PROJECT REPORT

SUB TYPING OF DYSLEXIA: APPLICATION OF AN ERP MEASURE

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Principal Investigators

Ms. Mamatha. N.M. Mamta
Lecturer in Audiology
Department of Audiology

Dr. Jayashree. C. Shanbal
Lecturer in Language Pathology
Department of Speech-Language Pathology

Co-Investigator

Mr. R. Gopi Sankar
Research Officer,
Department of Clinical Services

Research Officers

Ms. Dhatri. S. Devaraju
Department of Audiology

Ms. Vrinda. R
Department of Speech-Language Pathology

All India Institute of Speech and Hearing
Manasagangothri, Mysore-570006

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CHAPTER 1: INTRODUCTION

Dyslexia is a developmental disorder of reading that occurs in persons with otherwise normal intelligence, sensory acuity and general motivation (World Health Organization, 1993). Approximately 5–18% of the population is affected by dyslexia (Shaywitz, 1998; Snowling, 2000). Dyslexia can be defined as an unexpected difficulty in learning to read and the other associated problems include difficulties with writing, spelling, motor co-ordination and attentional abilities, which vary across individuals.

The National Institute of Neurological Disorders and Stroke gives the following definition for dyslexia: "Dyslexia is a brain-based type of learning disability that specifically impairs a person's ability to read. These individuals typically read at levels significantly lower than expected despite having normal intelligence. Although the disorder varies from person to person, common characteristics among people with dyslexia are difficulty with spelling, phonological processing (the manipulation of sounds), and/or rapid visual-verbal responding. In adults, dyslexia usually occurs after a brain injury or in the context of dementia. It can also be inherited in some families and so on, and recent studies have identified a number of genes that may predispose an individual to developing dyslexia".

There are a number of theories on the potential causes of dyslexia. The phonological theory (Liberman, 1973 & Snowling, 2000) is the most influential account for reading problems in dyslexics which says children with dyslexia have a specific impairment in the representation, storage and/or retrieval of speech sounds, i.e. a deficit with phonological awareness. In contrast, the auditory processing deficit theory (Tallal, 1980; Tallal, Miller, & Fitch, 1993) assumes that dyslexics have a deficit in rapid auditory processing and because of that no adequate phonological representations can be built, resulting in additional phonological impairments. Thus according to this theory, phonological problems are only secondary to the auditory deficits. Some researchers view dyslexia as a deficit arising from the impairment of the visual magnocellular system of the brain leading to deficiencies in visual processing (Lovegrove, Bowling, Badcock, &

Blackwood, 1980; Livingstone, Rosen, Drislane, & Galaburda, 1991; Stein and Walsh, 1997) such as blurred visual representations and thus giving rise to difficulties with the processing of letters and words on text. The visual theory does not exclude a phonological deficit, but emphasizes a visual contribution to reading problems, at least in some dyslexic individuals. Finally the cerebellar theory states that a mildly dysfunctional cerebellum can cause dyslexia (Nicolson and Fawcett, 1990; Nicolson et al., 2001). The cerebellum contributes to motor control during the articulation of speech and also to the automatization of learnt behaviors. This can cause articulation problems that can lead to deficient phonological representations or a weak capacity to automatize would affect many things including the learning of grapheme-phoneme correspondences. Evidences for poor performance of dyslexics in a large number of motor tasks support the cerebellar theory (Fawcett et al., 1996). All these theories have one thing in common; children with dyslexia have deficient phonological processing which can be a direct or indirect consequence of the cause leading to these reading problems in dyslexics. The phonological processing problems include, but are not limited to difficulties in pronouncing nonsense words, poor phonemic awareness, problems in representing phonological information in short-term memory and difficulty in rapidly retrieving the names of familiar objects, digits and letters, etc. (Stanovich, 1988; Wagner & Torgesen, 1987; Wolf & Bowers, 1999).

So it is understood that there is a causal connection between children's phonological skills and their acquisition of reading and spelling. Data from both normally developing and atypically developing children demonstrates that the quality of a child's phonological representations is important for their subsequent progress in literacy. This relationship has been found across all languages so far studied, for both normal readers (Bradley & Bryant, 1983; Hoien et al., 1995; Siok & Fletcher, 2001), and children with dyslexia (Bradley & Bryant, 1983; Bruck, 1992; Landerl, Wimmer, & Frith, 1997; Porpodas, 1999). However, the focus on understanding whether these deficits are at a perceptual level, awareness level or cognitive level has been attempted through offline behavioral tasks such as metaphonological or phonological awareness tasks.

Studies in the literature have used different methods such as lexical gating, priming, syllable similarity tasks etc to investigate implicit phonological representations in typically developing individuals as well as in reading-impaired populations. The lexical decision task is one of the most popular tasks to study word processing, both in the auditory and the visual modality. In majority of the studies reported in the literature, data collected from the normal subjects is compared with the atypically developing children, and had found that the second group performed poorly compared to the first group(Taroyan & Nicolson, 2009; Pizzioli & Schelstraete; 2007).These behavioral tasks revealed only the end performance of subjects; however an understanding of the complex neuro-cognitive processes involved in language processing would be difficult through such offline behavioral tasks. It is important that an assessment of phonological processing is done at an explicit as well as implicit level in order to understand the relative difficulty of a child with dyslexia at various levels such as lexical access, decoding, phonemic categorization and awareness. However, not all dyslexics suffer from deficits in all cognitive domains or profit equally from all remediation techniques. (Ramus, 2003). So it is possible that distinguishable pheno types of dyslexia exist. Untying different subtypes of dyslexia would be an essential perquisite for developing or applying specifically targeted and thus more specific remediation strategies (Russeler, 2006). But it is difficult to isolate distinguishing features that would categorize dyslexia as a single condition.

An explicit and implicit level of understanding will facilitate in identifying various subtypes of dyslexia and/or atleast phonological v/s non-phonological subtype of dyslexia. It is also important that the subtypes of dyslexia are tapped in order to facilitate intervention in a specific direction. There are attempts made at identifying the subtypes of dyslexia using behavioral methods using accuracy and reaction time measures (Gnanvel & Shanbal, 2009; Landerl, Wimmer & Firth, 1997; Rack, Snowling & Olson, 1992; Shanbal & Prema, 2007). Some of these measures were successful at identifying the subtypes, however the others were not. These inconsistent behavioral findings might be due to the limitations of using response times in isolation when investigating cognitive processes that necessarily invoke parallel and overlapping stages. This may be due to the fact that some aspects of semantic processing may not be easy to capture with discrete measures such as response time or accuracy.

In contrast, the event-related brain potential (ERP) methodology have been found successful in providing data that reflects processing at each millisecond from the onset of language stimuli, and multiple, differentiable cognitive operations. But there is a lack of thorough understanding of the complex neuro-cognitive processes involved in linguistic skills development due in part of a lack of adequate methodologies for exploring online, real-time language processing in the brain (Osterhout & Holcomb, 1995). The electrophysiological recording of event-related potentials (ERPs) of the brain is one of the few methods which are well suited for the investigation of real-time language processing in the brain. Previous electrophysiological studies have described many ERP components associated with different stages of lexical processing such as the N400 (Carreiras, Perea, & Grainger, 1997; Grainger & Jacobs, 1996; Holcomb, Grainger& O'Rourke, 2002; Kutas & Van Petten, 1994; Sears et al., 1995). N400 is an ERP that is associated with language processing. The N400 typically is the most negative peak which occurs at approximately 400 ms post-stimulus (Kutas & Hillyard, 1980a, 1980b, 1980c, 1984; McPherson & Ballachanda, 2000). The N400 can be elicited in response to semantic errors for both visual and auditory stimuli (Bessen, Faita, Czternasty, & Kutas, 1997; Kutas & Hillyard, 1980a, 1980b, 1980c, 1983, 1984; Federmeier et al., 2002, Swaab et al., 2003). Osterhout and Holcomb (1993) also found that grammatically incorrect sentences elicited larger N400 responses as compared to grammatically correct sentences. Polich (1985) investigated using different set of stimulus such as a series of words that were interspersed with occasional semantically inappropriate word and obtained N400 in both selective and active attention.

The N400 component has been elicited for both visual and auditory modalities (Holcomb & Neville, 1990; McCallum, Farmer, & Pocock, 1984). One difference that is noted in response for auditory versus visual stimuli is an earlier and more prolonged effect of the N400 for auditory presentation, slightly lateralized to the right hemisphere (Holcomb & Neville, 1990). However, there are very few studies investigating the N400 effects using only the auditory stimuli, especially how each word with and without meaning elicit N400 in school going children. The studies conducted by Connolly, Byrne, and Dywan (1995) and Byrne, Dywan, and Connolly (1995a, 1995b) indicated that the N400 could be elicited by semantic errors in both child and adult participants. However, there are fewer studies done on school aged children reporting N400 (Byrne et al., 1999; McCleery et al., 2010).

Studies discussed earlier have indicated that the reading disorder in children with dyslexia is because of the phonological and/or semantic impairment seen in them. There are very few studies done on N400 in children with dyslexia investigating phonological and/ or semantic impairment (Bonte & Blomert, 2004; Russeler, Becker, Johannes, & Munte, 2007). They report of abnormalities in the N400 responses in children with dyslexia and also in adults with dyslexia. In a sentence reading experiment to study the effect of semantic priming, the children with dyslexia demonstrated less negative N400 component for incongruent endings which was parieto-centrally distributed (Brandeis, Vitacco, & Steinhausen, 1994). They reported that later segment of the N400 was delayed in children with dyslexia. In contrast, studies have reported normal N400 priming effects in both children and adults with reading disorders (Silva-Pereyra et al., 2003; Russeler, Probst, Johannes, & Munte, 2003). A recent study by Schulz et al. (2008) using both fMRI and ERP demonstrated group differences between children with dyslexia and control children. A reduced N400 effect for incongruent sentence endings but not for the congruent sentence endings was found in children with dyslexia compared to control children. However, this difference was not mirrored in the behavioral results as the children with dyslexia demonstrated greater errors both in congruent and incongruent sentence endings. Friedrich and Friederici (2006) observed that the N400 component in 19 months old children elicited by semantically congruent/ incongruent stimuli could discriminate the children who showed poor expressive language skills at a later age i.e., at 30 months from the children who had age-adequate expressive language skills. These results suggest that the N400 response compared to behavioral scores could serve as a sensitive index of lexical and semantic processing deficits.

Though the N400 is associated with semantic processing, it has been shown that it is modulated by phonological factors. A deviant attenuated phonological priming N400 effect was noticed when word pairs which rhyme were visually presented in adolescents with dyslexia (Ackerman, Dykman, & Oglesby, 1994). McPherson, Ackerman, Holcomb, and Dykman (1998) and McPherson and Ackerman (1999) also reported abnormal phonological N400 effects in response to both auditory rhyming and auditory alliteration in adolescents with dyslexia. They found that these deficits varied as a function of the subtype of reading disability. They divided the reading disabled population into two groups based on their scores on visual non-word decoding task (McPherson et al., 1998) and an auditory phonological task (McPherson & Ackerman, 1999). The results in their study revealed that phonetic dyslexics showed a normal N400 priming effect for auditorily presented words, but dysphonetic dyslexics did not. The difficulties with phonological awareness tasks in dyslexics might be reflected in the deviant phonological N400 effects in them. However, N400 priming effects in children with dyslexia were found comparable to those seen in normal readers while studying implicit phonological processing (two-word alliteration priming) during spoken word recognition (lexical decision task) (Bonte & Blomert, 2004). As most of the previous studies use more complex stimuli such as sentences, series of words or with a prime, it is difficult to study how the semantic and phonological processes act separately. There are not any studies using ERPs investigating how implicit phonological processing is taking place during recognition of isolated words without a prime. Also, none of the previous studies have put an effort in sub typing the dyslexics using ERP measures.

It is important that an assessment of phonological processing is done at an explicit as well as implicit level in order to understand the relative difficulty of a child at various levels such as lexical access, decoding, phonemic categorization and awareness. The difficulties at various levels are sparsely studied in children with dyslexia. The semantic and phonological processing in children with dyslexia can be well understood using isolated words. As it has been discussed that N400 measure serve as a sensitive index to study semantic processing in dyslexics, this N400 measure can be effectively used to classify the children with dyslexia based, which may in turn help us better understand the semantic or phonological deficits in them. Hence the present study investigated the event-related potential (ERP) correlates of implicit phonological processing during the recognition of spoken words in typically developing children and children with dyslexia. The present study further has sub typed the dyslexic group using ERP measure.

Aim of the Study

The aim of the present study was to compare the behavioural correlates with event-related potential (ERP) correlates of implicit phonological processing during the recognition of spoken words in children with dyslexia and normally reading children and thus an attempt to subtype the dyslexia.

Specific Objectives

- ☛ To investigate the behavioral correlates (reaction time (RT) and accuracy) of implicit phonological processing during the recognition of spoken words (words & non words) in 30 typically developing children and 15 children with dyslexia in the age range of 8-10 years.
- ☛ To investigate the event-related potential (ERP) correlates (N400 measures) of implicit phonological processing during the recognition of spoken words (words & non words) in 30 typically developing children and 15 children with dyslexia in the age range of 8-10 years.
- ☛ To compare the performances of typically developing children and children with dyslexia on behaviors measures (including RT & accuracy) and N400 measures (including amplitude & latency).
- ☛ To investigate the subtypes of dyslexia using both behavioral and N400 measures.

CHAPTER 2: REVIEW OF LITERATURE

Children with developmental dyslexia are usually characterized by unexpected problems in learning to read for children of average or above average intelligence. Reading disability, or dyslexia, is the most common learning disability. It is defined as an unexpected difficulty in learning to read and is considered as a complex disorder with a prevalence of 5–10% in school age children (Shaywitz et al., 1990). It is a language-based learning disability that is characterized by problems with decoding, fluent word recognition, rapid automatic naming, and/or reading-comprehension skills. These difficulties typically result from a deficit in the phonologic component of language that makes it difficult to use the alphabetic code to decode the written word (Handler & Fierson , 2011).

The World Federation of Neurology defines developmental dyslexia as a “learning disability which initially shows itself by difficulty in learning to read and later by erratic spelling and lack of facility in manipulating written as opposed to spoken words. The condition is cognitive in essence and usually genetically determined. It is not due to intellectual adequacy, or to lack of socio-cultural opportunity, or to emotional factors, or to any known structural brain defect. It probably represents a specific maturational defect, which tends to lessen as child gets older and is capable of considerable improvement, especially when appropriate remedial help is afforded at the earliest opportunity” (Cited in Critchley, 1978).

The National Institute of Neurological Disorders and Stroke, (2010) defined “dyslexia as a brain-based type of learning disability that specifically impairs a person's ability to read. These individuals typically read at levels significantly lower than expected despite having normal intelligence. Although the disorder varies from person to person, common characteristics among people with dyslexia are difficulty with spelling, phonological processing (the manipulation of sounds), and/or rapid visual-verbal responding. In adults, dyslexia usually occurs after a brain injury or in the context of dementia. It can also be inherited in some families and so on, and recent studies have identified a number of genes that may predispose an individual to developing dyslexia".

In order to understand dyslexia in better terms and delineate a few of its possible causes various theories were proposed. These theories have been explained in the sections below.

2.1. Theories on developmental dyslexia

According to World Health Organization (1993) dyslexia is a developmental disorder of reading that occurs in persons with otherwise normal intelligence, sensory acuity and general motivation. Approximately 5–18% of the population is found affected by dyslexia (Shaywitz, 1998; Snowling, 2000). Individuals with dyslexia often have associated problems with spelling, writing, motor co-ordination and attentional abilities, which vary across individuals, making it difficult to specify the etiology (Habib, 2000; Snowling, 2001). Numerous theoretical approaches have identified different potential causes for dyslexia. Dyslexia is conceptualized as either a phonological, attentional, auditory, magnocellular or automatisation deficit by different theories.

2.1.1. The Phonological theory

The role of phonology and awareness to the phonological structure of a lexical representation is important in learning to read. Failure to acquire that skill is very well represented in the literature on dyslexia. Children with developmental dyslexia have difficulty with tasks tapping phonological awareness, indicating that dyslexia is related to the phonological component of language (Bryant, 1995; Elbro, 1996; Rack, 1994). Phonological awareness and decoding can provide a self teaching mechanism that can lead to and support accurate recognition of printed words. The mechanism is particularly important when children encounter unfamiliar words in independent reading (Jorm & Share, 1983; Share, 1995). The phonological theory (Liberman, 1973; Snowling, 2000) is the most influential account for reading problems in children with dyslexia.

According to phonological theory, children with dyslexia have a specific impairment in the representation, storage and/or retrieval of speech sounds. It relates dyslexia to a deficit in phonological awareness, i.e. the ability to segregate and manipulate the speech sounds which form a word (e.g., deleting the first sound from the word “pant” gives “ant”). It explains reading difficulties showed by the children with dyslexia as a break down in developing the correspondence between letters and constituent sounds of speech i.e. grapheme-phoneme correspondence. If the sounds are poorly represented, stored or retrieved, the learning of grapheme-phoneme correspondences will be affected which will affect the learning of alphabet system (Bradley & Bryant, 1978; Brady & Shankweiler, 1991; Snowling, 1981; Vellutino, 1979).

Poor verbal short term memory and slow automatic naming also points to a basic phonological deficit (Snowling, 2001). Phonological Short-term Memory (PSM) is assumed to form sound-based representations of written symbols being stored transiently in the left posterior parietal cortex of brain. Efficient phonetic recoding in Broca's area of brain appears to be an important tool for the early reader. At the neurological level, functional brain imaging studies (Pugh et al., 2000, Shaywitz et al., 2002) and anatomical work (Galaburda, Sherman, Rosen, Aboitiz & Geschwind , 1985) suggest that a congenital dysfunction of the left perisylvian brain areas forms the basis of the phonological deficit.

Converging lines of evidence suggests that children with dyslexia can be characterized by one of several phenotypic manifestations of a phonological deficit (e.g., phonological awareness, Phonological Short-term Memory (PSM), phonological re/de-coding [i.e., Rapid Automatized Naming (RAN)]) (Brady & Shankweiler, 1991; Rack, Snowling & Olson, 1992). Although the phonological awareness and RAN deficits have been presented here separately, the researchers now agree these deficits in dyslexia are part of a more general double deficit theory (Wolf & Bowers, 1999; Wolf, Bowers & Biddle, 2000).

