies done by (Maciejewska et al., 2013; Corbera, Escera, & Artigas, 2006) where they found statistically significant difference in the latency of P300.

The P300 amplitude in children with dyslexia was lesser (poorer) than typically developing children. It was statistically significant based on Man-Whitney U test which indicate that children with dyslexia have a difficulty in detecting the subtle differences in signals. There are supporting studies which indicates that abnormal P300 points to difficulties with hearing attention, memory, analysis of auditory signals, classification of sounds, or the inability to selectively attend to auditory stimuli (Hall et al., 2006; Jirsa & Clontz, 1990).

The P300 response is likely to have multiple generators, mostly in and around the hippocampus lobe in near to Fz and Cz electrodes, therefore the amplitude of Fz and Cz, was found to better than Pz amplitude in typically developing children in present study. There was no significant difference found in amplitudes of Fz, Cz and Pz position in case of children with dyslexia, which is probably indicative of hearing discrimination problems (Baldweg et al., 1999; Kujala et al., 2000). The literature suggests P300 waveform is small and delayed, there is evidence of a deficit in the cognitive processing

(Hall et al., 2006). Electrophysiological studies have shown physiological deficits in children with learning disorders (Purdy, Kelly, & Davies, 2002; Regaçone et al., 2014) and dyslexia (Bonte & Blomert, 2004; Leppänen & Lyytinen, 1997; Oliveira et al., 2013). Such deficits result in brain cognitive dysfunction linked to selective attention, working memory or language processing. In general, they observed delayed values of the components in a dyslexic children's group compared with children without dyslexia. In similar line, Kumar and Gupta, 2014 assessed the performance of children with dyslexia and typically developing children on speech evoked auditory late latency response. Researchers reported that children with dyslexia exhibited prolonged latencies and reduced amplitudes of speech evoked auditory late latency response. The findings of the study may be attributed to the abnormal encoding of speech signal at the cortical level in children with dyslexia.

In the present study P300 was absent in 42% of children with dyslexia. The absence of p300 in dyslexic children could be because of several contributing factors like attention deficit, subtypes of dyslexia, auditory perceptual deficits, maturational delays, and delayed neurological processing involvement. To conclude even though there are many non-auditory contributors to the P300, there is evidence which shows lesions in the auditory regions of cortex affects the P300 response.

2. Findings of tests of temporal processing and auditory working memory

The temporal processing ability of children with dyslexia and typically developing children were assessed using gap detection test and frequency discrimination test. Children with dyslexia exhibited poor performance in both the test of temporal processing. Similar results were reported by (Boscariol, Guimarães, Hage, Cendes, and Guerreiro in 2010 where the temporal processing ability in children with developmental dyslexia was assessed. They found statistically significant difference between the children with dyslexia and typically developing children. In a similar line, Zaidan & Baran in 2013 compared the Gap detection ability in Children with dyslexia, phonological deficits and typically developing children. Children with dyslexia and phonological deficits showed more (poorer) gap detection thresholds and lower gap identification scores than the typically developing children. Results of statistical and clinical testing revealed significant differences between the groups. Tajik et al., in 2012 compared the performance of children with dyslexia and dysgraphia based on gap in noise (GIN) test. An abnormal temporal resolution was found in children with dyslexia and dysgraphia in both the studies. The authors suggested that the brainstem and auditory cortex are responsible for auditory temporal processing, probably the structural and functional differences in dyslexic and dysgraphic children compared to normal children lead to abnormal coding of auditory temporal information. As a result, auditory temporal processing is inevitable in children with dyslexia. In similar line, Singh & Kumar in 2012 assessed the performance of children with dyslexia and typically developing children on gap detection test. Results showed that children with dyslexia exhibited reduced score in gap detection test compared to children without problem.