2.1.2. The double deficit hypothesis

Some children may have difficulties in developing sufficiently rapid processing rates for reading and reading comprehension. Processes which underlie naming speed are largely independent of phonological processes and they represent a second core deficit in dyslexia. Wolf et al. (2000) had suggested that deficits in phonological awareness and

RAN reflected a general impairment in automatizing low-level sub processes which is involved in reading. This suggests new sub-types that can be characterized by the presence, absence, or combination of the two core deficits in phonology and naming speed: the children with dyslexia having phonological-deficit, impaired word-identification accuracy (poor phonological awareness); the individuals with rate-deficit, exhibiting slowly word decoding profile and the double deficit reader, showing a general dysfunction on all decoding measures (Wolf et al., 1999). They also suggested that the presence of deficits in both phonological processing and RAN had an additive negative influence on reading performance above and beyond that of a single deficit.

Wolf et al. (2000) reported that the relationship of speeded naming to reading is dependent upon the subject's age and stimulus type. Semrud-Clikeman, Guy, Griffin and Hynd (2000) found that children with reading disability (RD) were found to be slower on letter- and number-naming tasks and made more errors on all tasks than controls. There was an age effect for the RAN/RAS tasks. Younger children with RD performed more poorly on all tasks, while the older children with RD showed poorer performance only on the letter- and number-naming tasks.

2.1.3. The Auditory processing deficit theory

The auditory processing deficit theory assumes that children with dyslexia have a deficit in rapid auditory processing. Auditory sensory deficits are proposed to cause impaired speech perception. There are evidences that children with dyslexia categorize speech stimuli less well than normal readers (Godfrey, Syrdal-Lasky, Millay & Knox, 1981; Steffens, Eilers, Gross-Glenn & Jallad, 1992; Werker & Teas, 1987) and also their physiological responses to speech stimuli are different compared to those of control listeners (Schulte-Ko¨rne, Deimel, Bartling & Remschmidt, 1998). Such speech perception deficits may lead to deficits in the ability to manipulate and process speech sounds or phonemic awareness deficits which can lead to difficulties in learning letter–sound correspondences during the process of reading development (Bradley & Bryant, 1983; Liberman & Shankweiler, 1985).

It is argued that no adequate phonological representations can be built due to this basic deficit, resulting in additional phonological impairments. Thus, according to this theory, phonological problems are only secondary to the auditory deficits i.e. the deficit lies in the perception of short or rapidly varying acoustic sounds (Tallal, 1980; Tallal, Miller, & Fitch, 1993). Support for this arises from evidence that children with dyslexia show poor performance on a number of auditory tasks, including frequency discrimination (McAnally & Stein, 1996; Ahissar, Protopapas, Reid & Merzenich, 2000) and also temporal order judgment (Nagarajan, Mahncke, Salz, Tallal, Roberts, & Merzenich, 1999; Tallal, 1980). The failure to correctly represent short sounds and fast transitions as in /ba/ versus /da/ phonetic contrast would cause difficulties. Evidences are also there that children with dyslexia may have poorer categorical perception of certain sound contrasts (Adlard & Hazan, 1998; Mody et al., 1997; Serniclaes, Sprenger-Charolles, Carre & DeÂmonet, 2001). Literature has suggested that phonological problems in dyslexia are often due to a more fundamental deficit in auditory temporal processing mechanisms (Tallal, 1980). It was also reported that children with dyslexia showed impaired discrimination and sequencing brief and rapid acoustic stimuli when compared normal peers (Tallal, 1980; Tallal,Miller & Fitch, 1993). Further basic perceptual deficits could result in a host of deficits which include disruption in terms of development of the phonological system. This disruption could lead to problems in reading and spelling (Nagarajan et al., 1999; Wright et al., 1997).

Some evidence has also been reported for auditory sensory processing deficits in dyslexia. McCroskey and Kidder (1980) used gap detection task and found that reading-disabled children needed longer inter-stimulus intervals to separate two sounds than did normal readers. Children with dyslexia have also been found to be less sensitive to changes in amplitude than normal readers (McAnally *et al*, 1997; Menell, McAnally, & Stein, 1999) and frequency (McAnally et al, 1996; Witton, Talcott, Hansen, Richardson, Griffiths, Rees, Stein, & Green, 1998) of acoustic stimuli. Tallal (1980) has reported that children with dyslexia are impaired relative to younger normal readers in determining whether two tones presented in rapid succession are the same or different. So the researchers concluded that, the auditory deficit is therefore the direct cause, in the course of development, of the phonological deficit in children with dyslexia.

2.1.4. The visual theory

For a long time it was assumed that dyslexia was not related to any deficiencies in visual functioning, but a problem with phonological deficit. In spite of this widespread belief, some researchers conceptualize dyslexia as a visual processing deficit (Livingstone, Rosen, Drislane & Galaburda, 1991; Lovegrove, Bowling, Badcock & Blackwood, 1980; Stein & Walsh, 1997) arising from the impairment of the visual magnocellular system in the brain. These studies demonstrated the presence of a variety of visual deficits among children with dyslexia giving rise to difficulties with the processing of printed text. This can take many forms such as unstable binocular fixations, poor vergence (Cornelissen, Munro, Fowler, & Stein, 1993; Stein & Fowler, 1993; Eden, Stein, Wood & Wood, 1994), or increased visual crowding (Spinelli, De Luca, Judica & Zoccolotti, 2002). This led to the development of training programs for visual-perceptual and/or visual-motor disabilities.

The visual theory does not exclude a phonological deficit, but emphasizes a visual contribution to reading problems, at least in some children with dyslexia. The basis of magnocellular-deficit theory is the observation that the visual pathway leading from the eyes to the visual cortex consists of two parallel systems: the magnocellular and the parvocellular systems. The prevailing theory of dyslexia is that the magnocellular system of dyslexic readers has reduced sensitivity.

The magnocellular-deficit theory assumes that the inhibition of the parvocellular system by the magnocellular system is selectively disrupted in certain dyslexic individuals, leading to deficiencies in visual processing, and, via the posterior parietal cortex, to abnormal binocular control and visuospatial attention (Hari, Renvall & Tanskanen, 2001; Stein et al., 1997). Evidence for magnocellular dysfunction comes from anatomical studies, psychophysical studies and brain imaging studies (Eden et al., 1996). There are anatomical studies showing abnormalities of the magnocellular layers of the lateral geniculate nucleus (Livingstone et al., 1991) and also psychophysical studies showing decreased sensitivity in the magnocellular range in children with dyslexia (Cornelissen et al., 1995; Lovegrove et al., 1980).

2.1.5 The automaticity or cerebellar theory

The Cerebellar Theory states that a mildly dysfunctional cerebellum can cause dyslexia. (Nicolson & Fawcett, 1990; Nicolson, Fawcett & Dean, 2001) The cerebellum contributes to motor control during the articulation of speech. The Cerebellar theory proposes that articulation problems can lead to deficient phonological representations that can cause dyslexia. The cerebellum also contributes to the automatization of learnt behaviors, which includes tasks such as driving, typing and reading. A weak capacity to automatize would affect many things including the learning of grapheme-phoneme correspondences. Evidences for poor performance of individuals with dyslexia in a large number of motor tasks support the cerebellar theory (Fawcett & Nicolson, 1996). Dual tasks which demonstrate impaired automatization of balance (Nicolson et al, 1990), and a non-motor cerebellar task, in time estimation (Nicolson et al., 1994) are a few supporting the same. Brain imaging studies have also shown metabolic, anatomical and activation differences in the cerebellum of children with dyslexia (Brown, Eliez, Menon, Rumsey, White & Reiss, 2001; Leonard, Eckert, Lombardino, Oakland, Kranzler & Mohr, 2001; Nicolson, Fawcett, Berry, Jenkins, Dean & Brooks, 1999; Rae, Lee, Dixon, Blamire, Thompson & Styles, 1998)

Different theories conceptualize dyslexia as phonological, auditory, visual or cerebellar deficit. But not all children with dyslexia suffer from deficits in all these domains. Such heterogeneity suggests the possibility of existence of distinguishable subtypes of dyslexia

2.2. Subtypes of Dyslexia/ Classification of dyslexia in literature

It is difficult to isolate distinguishing features that would categorize dyslexia as a single condition. Since long, classification of dyslexia has always been a matter of concern for many researchers. There is a long history of poor readers being classified on the basis of individual differences in reading (Boder, 1970; Ingram, 1964). Ingram (1964) grouped poor readers into audio-phonetic dyslexics and visuo-spatial dyslexics. The audio-phonetic dyslexics have problems in sound discrimination and blending and are poor in phonological decoding. On the other hand, the visuo-spatial dyslexics have difficulties in visual discrimination and spatial skills and problems reading by the sight-word route.

Boder (1970, 1973) developed a diagnostic screening tool for developmental dyslexia from which she divided poor readers into three subtypes based on misreadings and/or misspellings. They are: the dysphonetic, dyseidetic, and alexic.

i. Dysphonetic- This is the largest of the three divisions which has a primary deficit in auditory analytic skills. These children have great difficulty learning and using the phonological route. They may show phonetically inaccurate misreadings and misspellings. For example, the dysphonetic reader might spell ‘scramble’ as ‘sleber’ or pronounce ‘block’ as ‘book’

ii. Dyseidetic- This subgroup have deficit in the visual route. Consequently, they have particular problems with exception words such as ‘have’, ‘colonel’, etc.

These words are misspelled or misread as phonetic renditions: for example, spelling ‘*laugh’* as/ laf/ or reading ‘*talc’* for ‘*talk’*.

iii. Alexic or mixed dyseidetic and dysphonetic- This sub type combines the deficit of the first two groups. i.e., they have a deficit in both phonetic and visual route. Children with this form of dyslexia are usually unable to read or spell. This subgroup is the most handicapped of the three groups.

Later for subtyping dyslexia, Boder and Jarrico (1982) developed a diagnostic screening test. Using this test, researchers have provided some evidence of behavioral and electrophysiological differences between subtypes of dyslexics (Dalby & Gibson, 1981; Flynn & Deering, 1989). For example Flynn et al (1989), using spectral analysis of electroencephalograms recorded during cognitive tasks found that dyseidetic children demonstrated greater EEG activity in the left temporal-parietal region than did dysphonetic children during reading which suggested they over-use the linguistic abilities. Also Dalby et al (1981) found that children with dyslexia whose difficulties were related to auditory-verbal processing deficits failed to develop normal left hemisphere specialization for processing of auditory-linguistic material. They suggested that this was evidence of different processing capabilities among these subgroups. However, others have failed to unearth reading-related differences between these subgroups of poor readers (Godfrey, Lasky, Millag, & Knox, 1981; van den Bos, 1988). Godfrey et al., (1981), for example, failed to find a benefit in speech perception abilities among dyseidetic dyslexics as compared to dysphonetic dyslexics. Such a disparity would be expected if dysphonetic dyslexics had a phonological processing problem.

Cognitive neuropsychologists have also considered subgroups similar to those projected by Boder (Coltheart, Patterson, & Marshall, 1980; Marshall & Newcombe, 1973). However, they used terminology and procedures borrowed from the study of acquired dyslexia. Acquired dyslexia was defined as a reading disability following neurological damage in previously literate individuals (Rosenhan & Seligman, 1989). Three types of disability are often identified: deep, phonological, and surface dyslexia. Individuals with deep and phonological dyslexia may have major difficulty in phonological decoding. They are identified primarily on the basis of their problems pronouncing non words such as *meaf* or *jope*. Such words cannot be recognized by the visual route. So sound-letter correspondence rules are used to sound out the word. Individuals with deep dyslexia, unlike those with phonological dyslexia, also make semantic errors in reading. For example, when asked to read a word like *sun*, they might say "*moon"*. Other symptoms such as visual errors (confusing words like *wife* and *life*), morphological errors (misreading prefixes or suffixes), and recognizing content words as opposed to function words are also found (Thomson, 1984). Individuals with surface dyslexia have difficulty in reading exception words with irregular spelling (e.g. Yacht as yatchet), but can read regular words which indicates that these individuals have problems with the visual route. Even though the terms phonological and surface dyslexia roughly correspond to dysphonetic and dyseidetic readers, the former terms have become more popular in recent years.

Individuals with developmental reading disabilities were subtyped as phonological or surface dyslexics by the cognitive neuropsychologists primarily using case studies (Coltheart, Materson, Byng, Prior, & Riddoch, 1983; Holmes, 1978;

Marshall, 1984; Rayner & Pollatsek, 1989; Temple & Marshall, 1983). For example, Temple and Marshall (1983) described a case of developmental phonological dyslexia. This student, a 17 old girl, had considerable difficulty reading non words compared to real words. Her responses to non words were typically real words that were visually similar to the target words. Marshall (1984) found that this developmental case was very similar to a case reported by Patterson (1982) with acquired phonological dyslexia. Coltheart et al (1983) and Holmes (1978) also identified a number of cases of developmental surface dyslexia. Holmes identified four boys, between the age of 9 and 13, who had great difficulty reading exception words. They made errors like regularizing words (eg. *bread* as "breed"). Coltheart et al (1983) also reported a 15-year-old girl with dyslexia who had problems with homophones. For example, she read "pane" correctly, but defined it as "something that hurts."

Gnanavel (2009) investigated the subtypes of children with developmental dyslexia (CWD) based on dual route cascaded model (DRC). He considered two groups of children from grades III to VI comprising of 40 age matched normal children and 16 CWD. Single isolation deficits were not observed, but multiple deficits were observed based on DRC model. Out of the 16 CWD, three were grouped into pure phonological dyslexics and all others formed a heterogeneous group i.e. mixed dyslexics. The occurrence of phonological subtype of dyslexia could be due to the fact that only the sublexical route was affected leading to poor performance on phonological task where as for mixed types both lexical and sublexical route was affected resulting in poor performance on both phonological and non-phonological tasks.

Kuppuraj (2009) identified heterogeneity among the children with dyslexia and attempted to subtype the children with dyslexia using dual route model. Out of the 16 participants, five fell under phonological subtype, one under surface subtype and 10 under mixed subtype. The phonological subtype was hypothesized to be occurring due to poor sublexical processing; the surface subtype was hypothesized to be occurring due to poor lexical processing and the mixed was hypothesized to be due to deficit in both lexical and sublexical route of the dual route processing for reading.

The categorization proposed by cognitive neuropsychologists may lead to the impression that poor readers can be divided into distinct and homogeneous subgroups based on word recognition deficits. Ellis (1985) argued that there may be heterogeneity among poor readers in terms of word recognition strengths and weaknesses. Hence, it was concluded that poor readers do not form distinct subgroups. According to him, word recognition abilities can be viewed in two dimensions- one corresponding to reading by the visual route and the other representing reading by the phonological route. He believed that readers' abilities are distributed continuously along each of these dimensions, where some readers may show similar abilities in these dimensions or abilities in one dimension that are significantly better than those in the other.

These abilities can be displayed on a scatter plot in which performance on exception word reading represents one axis and scores on nonword reading constitutes the other. Ellis noted that cognitive neuropsychologists assume that there will be "galaxies" of dyslexics within the scatter plot when plotted like this. That is phonological dyslexics is expected to represent a cluster of poor readers and the surface dyslexics to cluster together separated from each other by their distinct pattern of phonological decoding skills. The phonological dyslexics have poor phonological decoding skills and good exception word reading skills, while the surface dyslexics have good phonological decoding skills and poor exception word reading skills. Ellis argued that a more valid conceptualization of heterogeneity is one without clusters or galaxies. He suggested that children with dyslexia are more likely to be distributed continuously in this multidimensional space, such that "there will be a complete and unbroken gradation of intermediate dyslexics linking the extreme cases" (Ellis, 1985). In this model, Ellis argues that children with dyslexia do not fall into distinct categories in terms of their word recognition skills. Some children can be characterized as surface or phonological dyslexics, but these children will differ by the degree of impairment and not the type of impairment.

Later, Ellis et al (1996) tested this view of the heterogeneity of word recognition by examining a group of thirteen children with reading disability. These children were 9 to 11 years old, had normal or above normal IQs and a reading age eighteen or more months behind their chronological age. There were three control groups, each consisting of thirteen children matched for reading level to the dyslexic group. One group consisted of age matched poor readers with lower IQ scores as that of the children with reading disability. The second group contained younger children who were reading at a level predicted for their age and the third group was an even younger group of precocious readers, children who were reading well above their age. The participants read a list of non words and real words (half of which were exception words). A scatter plot of nonword reading abilities against sight-word reading abilities showed considerable variability among the children with dyslexia. However, among the dyslexic readers there was no evidence of clustering. Instead, the children with dyslexia were distributed continuously throughout the scatterplot. Similar heterogeneity was found in the three control groups also.

Murphy and Pollatsek (1994) examined the heterogeneity of word recognition abilities, in a large sample of children with reading disability. Sixty-five children with reading disability in the age range of 10 to 13 years of age, were administered a variety of measures designed to test children's ability to read by the visual or phonological routes using regular, exception, and non words. A lexical decision task and a homophone definition task were also used. Participant’s phonological awareness and word retrieval abilities were also tested. They failed to uncover distinct clusters of poor readers and found much heterogeneity between poor readers in word recognition abilities

Poor readers differed primarily in terms of the severity of deficits, and not in the kind of deficits. Most children with reading disability were poor at reading by both visual and phonological route. A moderate correlation was also found between nonword and exception word reading. If discrete subgroups had been present, such a correlation would have been negative, or at least absent. Nevertheless, there were some children with reading disability who did show dissociation between phonological decoding and sight-word reading. These children, however, were still part of the same continuum and did not cluster together into discrete subgroups. They noted that some children fitting the profile of phonological dyslexics performed less well on a phonological awareness task and better on a phonological retrieval task than did children who displayed a surface dyslexia profile. They also speculated that individual differences can be due to instructional factors.

These studies suggest that poor readers cannot be divided into homogeneous subgroups based on their word recognition abilities. Some poor readers do, however, display dissociation in their ability to use the phonological as opposed to the visual route. This may be associated to differences in cognitive processing or reading instruction/experience (Murphy et al, 1994). Dissociation among poor readers despite the absence of distinct and homogeneous clusters suggests that the classification of poor readers on the basis of word recognition abilities might have some clinical/educational validity.

A reliable procedure is necessary to differentiate children with phonological and surface dyslexia for a classification system based on word recognition. Castles and Coltheart (1993) investigated different ways to identify word recognition subtypes. They tested 53 children with dyslexia and 56 normal children matched for chronological age with measures of exception word and nonword reading. Initially, they divided the poor readers into "hard" subtypes (Stanovich, Siegel & Gottardo, 1997). According to this, children with dyslexia who performed badly in exception word reading, as compared to same age peers, but normally in nonword reading were defined as surface dyslexics. Phonological dyslexics were defined as those subjects who showed poor nonword reading, but normal exception word reading. These procedures led to the identification of only 8 phonological dyslexics and 10 surface dyslexics. These numbers were smaller than were expected on the basis of previous reports. Castles et al (1993) noted that many of the poor readers showed a relative difference between nonword and exception word reading. So the researchers projected a statistical procedure that would identify children who showed relative differences, but not necessarily deficits, in one or the other area of reading. These can be called "soft subtypes." This technique involved the use of regression analyses to subgroup children with reading disability into those with better nonword reading than would be predicted on the basis of exception word reading (i.e., surface dyslexic), or those with better exception word reading than would be predicted on the basis of nonword reading (i.e., phonological dyslexic). Using this approach, Castles and Coltheart (1993) identified 16 surface and 29 phonological dyslexics. Thus, most of their poor readers (45 out of 53) showed a relative dissociation between nonword and exception word reading. The researchers argued that although these poor readers did not represent hard cases of surface or phonological dyslexia, the apparent dissociation in word recognition profiles could have important implications for understanding and treating reading disabilities.

Castles et al (1993) used chronological-age-matched control group to evaluate poor readers relative strengths in nonword and exception word reading. But, Stanovich et al (1997) believed that age-related data may not be appropriate for evaluating the relative strengths of poor readers who are reading at a level well below that of chronological-age-matched children. They suggested that the comparison for poor readers with a younger group of normal children reading at the same overall level as the poor readers is more appropriate. For this, regression analyses based on both chronological-age-(CA) and reading-level-(RL) matched control groups was used to divide 68 third-grade children with reading disability into phonological and surface dyslexic subtypes. Researchers using regression-based predictions from CA-matched children, found that 22 percent of the sample were identified as surface dyslexics (i.e. performed better on non words than exception words), and 25 percent as phonological dyslexics (i.e., scored better on exception words than non words). When using regression based predictions based on RL-matched controls, again 25 percent of the children with reading disability were classified as phonological dyslexics and only one child was identified as a surface dyslexic. That is, surface dyslexia essentially disappeared when compared to RL-matched children. Similar findings have also been reported in literature (Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Manis, Seidenberg, Stallings, Joanisse, Bailey, Freedman, Curtin, & Keating, 1999).

The findings from these studies provide some insights into the nature of the reading problems of phonological and surface dyslexics. Children identified as surface dyslexics, when compared to CA controls, may best be characterized as showing a developmental lag. These children did not exhibit deviant reading abilities; rather, their reading of nonword and exception word was like that of younger normal children. These children appear to be taking longer than same-age peers to learn to read. Stanovich and colleagues (1997) suggested that these children may have a mild form of a phonological processing deficit. They further speculated that this deficit when combined with exceptionally inadequate reading experience could result in a surface dyslexic profile. In contrast to surface dyslexia, phonological dyslexia may constitute a true developmental disorder. Phonological dyslexics continued to show a distinctly different pattern of performance when compared to younger normal children. Furthermore, the phonological dyslexics, in contrast to the surface dyslexics, performed less well than the RL-matched children on tests of phonological awareness, working memory, and syntactic processing.

Further research suggests that poor readers may be subgrouped on the basis of word reading speed and accuracy. Lovett and her colleagues (Lovett, 1984, 1987; Lovett, Ransby, & Barron, 1988; Lovett, Ransby, Hardwick, & Johns, 1989) proposed two subtypes of reading disabilities: *accuracy-disabled* children & *rate-disabled* children. The former was defined as those with significant problems in decoding accuracy, while the later were those with a marked deficit in reading rate despite grade-appropriate decoding ability. A child had to score at least one and a half years below grade-level expectations on at least four of five different measures of word recognition to be classified as accuracy-disabled. For rate-disabled, a child had to perform close to, at, or above grade level on four or more measures of word recognition and at least one and half years below grade level on four of five measures of reading speed.

An attempt to validate the above subgroups was done by Lovett (1987). For this, he administered a battery of oral and written language tests to 32 accuracy-disabled, 32 rate-disabled, and 32 normal children who were matched for chronological age, sex, and IQ. The results established the distinctiveness of the three groups. The accuracy-disabled children made more errors, read more slowly, and showed poorer comprehension than the rate-disabled and normal children. Lovett (1987) concluded that, "these data suggest that accuracy-disabled children suffer a multidimensional language impairment coupled with specific sound analysis difficulties and a seemingly inability to automatize or consolidate single letter identities and/or names" (Lovett, 1987).

There was more impairment on the reading abilities of the rate-disabled sample. There were no differences in their identification of regular and exception words between these children and the normal readers. This suggests that the groups were equally adept at phonological decoding and sight-word reading. But these children exhibited significant impairments in word recognition speed. The rate-disabled and normal readers were similar with one exception in oral language abilities where they were significantly slower on tasks measuring rapid automatic naming. Aaron, Joshi, and Williams (1999) also investigated word-reading speed and accuracy in poor readers. They examined 139 children in third, fourth, and sixth grade on various measures of word recognition speed, accuracy and listening comprehension and identified 16 poor readers who performed more than one standard deviation below the mean in reading comprehension. However, Aaron and colleagues found that 2 poor readers had normal decoding and listening comprehension abilities but significant deficits in word-reading speed.

Lovett's later work (Lovett, Benson, & Olds, 1990) is consistent with issues concerning the heterogeneity of clustering. Rather than treating accuracy-disabled and rate-disabled poor readers as separate subgroups, she and her colleagues have begun to consider the dimensions that underlie these subgroups as continuous variables.

2.3. Auditory Word/ Non- word recognition

According to the research in auditory psychophysics a listener can accurately identify at least 15 phonemes per second. To accomplish this, the fluctuations in air-pressure must be converted into a representation in the auditory system to access stored representations of words that allows the listener to recognize the word. When the signal is heard, the listener attempts to map the acoustic signal onto a representation present in the brain. Some segmentation procedure is used to extract phonetic features from the continuous speech signal which is selected from the acoustic background. The recognition process which includes the retrieval of lexical information and the activation of lexical candidates will use this information. Activated lexical candidates provide access to their meaning and to syntactic information. This “lexical access” in turn leads to the interpretation of the heard utterance as it is integrated with the ongoing discourse. There is a strong consensus that during auditory comprehension, various lexical entries are activated, at least to some extent, as soon as the first features or phonemes of an incoming word are identified.

For instance, according to the cohort model (Marslen- Wilson, 1978) an incoming phoneme activates all lexical entries that begin with that phoneme (i.e. selecting the “word-initial cohort”). As more information comes in, the size of this cohort is progressively reduced, until eventually only one candidate remains. Competition among the different activated candidates during the selection process is inherent in this model.

The first clear evidence in favor of the cohort model was reported by Marslen-Wilson (1973) who found that fast shadowers were able to repeat tape-recorded speech passages well before the utterance ended i.e. with delays of less than 200 ms, and thus before sufficient sensory information was available for unambiguous word identification (Marslen-Wilson, 1987). Additional evidence comes from studies using the gating technique (Grosjean, 1980; Tyler & Wessels, 1985 & Goldinger, Luce, Pisoni & Marcario, 1992) wherein people are asked to guess what word they hear from speech presented in segments (e.g. 50 ms) of increasing duration, as well as from cross-modal priming experiments using word-initial, partial primes (Zwitserlood , 1989).

Taft and Hamply (1986) did a study for exploring the cohort model of spoken word recognition. In one of their experiment, the stimulus considered were pairs of non word where, one member of each pair was derived from the other member by adding two or three phonemes to the end (e.g., MEP & MEPSIG). The reaction time analysis showed that shorter non words were responded faster than longer non words. From this, it was apparent that there is processing beyond the point at which the nonword deviates from a word (recognition point).The existence of phonemes following the deviation point is shown to be relevant to response times. The tendency for more errors on the shorter nonwords can be explained by saying that subjects occasionally confused the nonwords with real words. This was more likely to happen with the shorter nonwords, since these had a greater proportion of phonemes in common with real words than did the longer nonwords.

There are many factors which influence the efficiency with which spoken words are recognized. Variables influencing include various lexical characteristics (length, frequency, spoken stress, neighbourhood characteristics, etc.), nonword characteristics (deviation point from real words, neighbourhood characteristics, magnitude of deviation from real words, etc.) and contextual characteristics such as semantic or form priming, etc. (Goldinger, 1996).

2.4. Behavioural studies

Phonology is defined as a lower-level structural aspect of language involving the sounds of a language and their organization in that language (Wilson, Tregellas , Slason, Pasko & Rojas, 2011). It is well known that there is a causal connection between children’s phonological skills and their acquisition of reading and spelling. Data from both normally developing and atypically developing children demonstrates that the quality of a child’s phonological representations is important for their subsequent progress in literacy. Evidence for a phonological impairment in dyslexia has been well documented. This relationship has been found across all languages so far studied, for both normal readers (Bradley & Bryant, 1983; Hoien et al, 1995; Siok & Fletcher, 2001) and children with dyslexia (Bradley & Bryant, 1983; Bruck, 1992; Landerl, Wimmer, & Frith, 1997; Porpodas, 1999). However, the focus on understanding whether these deficits are at a perceptual level, awareness level or cognitive level has been attempted through offline behavioral tasks such as metaphonological or phonological awareness tasks. Children with dyslexia show difficulty on tasks that depend on implicit phonological processing, such as discrete and rapid naming (Bowers & Swanson, 1991; Katz, 1986; Snowling, van Wagtendonk, & Stafford, 1988), tests of verbal short-term memory (Brady, Shankweiler, & Mann, 1983; Jorm, Share, Maclean, & Matthews, 1984) and nonword repetition (Snowling, 1981). Problems have also been demonstrated at an explicit level of phonological ability, such as phoneme awareness and segmentation (Manis et al., 1997; Swan & Goswami, 1997). Some studies have also reported speech perception deficits in children with dyslexia (Adlard & Hazan, 1998; Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Manis, McBride-Chang, Seidenberg, Keating, Doi, Munson, B & Peterson, 1997). These deficits are subtle and suggest a weakness in categorizing particular phonemes rather than a more general problem with speech perception (Brady, 1991)

The tasks used to assess phonological awareness (PA) are most often explicit or analytical in nature. It requires the conscious manipulation of the segments of a word. For example, when a word is given to a child to segment into its individual sounds, the child should know the phonemic components of a word and then to manipulate those components at a conscious level. On the other hand, implicit level of phonological awareness does not require conscious manipulation of segments, but requires a child to respond in a way consistent with the phonological rules of the language. The individual have to be sensitive to the phonetic cues of speech without having to demonstrate a phonemic representation that is required for explicit manipulation. For example, if a young child can distinguish that two words rhyme, but she cannot tell why the words rhyme, then it shows that she has demonstrated an implicit level of phonological awareness. Studies in the literature have used different methods such as lexical gating, priming, syllable similarity tasks etc to investigate implicit phonological representations in typically developing individuals as well as in reading-impaired populations. Since segmental knowledge is not required for the implicit level of phonological awareness, it will reflect a non segmental or holistic level of phonological awareness (Morais, 1991). As such, this implicit phonological level may provide a more accurate description of phonological knowledge rather than the task proficiency demonstrated by explicit tasks (Morais, 1991; Perfetti, 1985).

Real words are employed by many of the tasks which are used to assess phonological awareness to measure children's understanding of the sound system. However the results obtained through these procedures will be confounded by word knowledge (Mann & Liberman, 1984; Perfetti, Beck, Bell & Hughes, 1987). The influence of word knowledge on the skill under investigation can be restricted the use of nonsense words in the assessment of phonological awareness ability. Pseudoword reading is the golden standard for assessing the deficits of dyslexics' phonological reading route (Siegel, 1993). Nonsense words may not completely eliminate lexical knowledge from phonological awareness assessment. Even though nonsense words may be influenced by associated lexical knowledge, they remain an important tool for the assessment of phonological awareness (Perfetti et al., 1987; Read, Zhang, Nie, & Ding, 1986). There were many studies that have found dyslexic readers to be worse than reading-level-matched normal readers on measures of phonological reading skill (Manis et al., *19*96; Holligan & Johnston, 1988, Olson et al., 1989).

Several tasks were used to infer whether a deficit exists underneath that of phonological awareness, a weakness that does not invoke a meta-cognitive level of processing. Studies investigating the nature of speech perception in children with dyslexia have yielded inconsistent evidences. The differences in methodological approach, sampling issues across studies and theoretical considerations had hindered the interpretation of individual studies and generalization across studies.

Gallagher, Frith, and Snowling (2000) found that children at risk for dyslexia were significantly worse at nonword repetition when the task used non words with unusual weak–strong stress patterns. Overall, researchers have interpreted these results as supporting the hypothesis that the phonological processing of participants with dyslexia is at least inconsistent, if not delayed or disordered, for speech stimuli.

Lance, Swanson and Peterson (1997) attempted to validate an implicit phonological awareness task. The task was to identify which stimulus of a pair of nonsense words violated the rules of consonant combination in English. Participants had to choose the stimulus which sounded more like a real word from the pair (e.g., shrib–shkib). Results on this task were significantly correlated with results on explicit PA tasks, a multisyllabic word production task, and two reading outcome measures. Lance et al. (1997) commented that implicit-level tasks such as the one they used do not require segmental knowledge per se and thus may reflect a more holistic level of phonological awareness. The participants would have analyzed the characteristics of the stimuli as a whole and determined that certain acoustic combinations are not plausible or not part of a linguistic experience base.

The gating task does not depend on the ability to utilize phoneme-level segments to process spoken words. So it can be used to explore the overall integrity of phonological representations and/or phonological processing. It is appropriate for children and is potentially more sensitive to problems with phonological representations and processing. Typically in a gating task a listener is presented with successively longer portions of the word (gates) beginning with the onset. The listener is asked to guess the entire word at each gate. Intact and highly integrated phonological representations are required for this kind of task because subjects must use limited acoustic information to identify a word by comparing the acoustic information to many possible stored representations (Salasoo & Pisoni, 1985). Children require more acoustic information than adults (Metsala, 1997a) to identify highly familiar words.

Metsala (1997) using a lexical gating paradigm found that participants with dyslexia needed more of the speech input than did their normally achieving peers. Boada and Pennington (2006) measured implicit phonological representations in 11 to 13 year old reading-disabled children using measures such as lexical gating, priming, and syllable similarity tasks. Children with dyslexia performed consistently worse than CA and RA controls when more segmental representations were required across all three tasks. Results provided a strong support for less mature implicit phonological representations in children with dyslexia.

Rack, Snowling and Olson (1992) reviewed a number of studies on non word reading in developmental dyslexia in English. They found non- word reading deficits in children with dyslexia compared to reading level matched children. Error rates were high typically between 40% to 60%. Rack et al., (1992) noted that English studies which did not find a non word reading deficits in children with dyslexia in comparison with reading level match typically used young readers (7 years) as controls and used non words with relatively similar orthographic patterns. (e.g. loast- [toast]). They concluded that non – words with familiar non- word analogies (like –oast in loast) are not the best test of phoneme- grapheme recoding skills.

Landerl, Wimmer and Firth (1997) studied non word reading in 12 years old English dyslexic children and 8 years reading level matched controls and the non words were of 1, 2 and 3 syllables in length. The authors found that children with dyslexia performed poorer in non word reading than the reading level matched controls. These difficulties were found at all syllable length, both groups performed poorly with the difficult 3- syllable words. For these words dyslexic children performed about 30 % correct and reading level controls performed 40% correct.

In phonological dyslexia, non word reading shows a deficit while word reading remains intact (Cestnick & Coltheart, 1999; Southwood & Chatterjee, 2001). In another study, longer latency was found for naming multi-syllabic low frequency words and non words in French than naming their monosyllabic counterpart but no such effect is found in high frequency words (Ferrand, 2000). Considering the arguments from the two studies together, the lexicalization of high frequency words depends largely on the lexical route while that of low frequency words and non words depends largely on the sublexical route.

To study the word processing, the lexical decision task is one of the most popular tasks used in both the auditory and the visual modality. In auditory lexical decision task the participants are presented with spoken stimuli and they have to decide whether the stimuli form a word or not. In majority of the studies reported in the literature, data collected from the normal subjects is compared with the atypically developing children, and had found that the second group performed poorly compared to the first group.

Nicolson and Fawcett (1994) tested five groups of children, including two groups of children with dyslexia using simple reaction, selective choice reaction, and lexical decision tasks. In simple reaction task to a pure tone, the dyslexic children reacted as quickly as their chronological age controls and significantly faster than their reading age controls. In selective choice reaction task, the dyslexic children were significantly impaired compared with their chronological age controls and no faster than their reading age controls. The lexical decision data indicated speed impairment; with the dyslexic groups responding significantly slower compared even with their reading age controls. The results suggest that at least two factors may contribute to slowness of dyslexic children: a general (non phonological) deficit reflected in slower stimulus classification speed and a linguistic (phonological) deficit reflected in slower lexical access speed. This experiment appeared to be the first systematic, direct investigation of speed of information processing in dyslexic children.

Taroyan and Nicolson (2009) studied the behavioral correlates of lexical decision processes in English speaking dyslexic and non-dyslexic readers. Nine dyslexic adolescents and 9 control adolescents were tested. Both groups showed significantly longer response times and lower accuracy for the pseudo words/non words. Furthermore, overall performance was significantly worse for the dyslexic group in terms of lower accuracy and longer response times.

Sela, Horowitz–Kraus, Izzetoglu, Shewokis, Izzetoglu, Onaral, and Breznitz (2011) did a study on twenty two adults (age 25±2.48 years) and twenty five 7th grade children (age 12.65±0.467 years) using a visual lexical decision task and found that younger group exhibited slower reaction time as compared to adults. They also found that compared to words both group exhibited longer reaction time for pseudo words. With respect to accuracy, they found that accuracy was higher for pseudo words in both groups.

Pizzioli and Schelstraete (2007) investigated lexical processing in children with SLI compared to two groups of normal language developing children. A lexical decision task was used to evaluate the accuracy and speed of spoken-word recognition. The result showed that differences concern response times rather than accuracy. Considering accuracy, there was no group effect. But in general more errors were made with pseudo-words compared to real-words. With respect to reaction time, no significant difference emerged between group of children with SLI and receptive vocabulary matched normal children, but they were slower than age-matched peers. Besides, there was a significant effect of word type, with longer reaction times for pseudo-words than real words

The above mentioned behavioral studies included tasks which only revealed the end performance of subjects; however an understanding of the complex neuro-cognitive processes involved in language processing would be difficult through such offline behavioral tasks. There have been many attempts by researchers to find out the neural correlates during lexical processing using various techniques such as Magnetic Resonance Imaging (MRI), functional Magnetic resonance imaging (fMRI), Positron Emission Tomography (PET), etc.

Neural correlates of word recognition

Spoken word recognition involves transformation of incoming acoustic information to a lexical representation in a person’s mental dictionary. This involves several processing starting from the auditory periphery up to the level of brain.

Phonological information has to be processed before lexical access can take place. At the lexical level morphological and semantic information have to be taken into consideration (Pulvermuller, 1999). Data from functional neuro imaging studies of normal subjects are used to find out the distributed set of brain regions that are engaged during a particular language task.