Another test which was done in the present study was frequency discrimination test, which shows a statistically significant difference in both the groups. There are studies which show that children with dyslexia produce an abnormal neurophysiologic response to various non-speech auditory stimuli (Baldeweg et al., 1999; Mcanally & Stein, 1996; Nagarajan et al., 1999). In similar line, studies done by several researchers reported poor frequency discrimination in children with (Ahissar, Protopapas, Reid, & Merzenich, 2000; Maciejewska et al., 2013). There are contradictory findings by Hill, Bailey, Griffiths, & Snowling, 1999 which showed no significant difference in frequency discrimination in children with dyslexia and typically developing children. The possible reason of not getting significant difference can be related to poor auditory working memory in the children with dyslexia as reported. All the previous studies used two intervals same different paradigms to assess frequency discrimination except Hill et al (1999). Instead, they utilized a four interval forced choice (4IFC) procedure. In the first and the fourth interval of each trail their subject heard two stimuli known to be identical. The subject had to indicate whether the second or the third interval contained a stimulus that differed from the initial and final sound. In two alternating choices, however the subject does not get the repeated exposure of the known stimulus. So to remove the effect of familiarity of the stimulus in frequency discrimination in the present study two alternating force choice AXB procedure was used along with to check the effect of auditory working memory digit span test was carried out.

In the present study the digit span test showed there was a significant difference between children with dyslexia and typically developing children. There are studies which support the findings (Cohen-Mimran & Sapir, 2007; De Jong & Van Joolingen, 1998; Plaza et al., 2001; Siegel & Ryan, 1989). Studies have shown that deficits in auditory working memory are a common feature of dyslexia including specific language impairment, attention deficit hyperactivity disorder, reading and mathematical difficulties (Archibald & Gathercole, 2007; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Holmes, 2012; Jeffries & Everatt, 2004; L. Swanson & Kim, 2007). Poor digit span can also occur in the absence of any diagnosed disorder and represent a significant risk factor for poor educational progress (Gathercole & Alloway, 2008). The Present study involved set of test to assess temporal resolution and auditory working memory to rule out the discrepancy in the results due to poor educational progress. To conclude, though the children with dyslexia have significant deficits in auditory temporal processing tasks as revealed by the previous studies, these findings may not be evident in all the measures of auditory temporal processing. Dyslexia can be associated with other disorder like (C) APD, cognitive deficit, ADHD. The performance is quite variable for auditory tests.

3. Correlation between P300, tests of temporal processing and auditory working memory.

The present study was carried out to check if any possible correlation between P300 (Latency and amplitude), tests of temporal processing and auditory working memory exists or not. The study showed there was a positive correlation between GDT and FDT, with P300 latency at different site of recordings. This suggests that the latency of P300 was prolonged when there was an increase in scores of gap detection test and frequency discrimination test and vice-versa. Similarly for the digit span test, there was a significant negative correlation for Cz and Pz position. The negative correlation between P300 latency and digit span test suggest that digit span score was less (poorer) when P300 latency was prolonged.

The present study also showed a strong correlation between GDT and FDT with P300 amplitude at Cz and Pz position. This suggests that the amplitude of P300 was lesser when there was an increase in scores of gap detection test and frequency discrimination test and vice-versa. Similarly for the digit span test, there was a significant positive correlation for Fz and Cz position. The positive correlation between P300 amplitude and digit span test suggests that digit span score was higher (better) when P300 amplitude was more (better). Study done by Krishnamurti in 2001 suggests electrophysiological measures using non-linguistic stimuli can be useful for the evaluation of CAPDs and can be correlated with behavioral tests. In similar line, Study done by Litovsky & Shinn-Cunningham in 2001 supports the study where they found positive correlation between just noticeable difference (JND) and cortical potentials. The study contradicts the findings of Oliveira, Murphy and Schochat in 2013 where they reported that children with dyslexia have present temporal auditory processing and figure-ground alterations, which was evidenced by behavioral auditory processing tests but there was no difference between the performances of both groups for the P300 measures. The possible reason can be the unequal selection of participants in control and experimental group.