Evidence from a variety of research indicates that phonological stages of spoken word recognition are supported by neural systems in the superior temporal lobe bilaterally, mainly superior temporal gyrus (STG) and superior temporal sulcus (STS). In neuroimaging studies, listening to speech bilaterally activated the superior temporal lobe which was largely symmetrical (Binder, Frost, Hammeke, Bellgowan, Springer, Kaufman, et al, 2000; Binder, Rao, Hammeke, Yetkin, Jesmanowicz, Bandettini, et al, 1994; Mazoyer, Tzourio, Frak, Syrota, Murayama, Levrier, et al,1993; Price, Wise, Warburton, Moore, Howard, Patterson, et al, 1996; Schlosser, Aoyagi, Fulbright, Gore & McCarthy, 1998). This does not reveal which aspect of speech recognition is processed in the two hemispheres. It is possible that activation in spoken word recognition is bilateral, but the phonological stages of processing are restricted to the left hemisphere. This means to say that damage to the left superior temporal lobe should produce profound phonological deficits in spoken word recognition. But damage to the left superior temporal lobe does not lead to severe impairments in phonological processing during spoken word recognition. This finding has led to the assumption that phonological processes in speech recognition are bilaterally organized in the superior temporal lobe (Hickok & Poeppel, 2000). Consistent with this assumption is the observation that damage to the STG bilaterally produces profound impairment in spoken word recognition, in the form of word deafness, a condition in which basic hearing is preserved but the ability to comprehend speech is effectively nil (Buchman, Garron, Trost-Cardamone, Wichter & Schwartz, 1986).

The Superior temporal sulcus (STS) was found to be an important location for representing and/or processing phonological information (Binder et al, 2000; Hickok et al, 2000; Indefrey & Levelt, 2004; Liebenthal, Binder, Spitzer, Possing & Medler, 2005; Price et al, 1996). Activation along the STS was found in functional imaging studies which isolated phonological processes in perception by contrasting speech stimuli with complex non-speech signals (Matsumoto, Iidaka, Haneda, Okada & Sadato, 2005; Sitnikova, Holcomb, Kiyonaga & Kuperberg, 2008; Van Petten, Coulson, Rubin, Plante, & Parks, 1999 M).

Indefrey and Cutler (2004) gave a broad perspective on the neural correlates of spoken word recognition. They reported a meta-analysis of 55 experiments in which subjects passively listened to tones, pseudo words, words, or sentences. It was observed that all of the different types of auditory stimuli reliably activated overlapping as well as partially differentiated central and posterior regions of the superior temporal gyri in both hemispheres. Some researchers manipulated the psycholinguistic variables that tap phonological processing systems to identify the phonological networks which again implicated STS (van den Brink, Brown & Hagoort, 2001). Many authors consider this system to be left dominant, but both lesion and imaging evidence suggest a bilateral organization (Binder, Medler, Desai, Conant & Liebenthal, 2005).

After the phonological form of a word has been recognized, its semantic and syntactic components are retrieved. Imaging studies of semantic processes at the word level indicate that the left middle temporal gyrus (MTG), the angular gyrus and the left inferior frontal gyrus (IFG) support semantic processes. fMRI studies using semantic tasks that require the semantic categorization of words or tasks that require judgments on the semantic properties of words consistently show activity in the left STS and the MTG (Cappa, Perani, Schnur, Tettamanti & Fazio, 1998; Gitelman, Nobre, Sonty, Parrish & Mesulam, 2005; Gold et al.,2006; Price et al., 1994; Pugh et al.,1996;). Also studies using distorted speech stimuli find that activity in the MTG and/or the IT increases as a function of intelligibility (Davis & Johnsrude, 2003; Giraud et al., 2004). Increased activity in the MTG is also observed when the number of words processed per trial is increased (Badre, Poldrack, Pare-Blagoev, Insler & Wagner, 2005). Studies on patients with aphasia had revealed that those with lesions in posterior temporal areas have difficulty performing semantic tasks that require access to lexical representations (Hart & Gordon, 1990; Kertesz; 1979). Dronkers, Wilkins, Van Valin, Redfern and Jaeger (2004) did a study on 64 patients where they found that MTG was the only region in which lesions led to significantly lower performance. Indefrey and Levelt (2004) did a meta-analysis of 82 imaging studies of language production and found that the left MTG was the only area that was reliably activated for tasks that required lexical selection. The posterior superior temporal gyrus (STG) has sometimes been associated with semantic processing. But most of the evidence suggests that its role is limited to early (auditory) stages of the sound-to-meaning transformation (Binder et al, 2000).

The frontal cortex is responsible for strategic and executive aspects of semantic processing (Fiez, 1997; Poldrack, Wagner, Prull, Desmond, Glover & Gabrieli, 1999). Activation of the left inferior frontal region (Broca's area) during auditory word processing has been observed during phonological judgements on heard stimuli (Demonet, Chollet, Ramsay, Cardebat, Nespoulous, Wise, et al.,1992; Demonet, Price, Wise & Frackowiak, 1994; Zatorre, Evans, Meyer & Gjedde 1992), the retrieval of words (Wise, Chollet, Hadar, Friston, Hoffner & Frackowiak, 1991; Warburton, Wise, Price, Weiller, Hadar, Ramsay, et al., 1996), semantic judgements on heard words (Demonet et al., 1994; Warburton et al., 1996) and silent 'repetition' of non-words with three repetitions per stimulus (Warburton et al., 1996). However, all these tasks require auditory-verbal short-term memory to remember the auditory stimuli while the phonological or semantic decisions are made. Activity in the Broca's area increases during auditory-verbal short-term memory tasks (Paulesu, Frith & Frackowiak, 1993) and its role during these tasks may be attributable to phonological rehearsal.

The posterior regions of the Left Inferior Prefrontal Cortex (LIPC) are involved in phonological processing while anterior and ventral areas may be more involved in semantic processing (Fiez, 1997; Buckner, Raichle & Petersen, 1995). Devlin, Matthews and Rushworth (2003), demonstrated that anterior and posterior regions contribute to both semantic and phonological processing, but it may be attributable to different extents. In summary, it can be concluded that a bilateral temporo-frontal network sub serves the spoken word recognition.

Neural underpinnings of dyslexic brain

Many researchers agree that dyslexia has a neuro developmental basis (Hynd & Semrud –Clikeman, 1989). There have been various neurological interpretations of the mechanisms responsible for dyslexia (Demonet, Taylor & Chaix, 2004; Grigorenko, 2001; Habib, 2000; Ramus, 2003). Various brain imaging tools have documented structural and functional differences between adults or children with dyslexia and good readers of comparable age (Berninger & Richards, 2002). These differences between individuals with dyslexia and good readers are often associated with phonological processing (Eckert, Leonard, Richards, Aylward, Thomson, & Berninger, 2003; Eden, Jones, Cappell, Gareau, Wood, Zeffiro et al., 2004; Fulbright, Jenner, Mencl, Pugh, Shaywitz et al., 1999). Brain areas involved in phonological processing such as left perisylvian cortices, left middle and inferior temporal cortex have been found to be dysfunctional in many studies (Helenius, Salmelin, Service, Connolly, Leinonen & Lyytinen 2002; Rumsey, Andreason, Zametkin, Aquino, King, Hamberger, et al, 1992). This disrupted neural response has been shown in a number of studies, across different methodologies using various tasks.

MRI studies have shown that individuals with dyslexia have a higher incidence of reduced or reversed asymmetry of temporo parietal language regions than exhibited in the normal population (Dalby, Elbro & Stodkilde-Jorgensen, 1998). MRI studies have demonstrated atypical asymmetry of the planum temporale in dyslexic individuals (Hynd, Semrud- Clikeman, Lorys, Novey & Eliopulos, 1990; Flowers, 1993). Larsen, Hoien, Lundberg, & Odegaard (1990) found that 13 out of the 19 dyslexic adolescents displayed symmetric planum. Among the individuals with dyslexia exhibiting pure phonological dysfunction, none showed the typical leftward asymmetry of the planum. These led authors to hypothesize that symmetrical planum temporali as a possible neural substrate for phonological processing impairments in developmental dyslexia.

Brown, Eliez, Menon, Rumsey, White and Reiss (2001) in their voxel-based morphometry (VBM) study, reported reduced grey matter in the orbital portion of the left inferior frontal gyrus and superior temporal gyrus, but also outside the classical language regions. No differences in white matter densities were reported. Brambati, Termine, Ruffino, Stella, Fazio, Cappa, et al (2004) using VBM observed significant reductions of grey matter volume in the planum temporale, inferior temporal cortex, cerebellar nuclei, and in the left superior and inferior temporal regions of the brain which are associated with language and reading processes in people with a family history of dyslexia in comparison with controls who had no reading problems.

In a PET study by Paulesu, Firth, Snowling, Gallagher, Morton and Frackowiak (1996) employed two visually presented phonological tasks: a rhyming task and a short term memory task. In normal control subjects, both tasks activated Broca’s area, Wernicke’s area and the insula, whereas parietal operculam activation was specific to phonological memory task. In individuals with dyslexia only a subset of brain regions involved in phonological processing including Broca’s area during rhyme judgment and left temporo parietal cortex during short term memory demands were activated. The insula of the left hemisphere was never activated. Paulesu and his collegues (1996) thought the left insular cortex to be crucial in the conversion of whole word phonology (temporo parietal regions) to segmented phonology (inferior frontal regions). They speculated that phonological deficits in dyslexia might result from a weak connectivity between anterior and posterior language areas.

Horwitz, Rumsey and Donohue (1998) studied the functional connectivity of dyslexia. They investigated the angular gyrus and its connections during phonological processing. They found lack of coherence between measurements in the angular gyrus and parieto-temporal regions, suggesting functional disconnection between the brain regions involved in the phonological analysis process at the initial stages of phonological decoding. Pugh, Mencl, Shaywitz, Shaywitz, Fulbright, Constable et al (2000) did fMRI functional connectivity study and found functional disconnections between the angular gyrus and parietal regions in the left hemisphere specific to the phonological processing.

Shaywitz, Shaywitz, Pugh, Fulbright, Constable, Mencl, Shankweiler, Libermann et al (1998) reported differential brain activation patterns in dyslexic and normal readers engaged in phonological analysis tasks of increasing complexiecity. The individuals with dyslexia showed relative under activation of Wernicke’s area, the angular gyrus, the extrastriate and striate cortex (posterior regions), and over activation of inferior frontal gyrus (anterior region). The researchers concluded that this finding provided neurological evidence of the critical role of phonological analysis in individuals with dyslexia.

Kovelman, Norton, Christodoulou, Gaab, Lieberman, Triantafyllou, Wolf, Whitfield-Gabrieli and Gabrieli (2011) used functional magnetic resonance imaging to identify the neural correlates of phonological awareness using an auditory word-rhyming task in typically reading children, children with dyslexia and a younger group of kindergarteners. Typically developing children and the younger group of kindergarteners recruited left dorsolateral prefrontal cortex (DLPFC) when making explicit phonological judgments. But a reduction of activity in the left DLPFC for phonological awareness in children with dyslexia was observed. Thus they concluded that left DLPFC may play a critical function in phonological awareness in typical development and that children with dyslexia do not engage this region for phonological processing. All of these studies reported some differences in the anatomy and activity of the brain and these differences were found in multiple brain sites.

Positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) are brain imaging techniques involved in studying the language processing. They are well known for their very good spatial resolution, though has drawbacks showing lesser precision in their temporal resolution. Hence there is a lack of adequate methodologies for exploring online, real-time language processing in the brain, due to which the thorough understanding of the complex neuro-cognitive processes involved in linguistic skills development has some drawbacks (Osterhout & Holcomb, 1995). Thus when focusing on the temporal aspects of the activation of different subcomponents during on-line language processing, the electrophysiological recording of event-related potentials (ERPs) of the brain are the only noninvasive techniques available, especially suited for a child population.

2.5. Event Related Potentials

Event Related Potentials (ERPs) are well known for measuring changes in electrical activity in brain, which is associated with a sensory or psychological process (Picton & Stuss, 1984). The ERP technique is based on the assumption that, different cognitive processes are mediated by differential patterns of brain activity. Thus, different ERP patterns recorded from electrodes placed across the scalp can be used to investigate separate linguistic representational levels based on their distribution or topographic location, functional polarity (positive or negative), latency (time in milliseconds relative to the onset of a stimulus) and amplitude (peak height) (Canseco-Gonzalez, 2000). ERPs represent the electrical activity of the brain averaged over several instances of the same event, which is time-locked to the presentation of a given target (Friederici, 1997). In order to increase the signal-to-noise ratio for the brain activity and the events not of interest averaging of this electrical activity of brain is necessary. The recordings of electrical activity in response to recorded events are taken at the same point in time. Thus averaging and time locked recording facilitates the recognition of the ERP, as the ERP recorded for each instance of an event remains constant throughout the averaging process (Friederici, 1997; Hillyard & Kutas, 1983; Picton & Stuss, 1984).

These scalp-recorded ERPs which reflect the sum of simultaneous postsynaptic activity of many neurons have been commonly divided into two subtypes

I. Exogenous potentials: These potentials have an earlier onset component which occurs before approximately 80 ms post-stimulus. They are often termed as “stimulus-bound” components due to their relative sensitivity to the physical parameters to the stimulus like duration, frequency and also insensitivity to changes in information processing demands, such as attentional state (Hillyard & Kutas, 1983; Picton & Stuss, 1984).

II. Endogenous potentials: They appear in conjunction with specific perceptual or cognitive processes and usually are longer latency components (Hillyard & Kutas, 1983; Osterhout & Holcomb, 1992; Picton & Stuss, 1984). These components are most affected by psychological state of an individual. For example, attentional state of an individual has significant effects for endogenous ERP responses, especially those occurring beyond 150 ms post-stimulus (McPherson & Ballachanda, 2000).

There exist four types of attentional states which may affect ERP measurement: selective, active, passive, and ignore (McPherson & Ballachanda, 2000). Comparisons across studies must be made carefully as different attentional states have different effects on ERPs over various tasks. When an active discrimination task (such as a same-different task) is employed *selective* attention comes into picture. Whereas when the subject is asked to physically respond to the stimuli by, for example, pushing a button, *active* attention is maintained. A *passive* attention state, describes the individuals who are awake and alert, but not necessarily attending to the stimuli. Finally, in the *ignore* state of attention individuals are distracted from the stimuli.

There is other brain activity which interferes with obtaining reliable measures. These are not time-locked to particular events of interest and produces noise that affect the desired signal. These frequencies that are outside those of interest to the researcher are said to be the artifacts. In general, an averaging procedure is utilized to increase the signal-to-noise ratio for the events of interest (Friederici, 1997). Artifacts are most often caused by muscle movement rather than brain activity. The two major sources of artifact contamination are movements of the eyes and eyelids in any ERP studies. Movements of the eye act as an electrical dipole, which by creating fluctuating electrical fields of positive and negative charges that are propagated back onto the scalp and picked up by scalp electrodes, contaminates the recording of the brain activity (Coles & Rugg, 1995). This movements activity occurs at the same frequencies as significant features of the ERP waveforms, often occurring after 50 ms, thus cannot be filtered (Coles & Rugg, 1995; McPherson & Ballachanda, 2000). Hence, the desired response can be obscured by eye movement artifacts or may even be mistaken for the desired response (McPherson & Ballachanda, 2000).

For managing these artifacts, three methods are considered, each of which includes disadvantages. The first method is, researchers can instruct the subjects to resist blinking until the measurement has been taken. The subject can be instructed to gaze at the fixation point and to only blink between the any two stimuli. The limitation of this method is that it might interfere with overall performance as this approach places an additional demand on the subject. The second method is that the epochs that are affected by an artifact can be discarded. The artifact rejection can be activated while recording with placement of an oblique electrode allows for monitoring eye movement and eye blinks (McPherson & Ballachanda, 2000). The disadvantage of this approach is that the researcher might end with an insufficient number of artifact-free trials. Especially for studies that require eye movement for good performance or in those studies investigating certain populations who may have difficulty keeping their eyes still, like the young and the aged. For preserving a pure ERP signal for the desired task, a third possible method is to estimate and remove the contribution of the eye movement (Coles & Rugg, 1995). This approach is more preferred as it neither affects the individual's performance nor result in reduced/ insufficient number of artifact free trials.

In recent days, the ERP recording softwares incorporate methods like ocular artifact reduction or eye blink reduction which allows the researcher to remove the eye movement artifact. The researcher has to record the ocular responses/ or activity by placing the electrodes around the eyes. Then the software has to be trained for accepting/ rejecting an eye blink. Once it's trained with a minimum number of sweeps, it calculates a linear regression line based on which the estimated amount of eye blink activity is subtracted from the desired activity. This method is widely used while studying various ERP components that underlie processing of language components.

2.5.1 Event-related potentials and Language

A strong element in the ERP research regarding the linguistics emerged by the discovery of the first "language" component, the "semantic" N400 (Kutas & Hillyard, 1980). Additional ERP components associated with phonological, acoustic-phonetic, syntactic, orthographic and prosodic processes have been discovered in the intervening years. The ERP components that are early (100-200 ms), fast, and automatic tend to be concerned with basic operations such as phoneme discrimination or word segmentation. Other components which have larger latencies (up to 1s) reflect integration or revision processes.

There have been five ERP components identified that are involved in language processing (Brown, Hagoort & Kutas, 2000).

1. ***Phonological mismatch negativity (PMN):*** PMN is the earliest component which is elicited by contextually unexpected phonemes in language tasks (Connolly, Phillips & Forbes, 1995). This ERP component peaks in the late 200 ms range (270-310 ms) and is fronto-centrally distributed. It is earlier than and distinct from the N400 reflecting pure semantic anomalies. The PMN precedes the N400 in combined violations of phonological and semantic expectations.

   PMN is found to occur in response to all sentence-ending words but is larger to those that violate phonological expectations. The PMN not related to the mismatch negativity (MMN) as the label phonological mismatch negativity (PMN) (Conolly & Philips, 1994) might appear misleading to the description of its behavior. Thus, the phrase that better describes its behavior is phonological mapping negativity as it referred now. As the PMN is equally responsive to words and non-words, it appears prelexical and also modality specific (auditory). It also appears to be related to phonological awareness, is insensitive to phonologically correct pattern masking and responds to single phoneme violations of localized expectations (Conolly et al., 1992). Preliminary data indicates that PMN is absent in many poor and dyslexic readers. Newman et al. (2004) has isolated the PMN from frequently occurring larger negativities using a phoneme deletion paradigm. These findings have confirmed that the PMN is a prelexical response, which reflects a compulsory stage of word processing that is sensitive to top-down phonological expectations. Currently, it has been suggested that PMN reflects phoneme awareness and the consequent phonological processing activity. Once a violation of expectations is perceived, although PMN is influenced by top-down phonological expectations, it does not appear to be sensitive to gradations of phonological relatedness. But rather shows an “all-or-none” response that is equally large for all violations. The PMN may reflect a phonological stage of word processing that operates at the level of transforming acoustic input into phonological code assisting in the establishment of a lexical cohort. It is also compatible with the data to suggest that the PMN may reflect the earliest point at which top-down contextual information influences bottom-up processes at or just prior to the isolation point within, for example, a version of the Cohort Model (Connolly & Phillips, 1994).

2. ***Left-anterior negativity (LAN):*** This component is elicited about 200–500 ms after word onset and it seems to be involved in the processes of working memory. Also, LAN is involved in the activation and processing of syntactic word-category information that is in a sentence whether the word is acting as a subject, a verb or an adjective, etc. (Friederici, 1995; Friederici, Hahne & Mecklinger, 1996; Kluender & Kutas, 1993). Early LAN (ELAN), between 100 and 300 ms, have been found particularly with the word category violations. ELAN appears to be more reliable in auditory than visual studies. ELAN has been elicited from the neural generators in Broca’s area and the anterior temporal lobe. The later LANs elicited between 300 and 500 ms represent other morpho-syntactic operations (and respective violations) which are processed in parallel to semantic information, affecting agreement features or verb arguments which already

depend on a phrase marker. ELANs are not influenced by the relative proportion of violations in an experiment, suggesting their “autonomous” status independent of processing strategies (Hahne & Friederici, 1999). ELANs are seen in robust to greater extent in auditory experiments. Similar early anterior negativity over the right hemisphere [ERAN (early right-anterior negativity)] have been reported in studies for certain musical violations (Patel et al., 1988). Hagoort et al. (2003) replicated ELAN effects in a Dutch reading study that avoided word initial markings of the word category. They observed an anterior negativity only between 300 and 500 ms which, moreover, was bilaterally distributed rather than left lateralized. Lau et al. (2006) found that clear LAN-like effects occurred only if local phrase structure imposed high constraints on the target word, whereas less predictable structures resulted in attenuated LAN effects. Predictability and expectations may be crucial to our understanding of LAN-like effects in morpho-syntactic processing more generally.

3. ***N400 component***: It is a negative waveform that is elicited between 300 and 500 ms after word onset. N400 is related to the semantic processing or, processing of the meaning of the stimulus in its context (Kutas & Federmeier, 2000). This component includes a centro-parietal distribution and, in several tasks, an additional frontally distributed component with a slightly different functional significance (Kounios & Holcomb, 1994). This peak is of importance in the present study and will be discussed in detail in the following sections.
4. ***P600 component***: A positive waveform that is seen about 500–700 ms after word onset and belongs to the P3b family of components (Kok, 2001). P3b components

are large, positive peaks elicited in response to a wide variety of stimuli. P600 are found to be elicited for syntactical violations in a sentence. For simple stimuli such as tones or coloured dots, they can peak as early as 275 ms post onset. Whereas for complex stimuli such as words, they peak at 600 ms. Depending on the difficulty of the task the peak can be delayed up to 2000 ms. Eventhough the latency can be so long, they still belong to the same family of P3b components because the distribution at the peak maximum is over parietal scalp sites. Also, because their amplitude can be modulated by the probability of the occurrence of a particular stimulus (Kutas, McCarthy & Donchin, 1977). It has been speculated that ending of the stimulus evaluation process has been reflected in P3b components. The amplitude increases as the amount of information that has been consciously extracted from the presentation of the stimulus increases (Debruille, 1998; Curran, 1999; Coulson, King & Kutas, 1998; Donchin & Coles, 1988). A large, positive and parietal component peaking at 600 ms post onset has been elicited for unexpected syntactic anomalies in several studies (Osterhout & Holcomb, 1992; Hagoort, Brown & Groothusen, 1993; Munte, Matzke & Johannes, 1997). The authors have thus claimed that P600 would not be a component of the P3b family and is elicited by words in normal discourse reflects a type of syntactic processing, such as “second pass parsing,” (Friederici, Hahne & von Cramon, 1996). However, it has been contradicted by many authors that it does not represent syntactic processing (Curran, 1999; Gunter, Stowe & Mulder, 1997; Munte, Heinze, Matzke, Wieringer & Johannes, 1998). In terms of contradiction, Kaan et al. (2000) demonstrated that P600 can be evoked by structurally more complex sentences even in the absence of any violation or ambiguity. Thus, these findings suggest that the P600 is a rather general marker for structural processing.

5. ***Slow Positive Shift:*** The slow positive shift is a broad component that develops throughout the span of a sentence. This slow positive shift has been recently identified which is related to the construction of a representation of the overall meaning of the sentence (Brown, Hagoort & Kutas, 2000).

Steinhauer and colleagues (1999) identified a new ERP correlate of prosodic processing, which was labeled as the ***Closure Positive Shift (CPS).*** This component is assumed to reflect prosodic phrasing (closure of intonational phrases) in listeners cross-linguistically and is reliably elicited at prosodic boundaries. It is independent of linguistic violations unlike most other language-related components. CPS is among the first brain responses observed and may help learners identify syntactic phrase boundaries and even word boundaries in both first and second language acquisition. CPS is also elicited during silent reading, both at comma positions and when subjects were instructed to reproduce prosodic boundaries at specific positions and by boundaries in delexicalized and hummed sentence melodies (Steinhauer & Friederici, 2001). Thus, the CPS establishes a link between covert prosody and punctuation (in reading and writing) and is independent of lexical/syntactic information.

Even among the exogenous potentials, N100 component has been related with the early processing of language.

The N100 and Language

The N100 is a negativity peaking around 100 ms. It was considered as an exogenous response which sensitive to the physical features of an auditory (e.g., loudness), visual (e.g., brightness), or tactile stimulus. N100 has been linked to word segmentation processes more recently (Sanders & Neville, 2003). Sanders and Neville (2003) examined whether the word onset responses were related to segmentation and word stress. ERPs to different types of sentence context for word initial and word medial syllables were obtained. They found that larger anterior N100 responses were obtained for word onset syllables than word medial syllables across all sentence conditions. It was also seen that N100 to stressed and unstressed word onsets showed a different scalp distribution compared to that seen for the N100 to word onset and word medial syllables which had been equated for physical characteristics. This aspect of language processing representing N100 responses are not much studied and attracts an attention.

The N400 and Lexico-Semantic Processing

The N400 was first discovered in a landmark study by Kutas & Hillyard (1980) in which ERPs were recorded in response to incongruous sentence endings (e.g., “He takes his coffee with cream and dog”). A broad negative deflection of the ERP that starts 200-300 ms and peaks after approximately 400 ms after a word has been presented auditorily or visually is termed as N400. The N400 can be elicited in response to semantic errors for both visual and auditory stimuli (Kutas & Hillyard, 1980a, 1980b, 1980c, 1983, 1984; Bessen, Faita, Czternasty & Kutas, 1997; Federmeier, McLennan, De Ochoa & Kutas, 2002; Swaab, Brown & Hagoort, 2003). Kutas and Hillyard in 1980 conducted several studies in which the N400 was observed. N400 was affected by semantic errors in two of the studies conducted by Kutas & Hillyard (1980a, 1980c). They observed that when a semantically incorrect word was substituted within or at the end of visual sentence stimuli, an enhanced negative peak at approximately 400 ms post stimulus has been found (Kutas and Hillyard 1980a, 1980b, 1980c, & 1984). They observed an inverse relationship between the amplitude of the N400 and the semantic appropriateness of the stimulus word (Kutas and Hillyard, 1980b, 1980c, 1984). In two studies, Kutas and Hillyard (1980a, 1980c) found that sentences that ended with a semantically inappropriate word elicited a strong N400 peak when the final words of sentences were presented in a large, bold-faced font in comparison to the normal typeset of the rest of the sentence.

Polich (1985) contradicted that the N400 is not a function of semantic processing. He used two different types of stimuli that were presented visually. The stimuli included word series with an occasional semantically inappropriate word and the same sentences as those used by Kutas and Hillyard (1980b). The participants were asked to perform both a selective and active attention task. Polich (1985) found that the N400 was elicited by word series and sentences ending in both semantically appropriate and inappropriate words which were in contrast to Kutas and Hillyard (1980b) findings. Also, during the active participation task the N400 was followed by a positive component. Polich (1985) concluded that rather than a distinctive response to semantic incongruities, the effect may be attributed to the brain’s overall capability to comprehend complex relationships. Osterhout and Holcomb (1993) also found larger N400 responses for grammatically incorrect sentences compared to grammatically correct sentences. The N400 response can be elicited by most meaningful stimuli, including isolated words (Bentin, McCarthy

& Wood, 1985; Rugg, 1985) and pronounceable non-words (such as ‘blicket’; also known as pseudowords) (Bentin, McCarthy & Wood, 1985; Rugg & Nagy, 1987), although is often associated with semantic anomaly. Additionally N400 responses can be elicited for visual stimuli like faces (Barrett & Rugg, 1989; Barrett, Rugg & Perrett, 1988) and pictures (Barrett & Rugg, 1990; Holcomb & McPherson, 1994; Ganis, Kutas & Sereno, 1996). The N400 has been shown to be evoked by semantic anomalies across many different languages (Friederici, 1997) such as English, French (Besson & Macar, 1987), Dutch (Brown & Hagoort, 1993), and German (Friederici et al., 1993; Münte, Heinz, & Mangun 1993).

Paradigms to record N400

There are mainly two paradigms to record N400 which are frequently found to alter the size of the N400 response. The first one is semantic-priming paradigm which involves the presentation of a related or unrelated word before a word target (such as ‘coffee–tea’ or ‘chair–tea’). The second is the semantic-anomaly paradigm which involves the presentation of a congruous or incongruous word as a continuation of preceding sentential material (such as, ‘I like my coffee with cream and sugar/socks’). During both paradigms, a response of smaller amplitude in the 300–500 ms interval is elicited for the condition in which the context is ‘semantically supportive’ (Kutas & Hillyard, 1980; Rugg, 1985). The latency and spatial distribution of the effects of the two paradigms are similar and are assumed to represent the same underlying response (Kutas, 1993). But the effects of sentential context on the N400 response tend to be bigger in magnitude i.e., the amplitude for unrelated word/ incongruous word is larger compared to semantically supportive word. Collectively, this modulation/ difference in N400 amplitude is referred as the ‘N400 effect’.

Localizing the N400 effect from ERP Studies

When visual presentation is used the context-dependent N400 effect tends to have a centroparietal (cp) scalp distribution, with a small but consistent bias to the right side of the head (Kutas, Van Petten & Besson, 1988). However, the N400 effects elicited during sentence completions presented to the ‘linguistic’ (left) hemisphere, support a left-hemisphere generator for the N400 effect in split-brain patients (Kutas, Hillyard & Gazzaniga, 1988). The centre-right scalp distribution of the N400 effect, given the strong left-lateralization for language observed elsewhere, has been interpreted as ‘paradoxical lateralization’. This means that a left-hemisphere generator affects right-hemisphere electrodes owing to fissural morphology and conductance properties (Hagoort, 2008; Van Petten & Luka, 2006; Van Petten & Rheinfelder, 1995).

The results on localization of N400 effect from ERP data are often attempted and have been inconsistent (Curran, Tucker, Kutas & Posner, 1993; Johnson & Hamm, 2000; Frishkoff, Tucker, Davey & Scherg, 2004). Brain damage to particular regions alters the N400 effect, which in turn will help in knowing about the generators of the N400 response by studying patients with various forms of brain lesion. The effects of semantic congruity on the N400 response are relatively preserved in patients with amnesia and Alzheimer’s disease (Iragui, Kutas & Salmon, 1996; Olichney et al., 2002; Olichney et al., 2000). But this result is difficult to interpret because the full extent of the areas that are affected by these disorders is unclear. Similarly, a reduced N400 effect for priming and semantic anomaly associated with poor language comprehension was seen in studies on patients with aphasia, but the areas of damage in these patients are often unknown. And a robust N400 effects was shown in patients with broca's aphasia and Wernicke's aphasia (Hagoort, Brown & Swaab, 1996; Swaab, Brown & Hagoort, 1997; Kojima & Kaga, 2003). The N400 congruity effects was seen in three patients with left frontal lesions (although these effects were attenuated) (Friederici, von Cramon & Kotz, 1999), whereas in another study no N400 congruity effect was found in a patient with a left temporal lesion (Friederici, Hahne & von Cramon, 1998). Further, patients with left temporal lobe epilepsy showed no N400 congruity effect, in contrast to patients with right temporal lobe epilepsy which evidences towards temporal involvement (Olichney, 2002). However, in general, the presence or absence of N400 effects in existing patient studies makes it difficult to associate damage to particular regions due to heterogeneous etiologies and small sample sizes.

Explanation for the N400 Effect

The integration view of the N400 effect

The integration view of the N400 effect is that it reflects the process of semantic integration of the critical word with the working context (Kutas & Hillyard, 1980; Hagoort, 2008; Osterhout & Holcomb, 1992; Brown & Hagoort, 1993). According to this view, the N400 effect is not from a 'simple' lexical-level processes but is a result of a combinatorial process i.e., integration of the target word with the previous context. Since the integration is easier in congruent contexts than in the N400 response amplitude is lesser. It is because a semantically anomalous sentence requires work to process an implausible continuation in a way that fits the discourse context or prior world knowledge. The less expected endings in a sentence produce larger N400 responses than more expected endings, which can also be explained as the integration is suggested to be more difficult when expectations are not met than when they are met. In case of semantic priming results in N400 effects the priming word is considered the ‘context’ into which the target word must be integrated. The N400 response occurs too late to reflect lexical access. Thus, the view that the N400 effect reflects post-access mechanisms is appealing (Sereno, Rayner & Posner, 1998; Hauk & Pulvermuller, 2004; Hauk, Davis, Ford, Pulvermuller & Marslen-Wilson, 2006). Furthermore, early studies masked the prime below conscious perception and found no change in the N400 amplitude (Brown & Hagoort, 1993).

The lexical view of the N400 effect

Alternatively, the lexical view of N400 effect postulates that the N400 effect is reflected as facilitated activation of features of the long-term memory representation that is associated with a lexical item (Kutas & Federmeier, 2000; Federmeier, 2007). According to this view, predictable words in context are easier to access from memory owing to the difference between the effects of anomalous and predictable endings but not because of the anomaly by itself. The lexical access less effortful because supporting context allows pre-activation of relevant lexical or conceptual features (Federmeier & Kutas, 1999). The lexical view does not imply that N400 amplitude variation in sentences is directly related to the degree of lexical association between words. Because even in the absence of such associations, the interpretation of the context as a whole has been shown to lead to remarkably specific lexical predictions (van Berkum, Hagoort & Brown, 1999; St George, Mannes & Hoffman, 1994; van Berkum, Zwitserlood, Hagoort & Brown, 2003; Chwilla & Kolk, 2005; Camblin, Gordon & Swaab, 2007). The process that underlies the N400 effect is itself non-combinatorial (cannot be effect of context), although prior semantic composition provided by the sentential or discourse context may give rise to the prediction.

A prediction that is largely borne out in the literature is the hypothesis that any factor that facilitates lexical access should reduce the N400 amplitude. Words with a higher frequency of occurrence and repeated words result in smaller N400 responses than lower-frequency words (Van Petten & Kutas, 1990; Allen, Badecker & Osterhout, 2003; Rugg, 1985). Larger N400 responses are elicited for word like non-words, which are associated with long reaction times in lexical decision tasks, than words (Holcomb & Neville, 1990; Holcomb, 1993; Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999). The two different mechanisms lead to an equivalent N400 response reduction, although are thought to act differently during semantic priming when different prime-target intervals are used (see below), suggesting that the N400 effect is associated with any priming mechanism that increases the activation of a lexical target (Anderson & Holcomb, 1995; Deacon, 1999; Hill, Strube, Roesch-Ely & Weisbrod, 2002; Franklin, Dien, Neely, Huber & Waterson, 2007). Finally, in contrast to the early findings, recent work suggests that N400 effect can be elicited for masked semantic priming even when the interval is short enough (Kiefer, 2002; Grossi, 2006).

As seen from the two views of N400 effect, there might be various factors affecting the N400 responses. The following are the factors affecting the N400 responses.

i. *Typicality*

The “Typicality” of a word means how well a stimulus word fit into a particular category, which affects N400 responses. Stuss, Picton, and Cerri (1988) conducted a study which confirmed the involvement of the N400 where participants judged the “typicality” of a word. They found that greater N400 amplitude which was independent of occurrence of usage was associated with greater atypicality. For high usage atypical words, a longer N400 latency was found as compared to low usage atypical words, supporting the idea that the N400 reflects lexical access. Thus, N400 acts as a representation of lexical access or how easily and quickly words are accessed (Attias & Pratt, 1992).

ii. *Semantic Priming*

Semantic priming is defined as the presentation of a word in a semantically appropriate context. The N400 component has an effect of semantic priming, which was further evaluated. The speed and accuracy of semantic processing increases as the use of semantic priming increases as observed by the researchers (Bentin et al., 1993; Mitchell, Andrews, & Ward, 1993). Radeau, Besson, Fonteneau, and Castro (1998) recorded N400 to examine auditorily presented semantic, phonological, and repetition priming for words. They found smallest N400 peak to words when preceded by a semantic prime and when words were preceded by a phonological prime found an intermediate N400 peak. When the word was preceded by an unrelated word, the largest N400 peaks were elicited.