To conclude the behavioral tests have been widely accepted to be the test of choice; however processing deficit may be co-morbid with a number of pathologies that prevent the administration of behavioral tests. Hence, an attempt was made to check the equivalency of electrophysiological tests like P300 in the evaluation of children's with dyslexia. An attempt was also needed to find the responses obtained from central auditory function tests (Gap detection test, and pitch discrimination test), working memory (auditory digit span) and electrophysiological test (P300) are related or independent in children with dyslexia. The findings of the study suggest electrophysiological tests like P300 and behavioral tests both are important for the diagnosis of children with dyslexia. The combination of both electrophysiological and behavioral measures of temporal processing and auditory working memory will help in early detection and intervention of auditory based processing deficit in children with dyslexia.

Chapter 6

Summary and Conclusion

The present study was taken up with an objective to see the relationship between P300, temporal processing and auditory working memory in children with dyslexia. Since P300 reflects mainly the thalamus and the cortex activity; these structures involve sound discrimination, integration and attention. It could be expected to have a correlation between P300, Gap detection test, frequency discrimination test and digit span test. However there are limited number of literature which has shown relationship between higher cognitive potential like P300 and behavioral tests of temporal processing and auditory working memory.

The present study was undertaken to accomplish the following aims:

- To compare the performance of children with dyslexia and typically developing children in behavioral tests of temporal processing (Gap detection test, and frequency discrimination test).
- To compare the performance of children with dyslexia and typically developing children in auditory working memory (auditory digit span).
- To compare the P300 responses in children with dyslexia and typically developing children.
- To investigate the relationship between P300 responses, auditory working memory and behavioral tests of temporal processing in children with dyslexia.

To accomplish the following aims, 17 children with dyslexia and 17 typically developing children in the age range of 8-12 years were included in the study.

The results of the study were as follows:

A. Latency and amplitude measures of P300

- P300 was traceable in 16 (94%) children at Cz position, 14 (82 %) children at Pz position and 13 (76.5%) children at Fz position in typically developing children. However in clinical group, out of 17 children with dyslexia, P300 was traceable only in 9 (58%) children at Cz, Pz and Fz position each.
- The latency of P300 was prolonged in children with dyslexia compared to TDC but it was not statistically significant.
- There was a significant difference in amplitude of P300 at all positions (Fz, Cz and Pz) between children with dyslexia and typically developing children.

B. Tests of temporal processing and working memory

- Mean gap detection threshold was 4.07 ms in typically developing children, whereas in dyslexic children the mean gap detection threshold was 8.71 ms.
- Mean frequency discrimination scores in typically developing children were 28.95 Hz and in children with dyslexia it was 43.18 Hz.
- Mean score in digit span test was 6.47 in typically developing children and 5.53 in children with dyslexia.
- GDT, FDT and auditory digit span scores were statistically significant between two groups.

Results of behavioral tests depicted that children with dyslexia have poor performance on auditory temporal processing and auditory working memory.

C. Relationship between P300 (Latency and amplitude), tests of temporal processing and auditory working memory.

- Statistically significant positive correlation was found between P300 latency and tests of auditory temporal processing (GDT & FDT).
- Statistically significant negative correlation was found between P300 latency and digit span test.
- Statistically significant negative correlation was found between P300 amplitudes and gap detection test.
- A significant negative correlation was found for amplitude of P300 and frequency discrimination test.
- A significant positive correlation was noticed for digit span and amplitude of P300.
- The Results of these findings revealed that, there is a relationship between P300, test of temporal processing and auditory working memory. However, this relationship may not be present in all the children with dyslexia. There can be a chance factor where children with dyslexia perform better in behavioral tests.

Implication of the Study

- This study might be helpful in better understanding of the etiology of dyslexia, better assessment and rehabilitation of the disorder.
- The findings of this study may reinforce the need for the test battery approach in assessing dyslexia.

- May be helpful in allocating children with dyslexia into deficit specific categories of CAPD.
- Electrophysiological measures possess relatively appreciable sensitivity to tap the desired processes.
- Adds on to the literature

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