Fujihara et al. (1998) combined both semantic priming and typicality effects to study N400 responses. They concluded that the category is based on a category prototype and categorization is based on how similar a target item is to the category prototype. It was noted that the use of typical words within a category acted as semantic primes for typical target words. They found that atypical target words were processed slower than typical target words, however, because they were not primed by typical words in the same category.

iii. Predictability

Predictability refers to how expected a word is in its context. The amplitude of the N400 response that is elicited by words in sentential contexts is modulated by predictability as well with the degree of anomaly. Even when both endings are semantically congruent, a larger N400 response are generated for less expected sentence endings than highly expected ones (for example, ‘I like my coffee with cream and honey’ would generate a larger N400 response than ‘I like my coffee with cream and sugar’) (Kutas & Hillyard, 1984). The response to anomalous endings is modulated by the relationship of the target word to the ‘expected’ ending. A smaller N400 response is produced with an anomalous ending that shares semantic features with the most contextually predicted ending (for example, ‘I like my coffee with cream and salt’) than an ending that is not semantically related to the predicted ending (for example, ‘I like my coffee with cream and socks’) (Kutas & Hillyard, 1984; Federmeier & Kutas, 1999).

iv. ***Ambiguous Words***

Ambiguous words have an influence over N400 responses. Class-ambiguous words (nouns or verbs) are those words that have the same form, but may have two or more meanings. Federmeier, Segal, Lombrozo, and Kutas (2000) visually presented stimuli sentences containing some class-ambiguous words to assess word class processing. They reported that N400 were more negative in response to word-class ambiguous items. Pseudo words elicited the most increased N400, especially when used as verbs as opposed to nouns. Greater negativity was elicited when ambiguous items were used as nouns. Unambiguous nouns also elicited a greater negativity than unambiguous verbs. Unambiguous words, embedded in an incorrect context (i.e., a noun was used when a verb should have been used), elicited larger N400 and P600 responses. Similarly, Osterhout and Holcomb (1993) found larger N400 and P600 responses for grammatically incorrect sentences as compared to grammatically correct sentences.

v. *Visual versus Auditory Stimuli*

The N400 component has been reported using both visual and auditory modalities (Holcomb & Neville, 1990; McCallum, Farmer, & Pocock, 1984). Connolly, Byrne, and Dywan (1995) and Byrne, Dywan, and Connolly (1995a, 1995b) used a combination of auditory and visual stimuli and conducted three related N400 studies. The results of these studies showed that N400 could be elicited by semantic errors in both child and adult participants. Larger N400 amplitude was elicited only when the vocabulary was understood by the participants. One difference in response for auditory versus visual stimuli includes an earlier and more prolonged effect of the N400 for auditory presentation, slightly lateralized to the right hemisphere (Holcomb & Neville, 1990).

However, there are very few studies investigating the N400 effects using only the auditory stimuli, especially how each word with and without meaning elicit N400 in school going typically developing children and in children with dyslexia. Also, there are fewer studies done on school aged typically developing children reporting N400 (Byrne, Conolly, MacLean, Dooley, Gordon & Beattie., 1999; McCleery, Ceponiene, Burner, Townsend, Kinnear & Schreibman, 2010). Byrne, Conolly, MacLean, Dooley, Gordon and Beattie (1999) recorded ERP from 56 typically developing children in the age range from 5 to 12 years. The N400 amplitude was found to be significantly higher to the incongruent picture-word pair than to the congruent picture-word pair. This effect was found for each of the four age groups i.e., 5 to 6 years, 7 to 8 years, 9 to 10 years, and 11 to 12 years. Coch, Maron, Wolf and Holcomb (2002) studied N400 for words in 10 to 11 years aged children. But the stimulus consisted only of visual and pictorial representations of the words. However, there are very few studies which have recorded N400 responses in individuals with dyslexia.

2.6 N400 in Dyslexia

Studies discussed earlier have indicated that the reading disorder in children with dyslexia is because of the phonological and/or semantic impairment seen in them. There are very few studies done on N400 in children with dyslexia investigating phonological and/ or semantic impairment (Bonte & Blomert, 2004; Russeler, Becker, Johannes, & Munte, 2007). They report of abnormalities in the N400 responses in children with dyslexia and also in adults with dyslexia. The abnormalities seen dyslexic adults and reading-age children in the N400 component compared to fluent readers are delayed latencies (Brandeis, Vitacco, & Steinhausen, 1994; Neville, Coffey, Holcomb, & Tallal, 1993), reduced amplitude and concentration to frontal areas (Stelmack & Miles, 1990) or increased amplitudes (Robichon, Besson, & Habib, 2002). However, it should be noted that a recent study did not find differences between dyslexic and normal children in the N400 response, but did find abnormalities in earlier ERP-components (Bonte & Blomert, 2004). Stelmack et al. (1988) found larger frontal N400 amplitudes for normal readers with respect to reading disabled children during word recognition. They believe that this effect is consistent with a more extensive semantic evaluation or memory search attributed to that component. In a sentence reading experiment to study the effect of semantic priming, the children with dyslexia demonstrated less negative N400 component for incongruent endings which was parieto-centrally distributed (Brandeis, Vitacco, & Steinhausen, 1994). They reported that later segment of the N400 was delayed in children with dyslexia. In contrast, studies have reported normal N400 priming effects in both children and adults with reading disorders (Silva-Pereyra et al., 2003; Russeler, Probst, Johannes, & Munte, 2003). A recent study by Schulz et al. (2008) using both fMRI and ERP demonstrated group differences between children with dyslexia and control children. A reduced N400 effect for incongruent sentence endings but not for the congruent sentence endings was found in children with dyslexia compared to control children. However, this difference was not mirrored in the behavioral results as the children with dyslexia demonstrated greater errors both in congruent and incongruent sentence endings. Friedrich and Friederici (2006) observed that the N400 component in 19 months old children elicited by semantically congruent/ incongruent stimuli could discriminate the children who showed poor expressive language skills at a later age i.e., at 30 months from the children who had age-adequate expressive language skills. These results suggest that the N400 response compared to behavioral scores could serve as a sensitive index of lexical and semantic processing deficits.

Though the N400 is associated with semantic processing, it has been shown that it is modulated by phonological factors. A deviant attenuated phonological priming N400 effect was noticed when word pairs which rhyme were visually presented in adolescents with dyslexia (Ackerman, Dykman, & Oglesby, 1994). McPherson, Ackerman, Holcomb, and Dykman (1998) and McPherson and Ackerman (1999) also reported abnormal phonological N400 effects in response to both auditory rhyming and auditory alliteration in adolescents with dyslexia. They found that these deficits varied as a function of the subtype of reading disability. They divided the reading disabled population into two groups based on their scores on visual non-word decoding task (McPherson et al., 1998) and an auditory phonological task (McPherson & Ackerman, 1999). The results in their study revealed that phonetic dyslexics showed a normal N400 priming effect for auditorily presented words, but dysphonetic dyslexics did not. The difficulties with phonological awareness tasks in dyslexics might be reflected in the deviant phonological N400 effects in them. However, N400 priming effects in children with dyslexia were found comparable to those seen in normal readers while studying implicit phonological processing (two-word alliteration priming) during spoken word recognition (lexical decision task) (Bonte & Blomert, 2004). As most of the previous studies use more complex stimuli such as sentences, series of words or with a prime, it is difficult to study how the semantic and phonological processes act separately. There are not any studies using ERPs investigating how implicit phonological processing is taking place during recognition of isolated words without a prime. Also, none of the previous studies have put an effort in sub typing the dyslexics using ERP measures.

It is important that an assessment of phonological processing is done at an explicit as well as implicit level in order to understand the relative difficulty of a child at various levels such as lexical access, decoding, phonemic categorization and awareness. The difficulties at various levels are sparsely studied in children with dyslexia. The semantic and phonological processing in children with dyslexia can be well understood using isolated words. As it has been discussed that N400 measure serve as a sensitive index to study semantic processing in dyslexics, this N400 measure can be effectively used to classify the children with dyslexia based, which may in turn help us better understand the semantic or phonological deficits in them. Hence, the present study investigated the event-related potential (ERP) correlates of implicit phonological processing during the recognition of spoken words in typically developing children and children with dyslexia. The present study has further attempted to sub type the group with dyslexia using ERP measure (N400).

CHAPTER 3: METHOD

The aim of the present study was to compare the behavioural correlates with event-related potential (ERP) correlates of implicit phonological processing during the recognition of spoken words in children with dyslexia and typically developing children. The study also attempted to subtype the group with dyslexia based on ERP measures.

3.1 Participants

The participants included three groups- Group 1 with typically developing children (TDC) in the age range of 8-10 years, group 2 included TDC in the age range of 9-10 years and group 3 included children with dyslexia in the age range of 8-10 years. Thirty typically developing children and 15 children with dyslexia were selected for the study. Each group was divided into two subgroups considering the age of the children as 8-9 years and 9-10 years. Children with dyslexia were selected based on the diagnosis made by Speech-Language Pathologists and Clinical Psychologists. The following inclusionary criteria were followed for selecting the children for the present study:

- All the children were screened using the WHO ten disability checklist (cited in Singhi, Kumar, Prabhjot & Kumar, 2007) and Developmental screening test (Bharath Raj, 1972) to rule out any sensory, motor, behavioural, or intellectual deficits.
- ELTIC (English Language Test for Indian Children; Bhuwaneshwari, 2010) was administered for adequate English language skills in the children.
- Native language of all the participants was Kannada with English as the medium of instruction in school.

- All the participants had Air conduction thresholds and bone conduction thresholds within 15 dB HL at octave frequencies from 250 Hz - 8 kHz and 250 Hz - 4 kHz respectively (ANSI S3.21, 2004).
- There were no symptoms of otological and neurological disorders.
- There was no history of any middle ear pathology. “A” type tympanogram with normal ipsilateral and contralateral acoustic reflex thresholds were obtained for all the participants.
- Participants with good speech perception in noise with SPIN scores of more than 60% were considered for the study

3.2 Instrumentation

The following instruments were used to carry out the study,

- A calibrated two-channel Madsen Orbiter-922 clinical audiometer (version 2) with TDH-39 headphones and Radio ear B-71 bone vibrator to establish air conduction and bone conduction pure tone thresholds respectively.
- A calibrated Grason Stadler Inc.-Tympstar immittance meter (version 2) to rule out middle ear pathology.
- Compumedics Neuroscan instrument with Scan™ 4.4 module along with Quick Cap®, Model C190 for recording of cortical evoked event related potentials. And Stim^2 version 4.4 module was used to deliver the stimulus.
- A personal computer with DMDX software version 3.13.0 (Forster & Forster, 2003) to carry out the behavioural task.

3.3 Preparation of stimuli

A list of 100 stimuli was prepared which included 50 pairs of words - non words (e.g. leaf-meaf). All the words selected were picturable which occurred in the vocabulary of 8-10 year old children. The non- words were prepared by substituting the initial phoneme of the word conforming to the rules of English. It was also made sure that the changed phoneme in the non-word accounted to the frequency spectrum of the initial phoneme of the word. This stimuli list was given to five experienced judges (Speech-Language Pathologists and Audiologists) for familiarity rating on a three- point scale of 'highly familiar', 'familiar', and 'unfamiliar'. Out of the 50 word pairs, 30 pairs which were rated as highly familiar or familiar by at least three out of the five judges were selected. The list of 30 words and 30 non-words is given in the Appendix-1. The selected 30 pair of words was recorded by 4 male speakers. The audio samples were given for goodness rating to 5 audiologists. The audio samples were rated on a 0-5 rating scale, 5 representing the higher quality and 0 representing the poorest. The ratings were done by considering the parameters: intelligibility, clarity, loudness, naturalness and the overall quality of the audio sample. The audio sample which got the highest rating was selected as the final stimulus.

3.4 Stimuli presentation

Two tasks were considered for the study.

- » Behavioural task
- » ERP measure

For the behavioural task, the 30 recorded words were programmed on DMDX software for presentation. The presentation of the stimuli were controlled and was presented through the DMDX software version 3.13.0 (Forster & Forster, 2003) for measuring the response times (RTs) and accuracy of responses. A practice session with 10 stimuli (5 words & 5 non-words) was given to familiarize the subjects with the instructions and task. Stimuli words in each list was randomized and presented.

For the ERP recording, the stimuli were presented using Gentask module in Stim^2. Each word and non-word was presented twice in a list. Thus, the list consisted of 120 stimuli. A total of 4 lists were made arranging the words and non words in a random order. Each participant was presented two out of the four lists randomly during the ERP recording. The inter stimulus interval between any two word in a list was 3000 ms. Different trigger values were specified for word and non-word respectively. The stimuli were presented binaurally at 60 dB SPL using ER-3A insert earphones.

3.5 Procedure

The following procedure was carried out to record the responses during behavioral and ERP task in both TDC and children with Dyslexia.

Behavioral task

All the participants were tested individually in a quiet room. The recorded stimuli which was prepared for ERP measure was also used for the behavioural task. The stimuli (Appendix 1) were presented using a multimedia head phone. The subjects were instructed as follows: “You will hear words. It may be true words/ meaningful words or false words/non words/ non meaningful words. You have to press ‘1’ for a meaningful word and ‘0’ for a non-meaningful word as soon as you hear the stimuli”. Reaction times in milliseconds were recorded and stored in the computer and error rates were calculated.

A ‘+’ sign appeared on the screen for 300 ms before the stimuli was presented. This would help the subject to be vigilant for the upcoming stimuli. The target word was then presented while the screen remained blank and remained so for the next 4000ms or till the subject responded, whichever occurred first. If the subject failed to respond to a target within 4000ms, that item was recorded as an error.

For the ERP measure, the subjects were considered with a gap of minimum 10 days after the behavioural test to avoid any learning effect. The stimuli were also presented in a random order to avoid order effect.

ERP measure

The cortical event related potentials were recorded using SynAmps^2. The participants were seated comfortably in a reclining chair. The Quick Cap consisting of 64 sintered silver chloride electrodes was used for recording evoked potentials. The event related potential was recorded from 15 electrode sites of 10-20 system: Fz, FCz, Cz, CPz, Pz, F3, F4, C3, C4, C5, C6, T7, T8, P3 & P4 (Jasper, 1958). The scalp distribution of different electrode sites is depicted in the Figure 3.1. Linked mastoid was used as a reference/ active electrode. An electrode site between FPz and Fz was used as ground electrode. The electrode impedance was lesser than 5kΩ. The participants were shown a cartoon video while placing the electrodes to distract their attention and facilitate electrode placement. A blunt needle was used to clean the electrode site. Quick Gel™ filled up in the syringe was used as conduction gel to bridge the scalp with the electrode surface.

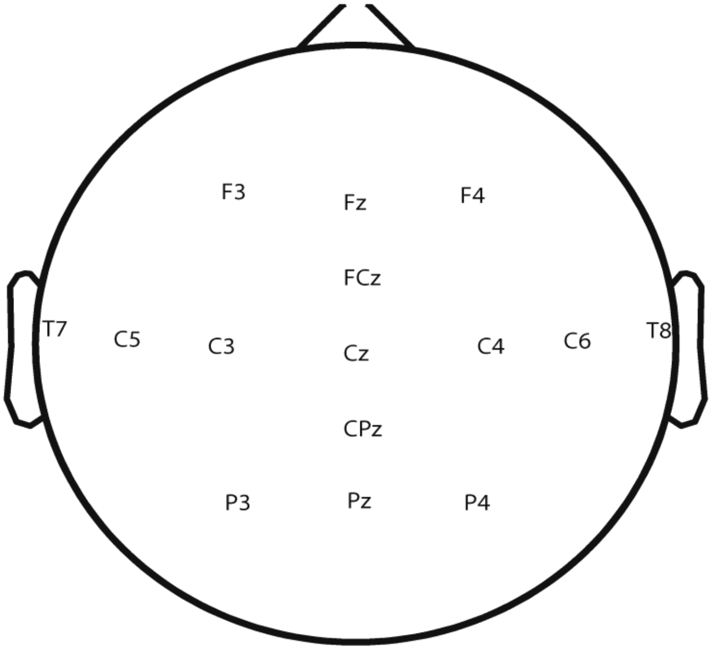

Figure 3.1 Scalp distribution of various electrode sites used in the present study

A continuous EEG data was recorded and digitized at a sampling rate of 1000 Hz. The data was low pass filtered at 100 Hz, and high passing DC. The time window of 1000 ms with a pre stimulus interval of 200 ms was considered for online averaging. The corresponding trigger values as given in Stim^2 was entered such that the responses recorded will be time locked with the stimulus given. To maintain the attention of the participants, they were instructed to press the button no.1 on a response box if they hear meaningful word and to press the no. 2 on a response box if they hear non-meaningful word. Two recordings were obtained to check for the replicability of the waveforms. The total duration of the testing was approximately one hour per participant.

3.6 Scoring and Analysis

On behavioral tasks, the reaction time was recorded in milliseconds (ms). All wrong responses and those responses which exceeded the 4000ms frame duration were eliminated from the data analysis. This was done for both the groups 1 and 2. Accuracy was calculated for both words and non-words. A score of ‘1’ was provided for each correct response and ‘0’ for wrong/ absent response. The behavioral data was coded and tabulated and then subjected to statistical analysis**.**

Offline analysis of ERP waveforms

The continuous EEG waveform was DC offset corrected with a polynomial order of 2 to decrease the drift in the waveforms. The DC corrected waveforms were band pass filtered at 0.1-10 Hz. The continuous filtered EEG waveform was epoched from -100 to 1500 msec and was baseline corrected. Finally the epoched files were averaged to obtain different waveforms for words and non words. The negativity between 400 to 800 ms was marked as the N400 peak. The peak amplitude and latency of N400 for 15 channels was calculated and tabulated for further statistical analysis. Appropriate statistical analysis was done using Statistical Package for the Social Sciences (SPSS) version 17.0 software. The following statistical analyses were used to analyze the data,

- Mixed ANOVA was done to examine the interaction of groups with stimuli on reaction time and accuracy measures.
- A Duncan post hoc analysis was done to explore which group is significantly different from the other for both reaction time and accuracy measures.

- Mann Whitney test was done to compare the performance of typically developing children and children with dyslexia on reaction time and accuracy measures.
- Paired sample t-test was done to compare RT and accuracy for words and non-words across three groups (8-9 year old TDC, 9- 10 year old TDC & children with dyslexia in the age range of 8-10 year)
- Mixed ANOVA was done to examine the interaction of groups with stimuli and channels on N400 peak amplitude and latency.
- Repeated measures Analysis of Variance was used to compare latency and amplitude of N400 peak across different channels and stimuli (word & non-word) in typically developing children and children with dyslexia separately.
- Paired sample t- test was used to compare the latency and amplitude of N400 peak for word and non-word in each channel and in each group separately.
- Bonferroni's pair wise comparison and Least Significant Difference (LSD) was used as post hoc tests to arrive at the channels which are significantly different in peak amplitude and latency of N400 for words and non-words separately in each group.
- Mann Whitney U test was done to compare between typically developing children and children with dyslexia on N400 peak latency and amplitude for word and non-word. .
- Karl Pearson's correlation was used to find the relation between behavioral measures and ERP measures
- Discriminant function analysis and Cluster analysis was done for sub typing of children with dyslexia based on ERP measures for non-words.

CHAPTER 4: RESULTS AND DISCUSSION

The aim of the present study is to compare the behavioural correlates with event-related potential (ERP) correlates of implicit phonological processing during the recognition of spoken words in children with dyslexia and typically developing children (TDC) and thus an attempt to subtype the dyslexia. The participants included were 30 typically developing children divided into two groups: 8-9 years and 9-10 years old and 15 children with dyslexia in the age range of 8-10 years. Both behavioral and ERP data were analyzed. The behavioral data included reaction time (RT) in milliseconds and accuracy for words and non-words. The ERP data included latency (in milliseconds) and amplitude (in micro volts) of the N400 peak at 15 different channels. Various statistical procedures as mentioned above were employed to analyze the behavioral and the ERP data.

The results of the present study are discussed under the following sections:

- Comparison of performance of typically developing children (TDC) and children with dyslexia on behavioral measures
- Comparison of performance of typically developing children (TDC) and children with dyslexia on ERP (N400) measures
- Correlation of behavioural measures and ERP (N400) measures in typically developing children (TDC) and children with dyslexia
- Sub typing of dyslexia using ERP (N400) measures

4.1. Comparison of performance of typically developing children (TDC) and children with dyslexia on behavioral measures

The results of performance of TDC and children with dyslexia for words and non words were analyzed for reaction time (RT) and accuracy measures. All inaccurate responses and those responses which exceeded the 4000ms duration were eliminated from the data analysis. The reaction time was tabulated in milliseconds (ms). Accuracy was calculated by providing a score of '1' for each accurate response and '0' for inaccurate / absent response.

4.1.1. Reaction time measure

The reaction time (in ms) was analysed for word and non-word in 3 groups i.e., Group 1 (8-9 year), Group 2 (9-10 year) of typically developing children and Group 3 (children with dyslexia). The mean and standard deviation (SD) for performances of two groups of TDC (Group 1 & Group 2) and children with dyslexia (Group 3) on words and non words for reaction time were measured using descriptive statistics and it is shown in Table 4.1.

Table 4.1

Mean and SD for reaction time performance on words and non-words in TDC and dyslexics

Groups	**N**	**Mean (SD)**	
		Word RT (ms)	**Non word RT (ms)**
8-9 years TDC	15	735.13 (196.69)	984.19 (347.67)
9-10 years TDC	15	680.22 (250.74)	900.87 (401.99)
Total	30	707.68 (223.17)	942.53 (371.70)
Dyslexics	14	1012.62 (225.16)	1308.48 (346.54)

It is evident from the Table 4.1 that for TDC, the reaction time for words (Mean=707.68 ms; SD=223.17ms) was shorter compared to non words (Mean=942.53 ms; SD=371.70ms). For 8-9 year old TDC, the performance on words was faster (Mean= 735.13 ms; SD= 196.69ms) than non words (Mean= 984.19ms; SD= 347.67ms). For 9-10 year old TDC also, the performance on words was faster (Mean= 680.22 ms; SD= 250.74ms) than non words (Mean= 900.87ms; SD= 401.99ms). A developmental trend in the performance of TDC for both words and non-words was also observed (see figure 4.1).

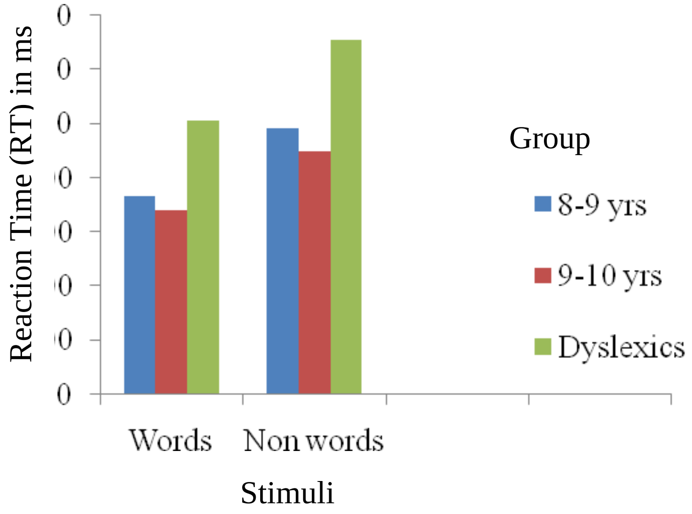

Figure: 4.1 Comparison of mean reaction time for words and non words across groups

Out of 15 children with dyslexia one of the participants did not give any accurate response in recognizing non word. Hence, this data was eliminated. Therefore a total of 14 children were considered for further analysis for reaction time measure. It is evident from Table 4.1 that for the children with dyslexia the performance on reaction time for non words was longer (Mean=1308.48; SD=346.54ms) compared to words (Mean=1012.62; SD=225.16ms).

Mixed analysis of variance (Mixed ANOVA) was carried out to see the interaction of groups (Group 1, Group 2 & Group 3) with stimuli (word, non-word) on reaction time measure. The analysis of results on Mixed ANOVA revealed a significant main effect across words and non-words i.e. F (1, 41) = 64.29, $p<0.05$. That is there is a significant difference in performance for words and non words. The results also revealed that there is no significant interaction effect across tasks and groups. But there was a significant effect in performance across groups [F (2, 41) = 6.808, $p< 0.05$]. Duncan Post-Hoc test revealed no significant difference between the two groups of TDC; but a statistically significant difference between children with dyslexia and the other two groups of TDC (Group I & Group 2) was observed.

Since there was no significant difference between the two typically developing children groups (Group 1 & Group 2) on their performance on reaction time, both the groups were combined into a single group of TDC. So the TDC group included a total of 30 children and dyslexic group included 15 children. As there was unequal number of participants in both the groups, non parametric tests were done to compare the two groups. Mann Whitney test revealed that there is a statistically significant difference between the two groups (TDC & children with dyslexia) for their performance on reaction time for words and non words. ($Z = 3.419$, at $p < 0.05$)

As previously evidenced in literature reaction time was less for words as compared to non-words (Pizzioli & Schelstraete, 2007; Taroyan & Nicolson, 2009; Sela et al., 2011). There is some processing beyond the recognition point at which the non-word deviates from a word (Taft & Hamply, 1986). It was also found that the subjects may take longer time to identify a non-word if it was similar to true words. These could be the reason for longer reaction time for non-words seen in both TDC and children with dyslexia in the present study. Also the lexical processing of words depends largely on lexical route which is more automatized and processing of non-words depends on a sublexical route. Processing through the more automatized lexical route will be faster than that through the sublexical route which may take more time. Hence the reaction time for words was shorter and longer for non words. The participants of the TDC group (8-9 year old & 9-10 year old) exhibited age effect with older group performing better than the younger group even though it was not statistically significant. This can be due to the fact that as children grow older, task such as lexical processing becomes more automatic and faster.

The findings also indicated that the performance of children with dyslexia was poorer compared to their TDC counterparts. That is, the children with dyslexia required more time to identify a word as word/ non word as compared to TDC. The same has been depicted in Figure 4.1. Further, Paired Sample t-test was done to analyze the RT (in ms) for words and non words in each group (TDC & children with dyslexia) separately. A significant difference was found for performance of TDC between word and non-word on reaction time measure ($t=-6.667$, ($p<0.05$)], and also for performance of children with dyslexia ([$t=-4.603$, ($p<0.05$)].

4.1.2 Accuracy measures

The accuracy for word and non-words was analysed in 3 groups i.e., Group 1 (8-9 year), Group 2 (9-10 year) of typically developing children and Group 3 (children with dyslexia in the age range of 8-10 year). The mean and standard deviation (SD) for performances of two groups of TDC (Group 1 & Group 2) and children with dyslexia (Group 3) on words and non words for accuracy measure was calculated using descriptive statistics and is depicted in Table 4.2.

Table 4.2

Mean and SD for performance on words and non-words for accuracy for TDC and dyslexic children

Groups	N	Mean (SD)	
		Word accuracy	Non word accuracy
8-9 years TDC	15	25.40 (3.38)	21.13 (2.79)
9-10 years TDC	15	25.40 (2.41)	21.33 (3.75)
Total	30	25.40 (2.88)	21.23 (3.25)
Dyslexics	15	26.67 (2.19)	19.67 (7.54)

It is evident from the Table 4.2 that for TDC, the accuracy for words (Mean=25.40; SD=2.88) was better compared to non words (Mean=21.23; SD=3.26). For 8-9 year old TDC, the performances on words was better (Mean= 25.40; SD= 3.37) than non words (Mean= 21.13; SD= 2.79). For 9- 10 year old TDC also, the performance on words was better (Mean= 25.40; SD= 2.41) than non words (Mean= 21.33; SD= 3.75). For children with dyslexia, the mean accuracy for words (Mean=26.67; SD=2.19) was found to be higher than that for non words (Mean=19.67; SD=7.54).

Mixed analysis of variance (Mixed ANOVA) was carried out to see the interaction of groups (Group 1, Group 2 & Group 3) with stimuli (word, non-word) on accuracy measure. The analysis of results on Mixed ANOVA revealed a significant main effect across words and non words [F (1, 42) = 35.07, $p<0.05$]. That is there is a significant difference in performance for words and non words. The results also revealed that there is no significant interaction effect across tasks and groups and also no significant difference in performance across groups. Mann Whitney test was done combining the two TDC group (Group1 & Group 2). This result also revealed that there is no significant difference between the two groups for their performance on accuracy for words and non words.

The results indicated that more errors were observed for performance on non-words than words in all the 3 groups. As depicted in figure 4.2, the error rates were high for children with dyslexia in identifying the non words.

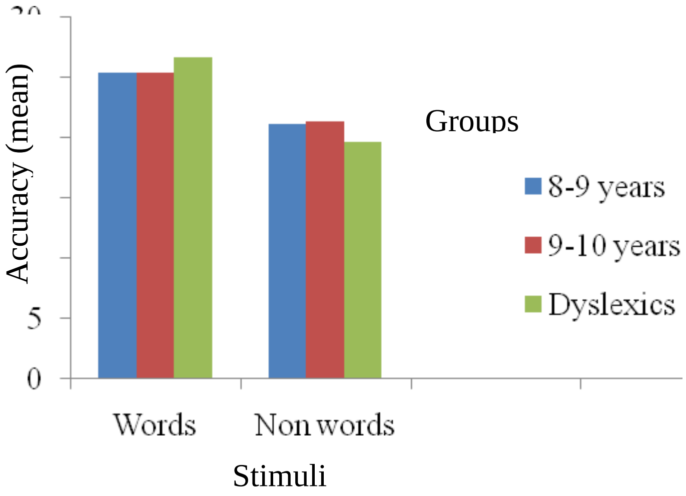

Figure: 4.2. Comparison of mean accuracy for words and non words across groups

Further, Paired Sample t-test was done to analyze the accuracy for words and non words in each group (TDC & children with dyslexia) separately. A significant difference was found for performance of children between word and non-word on accuracy measure in TDC [$t=4.842$, ($p<0.05$)], and in children with dyslexia [$t=-3.670$, ($p<0.05$)].

From the Table 4.1 it was observed that reaction time was shorter for words as compared to non words except in three TDC (two in Group 1 & one in Group 2) and two children with dyslexia whose reaction time for words was found to be slightly longer than that for non words. The performance on reaction time for the above mentioned three TDC were (838.98 ms, 818.21 ms), (508.82ms, 492.78ms), (556.87ms, 530.79ms) and that of children with dyslexia were (1239.69ms, 1174.94ms), (992.61ms, 924.13ms) for words and non words respectively. Also the RT was longer for children with dyslexia as compared to that of TDC. In TDC, the average reaction time for words ranged from 458.05 ms (for the word “grapes”) to 1261.38 ms (for the word “bench”) and for non words it ranges from 685.78 ms (for the stimuli “zench”) to 1238.73 ms (for the stimuli “pum”). In children with dyslexia, the average reaction time for words ranged from 723.42 ms (for the word “grapes”) to 1689.84 ms (for the word “pipe”) and for non words it ranges from 880.31ms (for the stimuli “jouth”) to 1788.73 ms (for the stimuli “plass”).

Results of behavioral task also showed that the children with dyslexia required more time than the age matched TDC to recognize the word or non word. The children with dyslexia were found to have problems in phonological awareness and decoding which may lead to longer time in the lexical processing which could be attributed to the poor performance of children with dyslexia in the present study. According to phonological deficit theory (Liberman, 1973; Snowling, 2000), the ability to segregate and manipulate the speech sounds is affected in children with dyslexia which will also result in slower lexical access speed as evidenced in the present study.

Another possible explanation for the observed deficit in children with dyslexia is poor verbal short term memory. According to (Snowling, 2001) poor verbal short term memory is another manifestation of children with dyslexia. The children are required to keep the heard utterance in their short term memory while it is being processed; when incapable to do so will lead to poor performance in phonological tasks. Thus the poor performance of children with dyslexia in the present study is likely to result from poor verbal short term memory. A general deficit in children with dyslexia such as poor/ reduced attention will also affect the outcome of the performance. Nicolson and Fawcett (1994) stated that a general (non phonological) deficit which reflect in slower stimulus classification speed and a linguistic (phonological) deficit which reflect in slower lexical access speed may be contributing to the slowness of children with dyslexia. This reason holds good here also.

The observed deficits in children with dyslexia could also be explained through auditory temporal processing deficit theory. According to auditory temporal processing deficit theory (Tallal, 1980; Tallal, Miller, & Fitch, 1993), children with dyslexia have a deficit in rapid auditory processing. That means these children may have difficulties in developing sufficiently rapid processing rates for word recognition. This could be a reason for the longer reaction times for children with dyslexia in the present study. Children with dyslexia were also reported to have speech perception difficulties (Godfrey et al, 1981). Such speech perception deficits may lead to deficits in the ability to manipulate and process speech sounds and may also result in longer duration for lexical processing as seen in the performance of children with dyslexia in the present study.

Children with dyslexia were also reported to have poor performance on auditory tasks such as frequency discrimination (McAnally & Stein, 1996; Ahissar et al, 2000), temporal order judgment (Nagarajan et al, 1999; Tallal, 1980) and also poor categorical perception of certain sound contrasts (Adlard & Hazan, 1998; Mody et al., 1997; Serniclaes et al, 2001). All these auditory processing deficits will interfere with the identification of phonological cues that are typical for spoken word recognition and hence the children with dyslexia may perform poorer and slower compared to normal participants. Poorer performance on temporal related tasks in dyslexia could be related to temporal processing deficits explained in lieu of the temporal processing deficit theory (Tallal, 1980). Sub groups of children with dyslexia are found to exhibit difficulties in auditory related tasks such as spectral parameters of frequency. Hence, a deficit in spectral related characteristics such as frequency discrimination could lead to poorer perception of speech sounds which require fine-grained auditory discrimination such as minimal pairs of words. Literature has suggested that phonological problems in dyslexia are often due to a more fundamental deficit in auditory temporal processing mechanisms (Tallal, 1980). It was also reported that children with dyslexia showed impaired discrimination and sequencing brief and rapid acoustic stimuli when compared normal peers (Tallal, 1980; Tallal,Miller & Fitch, 1993). Further basic perceptual deficits could result in a host of deficits which include disruption in terms of development of the phonological system. This disruption could lead to problems in reading and spelling (Nagarajan et al., 1999; Wright et al., 1997).

The poor performance of the children with dyslexia in the present study could also be described using cerebellar theory (Nicolson & Fawcett, 1990; Nicolson, Fawcett & Dean, 2001), which says that cerebellar abnormality is the cause for the difficulties suffered by the children with dyslexia. The cerebellum is involved in speech perception (Mathiak, Hetrich, Grodd & Ackermann, 2002) and the automatization of any skill, whether motor or cognitive. So in children with dyslexia, abnormality in the cerebellum may lead to deficit in speech perception which will consequently result in poor performance on lexical processing. A weak capacity to automatize would also have an impact on the lexical processing and can result in longer reaction time as evidenced in the present study.

The results also revealed that the performance of children with dyslexia on non words were poorer than words indicating longer response time for non words. As discussed earlier, the lexical processing of words is dependent on the lexical route and that for non words is dependent on sub lexical route. Children exhibiting phonological deficits may have problems with the sub lexical route as a consequence of which they may show problems in non word processing. This could be the reason for the poor performance on non words of children with dyslexia in the present study. This finding of the present study is in consonance with the findings of Nicolson and Fawcett (1994) and Taroyan and Nicolson (2009) where they found that children with dyslexia had significantly longer response times.

Analysis of results on accuracy measures revealed that the accuracy for non words was poor compared to that for words indicating more errors for performance on non-words. Here also, performance of three TDC (two in Group 1 & one in Group 2) and one child with dyslexia was different, where they were more accurate in recognizing non words than words. The accuracy for performance of the above mentioned three TDC were (23, 26), (21, 23), (18, 26) and that of the child with dyslexia was (25, 26) for words and non words respectively. Comparing the performance of children with dyslexia and TDC, the performance of the former group was better for words. With respect to non words, the performance was poor for children with dyslexia. Words which were identified with 100 percent accuracy by TDC were “phone” and “milk” and those by the children with dyslexia were “leaf”, “socks”, “fish”, “phone”, “lion”, “glass”, “gum” and “light”. None of the non words were identified with 100 percent accuracy by the participants of two groups (TDC & children with dyslexia). It was also observed that, majority of the TDC made errors on the word stimuli “bus” and “brush”. That means the subject identified these words as non words. The maximum errors demonstrated by the children with dyslexia were on the word “mosque”. Considering non words, the stimuli “drush” had the maximum errors followed by the stimuli “pum” and “galk” in TDC and in children with dyslexia, the stimuli “drush” and “shirl” had the maximum errors followed by the stimuli “pum”. This means that the children identified those non words as true words.

With regard to accuracy the performance was poorer for non words compared to words indicating more inaccurate or wrong responses in recognizing non words. The study also failed to find a significant difference between TDC and children with dyslexia on their performance on accuracy. The tendency for more errors on non words can be explained by the fact that subjects occasionally confused the non words with real words, and this was more likely to happen with the shorter non words, since these had a greater proportion of phonemes in common with real words than did the longer non words.

Other factors such as attention and verbal short term memory also may affect the outcome of the performance on accuracy measures. For the processing of non words, the input has to be kept in the memory for a longer time as it utilizes the sub lexical route which is slower in action. Failure to do so could have resulted in absent or inaccurate responses. In the present study, 4000ms was only given for the participant to respond for a particular stimulus. So, the absent responses observed in the present study which resulted in lower accuracy could be a consequence of slower lexical access speed. The results of the previous studies (Pizziolo et al., 2007; Taroyan et al., 2009) indicated a lower accuracy for non words. The results of the present study confirm those of the above studies but contraindicated with the study by Sela et al (2011) which showed higher accuracy for pseudo words.

The present study shows that differences concern reaction times rather than accuracy. The children with dyslexia were as accurate as TDC of the same age in accepting words and refusing non words. Despite the fact that they were not less accurate, they were slower than age-matched peers in recognizing words and non words. Thus, children with dyslexia seem to be delayed and not deviant from the lexical developmental pattern. Similar kind of results was obtained by Pizzioli and Schelstraete (2007), where they investigated the children with Specific Language Impairment (SLI).

4.2. Performance of typically developing children (TDC) and children with dyslexia on ERP (N400) measures

The ERP measures included the peak latency (in milliseconds) and peak amplitude (in microvolts) of N400 potential. The peak latency and amplitude of N400 potential were measured across 15 different channels in 30 typically developing children and 15 children with dyslexia. The peak latency and amplitude of N400 was compared between words and non-words across different channels separately.

4.2.1. Performance of typically developing children (TDC) on ERP (N400) measures

The peak latency and amplitude of N400 was analyzed in thirty TDC of 8-9 year old and 9-10 year old, containing 15 children each. Figure 4.3 and Figure 4.4 shows grand averaged ERP waveforms of TDC children for words and non-words at Cz and 15 different channels respectively.

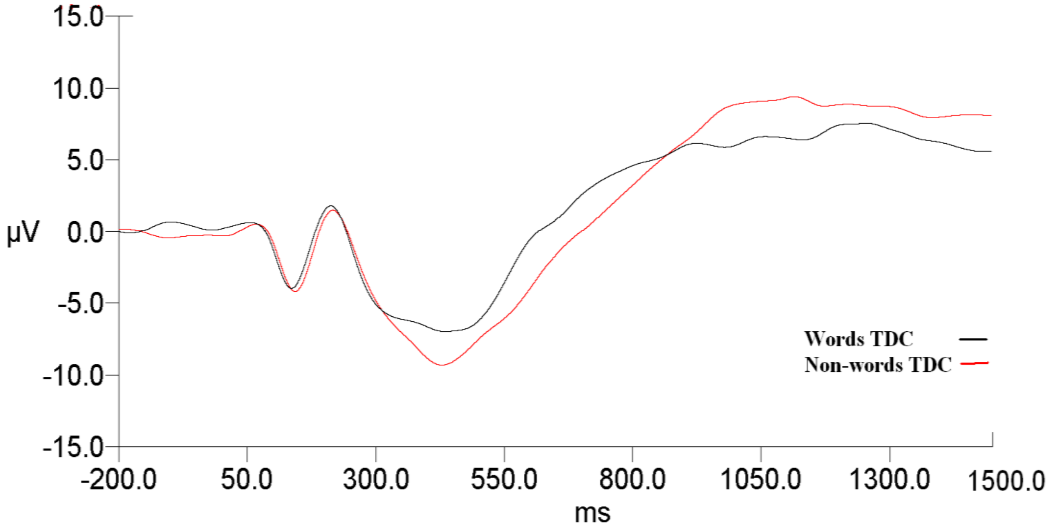

Figure 4.3 Grand average waveform of 30 TDC for words and non-words at Cz.

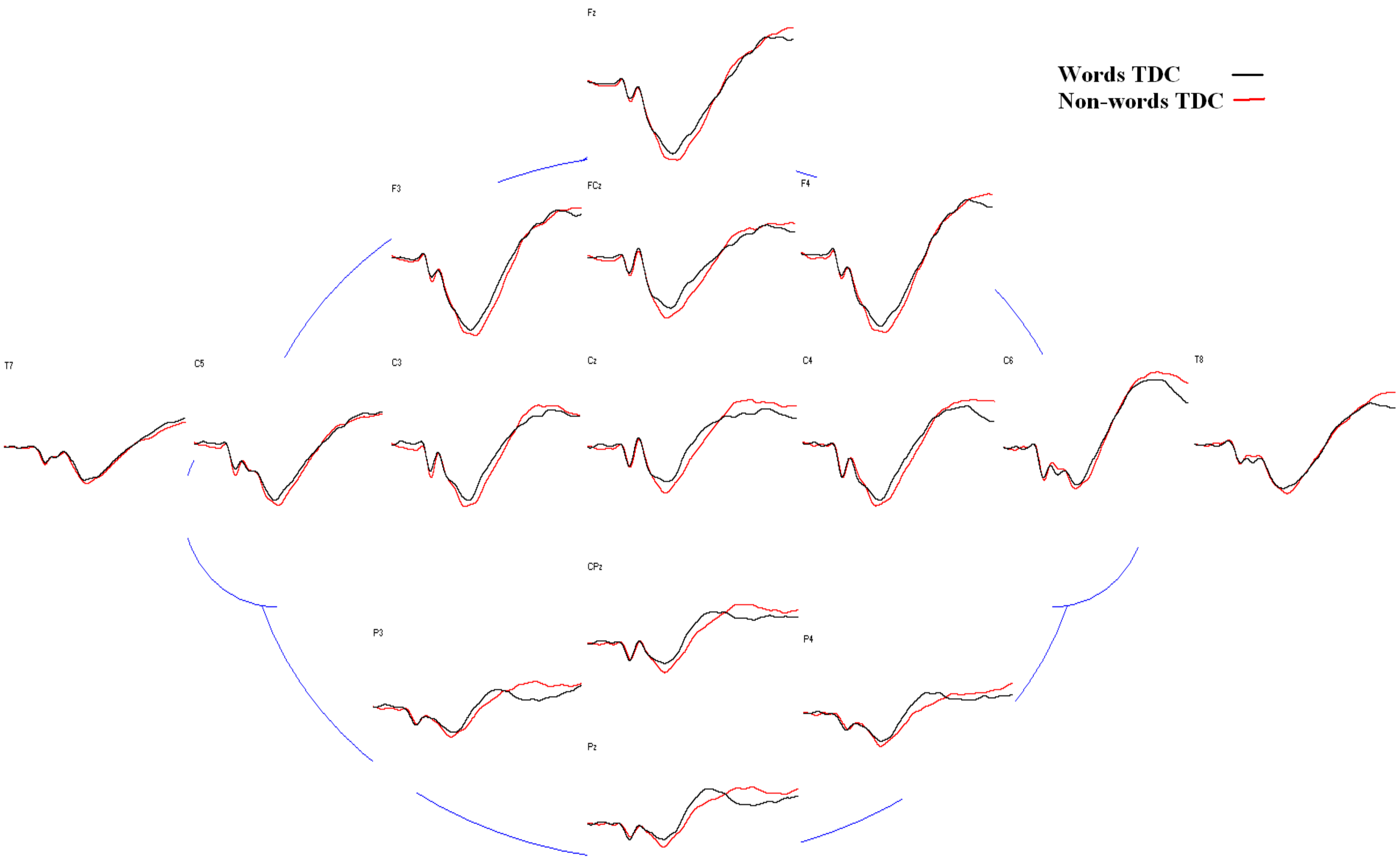

Figure 4.4 Grand average waveforms of 30 TDC at 15 different channels for words and non-words

Amplitude of N400

The peak amplitude of N400 was analysed for words and non-words in 2 groups i.e., Group 1 (8-9 year) and Group 2 (9-10 year) of typically developing children. From the Figure 4.3 & 4.4, it can be evidenced that the mean peak amplitude of N400 for non-words was greater than that for the words. The mean and SD of N400 peak amplitude for both word and non-word for Group 1 and Group 2 at 15 different channels are shown in Table 4.3.

Table 4.3

Mean and SD of peak amplitude of N400 for words and non-words in two groups of typically developing children at 15 different channels

	Word (Amplitude in µV)				**Non-word (Amplitude in µV)**			
	Group 1 (8-9 years)		**Group 2 (9-10 years)**		**Group 1 (8-9 years)**		**Group 2 (9-10 years)**	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
F3	-16.51	5.27	-17.60	6.66	-17.79	5.26	-22.38	5.97
Fz	-16.71	5.53	-17.57	7.37	-18.39	5.75	-22.02	7.79
F4	-16.65	5.15	-17.85	6.77	-17.85	5.22	-22.40	8.12
FCz	-12.76	5.19	-12.92	8.32	-14.26	4.59	-17.36	7.60
T7	-5.22	4.30	-7.40	5.93	-6.73	4.69	-9.91	5.16
T8	-8.67	4.54	-9.14	5.36	-9.11	2.91	-11.54	5.35
C3	-10.15	4.89	-11.99	5.30	-11.77	4.05	-15.39	6.18

Cz	-7.40	4.08	-8.02	8.32	-9.05	3.71	-11.38	7.64
C4	-9.73	6.06	-12.01	6.62	-11.49	4.64	-15.71	7.89
C5	-11.21	4.62	-11.84	5.16	-11.65	4.04	-14.69	5.14
C6	-8.47	4.51	-8.84	5.43	-6.65	2.78	-11.77	5.79
CPz	-5.86	3.72	-5.56	6.76	-6.46	3.92	-8.44	6.98
P3	-5.47	4.85	-6.93	5.39	-5.98	4.62	-8.71	5.65
Pz	-4.24	3.42	-4.15	5.62	-5.00	4.66	-6.77	6.14
P4	-6.80	3.54	-6.70	6.52	-7.65	3.39	-9.38	7.13

The results from Table 4.3 indicates that the mean N400 peak amplitude for non-word is greater than that for word. The difference in mean peak amplitude of N400 for words and non-words is greater in Group 2 when compared to Group 1. The difference in mean peak amplitude of N400 also varied across channels in both the groups. These differences can be well noted in the Figure 4.5.

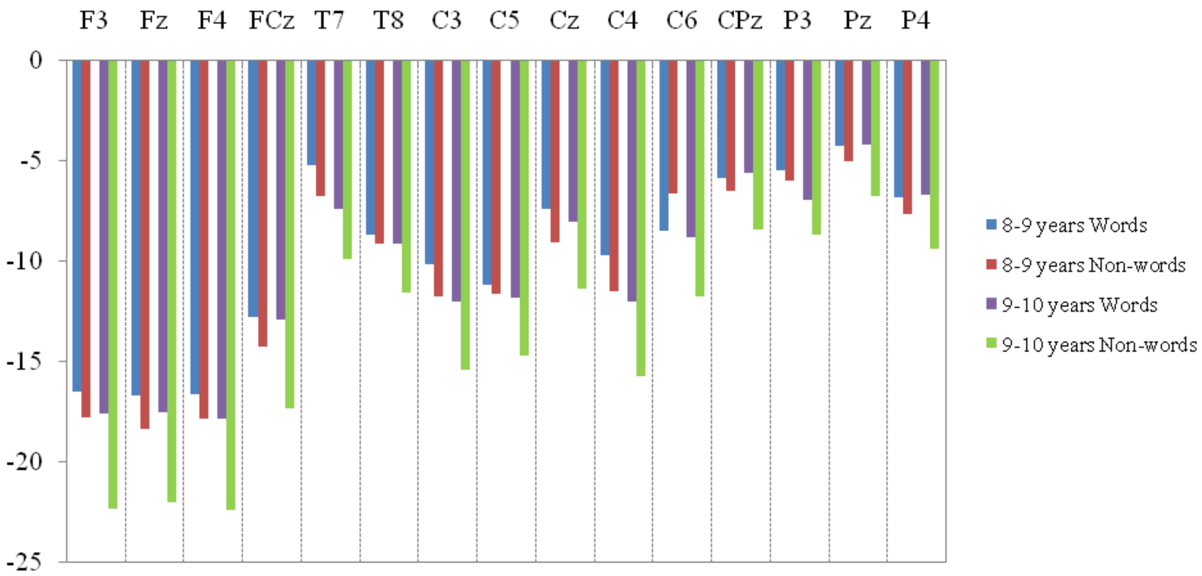

Figure 4.5 Mean N400 peak amplitude in 8-9 years and 9-10 years old TDC for words and non-words at 15 different channels

This difference in N400 peak amplitude for word and non-word is termed as "N400 effect". Hence, N400 effect was observed across channels. This indicates that there was N400 effect even when the stimulus is presented in auditory alone condition. The results also showed that the N400 effect can be seen for auditory stimuli without any semantic priming. This indicates that activation has taken place for lexical processing which is reflected from the N400 effect seen in terms of processing words and nonwords in the present study. Lau, Philips and Poeppel (2008) discussed the N400 effect in terms of the lexical view. According to this view, it has been postulated that the N400 effect reflects a facilitated activation of features represented in the long term memory for a lexical item. The lexical view hypothesis also implied that any factor that facilitated lexical access should reduce the N400 amplitude. Hence, for word-like nonwords which are associated with longer reaction times on lexical decision tasks were found to elicit larger N400 amplitudes for nonwords than words (Holcomb, 1990; Holcomb & Neville, 1993). The average absolute N400 peak amplitude for either word or non-word was found to be around 10μV. The previous studies have reported average N400 peak amplitude of around 8μV (Borovsky, Elman & Kutas, 2012; Nishida, 2005), which was found to be greater in the present study. This might be due to the stimulus used which was different from the previous studies or might be the negative shift observed in whole waveform due to attention given to the stimulus which has been called as processing negativity. It can also be seen from the Figure 4.4 that the N400 peak is broader and of more amplitude in frontal channels compared to other channels. There is difference in the amplitude of N400 for words and non-words in the parietal channels, but not as much as in the frontal channels. In temporal channels such as T7 and T8, T8 shows a little N400 effect while there is very lesser N400 effect seen in T7 when compared to T8. The coronal channels shows lesser N400 effect than the frontal channels and it decreases gradually from Cz to the C6 in right channels and to C5 in left channels.

Mixed analysis of variance (Mixed ANOVA) was carried out to see the interaction of groups (Group 1, Group 2) with stimuli (word, non-word) and channels (15 channels) as independent variables and N400 peak amplitude (in microvolts) as the dependent variable. The results indicated that there was a significant main effect for stimuli [$F(1,28)=19.101$, at $p< 0.01$)] and channels [$F(14, 392)=59.063$, at $p<0.01$]. A significant interaction effect was found between stimuli and groups [$F(1,28)= 5.967$, at $p<0.05$], and also stimuli and channels [$F(14,392)= 2.068$, at $p<0.05$]. There was no significant difference across groups [$F(1, 28)= 1.719$, at $p>0.05$].

As there was no significant difference across the two groups (Group 1 & Group 2 of TDC), the two groups were combined to form one group of typically developing children and was analysed further. As there was significant difference between stimuli on mixed ANOVA, Paired Sample t-test was done to compare the amplitude of N400 for words and non-words at each channel. The results indicated a significant difference between amplitude of N400 for words and non-words at channels F3 ($t=4.11$, at $p<0.01$), Fz ($t=3.96$, at $p<0.01$), F4 ($t=3.51$, at $p<0.01$), FCz ($t=4.03$, at $p<0.01$), T7 ($t=3.00$, at $p<0.01$), Cz ($t=3.09$, at $p<0.01$), C4 ($t=3.03$, at $p<0.01$), CPz ($t=3.54$, at $p<0.01$), Pz ($t=3.65$, at $p<0.01$), P4 ($t=3.47$, at $p<0.01$) and at channels C3 ($t=2.63$, at $p<0.05$), P3 ($t=2.27$, at $p<0.05$), and C5 ($t=2.47$, at $p<0.05$).

The topographical scalp distribution of activity from 0 ms to 1000 ms (1sec) in 100 ms interval is shown in Figure 4.6 and Figure 4.7 for words and non-words respectively. From the Figure 4.6, the activity was seen more in the frontal area at 400 ms, spreading towards the coronal areas more towards right from 500 to 600 ms when considered for words. There is no activity seen in the parietal areas. When non-words are considered in Figure 4.7, the activation follows the same pattern as for words, but there is more activity and spread of activation than words. It also involves some amount of activity in the parietal regions as well. This evidences the amount of N400 effect that is seen across channels in TDC. Irrespective of word or non-word, there is more activation towards right hemisphere than left hemisphere. This result is in conjugate with the study by Holcomb & Neville (1990), who opined that there is earlier and more prolonged effect of the N400 for auditory presentation, slightly lateralized to the right hemisphere. In their study stimuli paradigm consisted of priming task in auditory mode and in the present study there was no prime that was used, still yielding the same results. Furthermore, early studies have failed to show any change in the N400 amplitude when the prime was masked below conscious perception (Brown & Hagoort, 1993), contradicting the integration view of the N400 effect

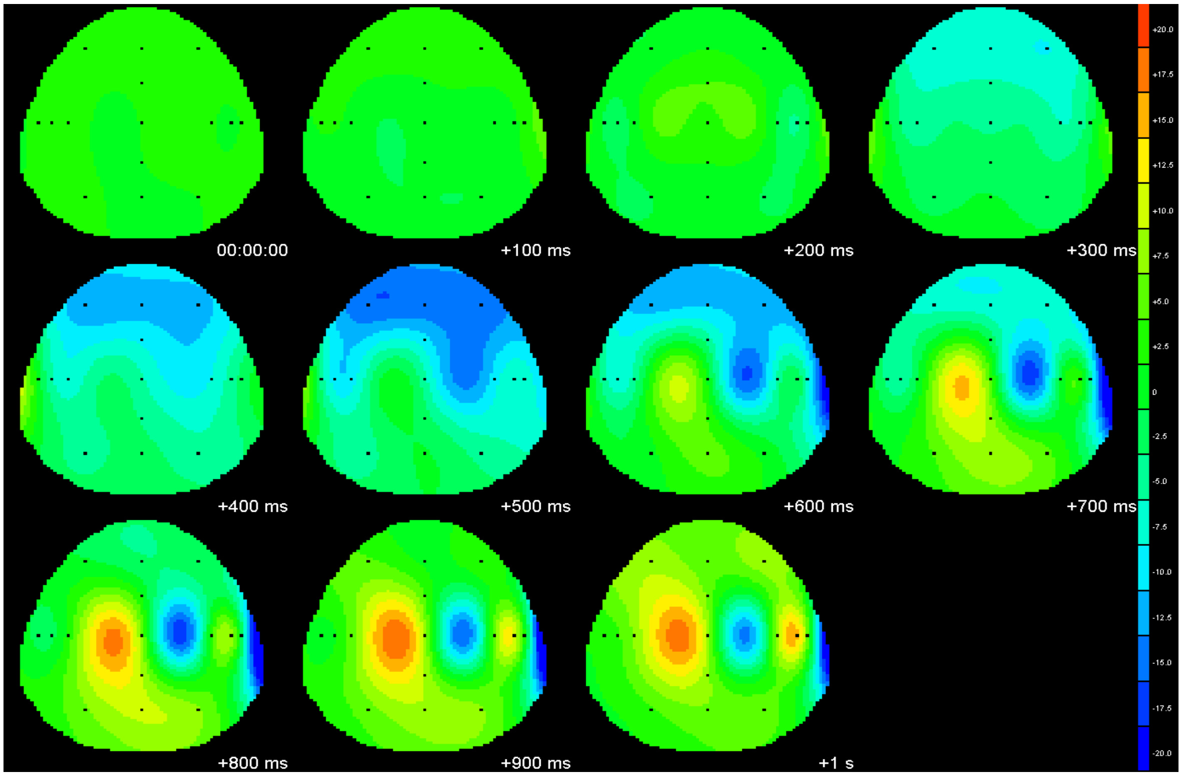

Figure 4.6 Scalp distribution of N400 peak from 0 to 1000 ms for words in TDC

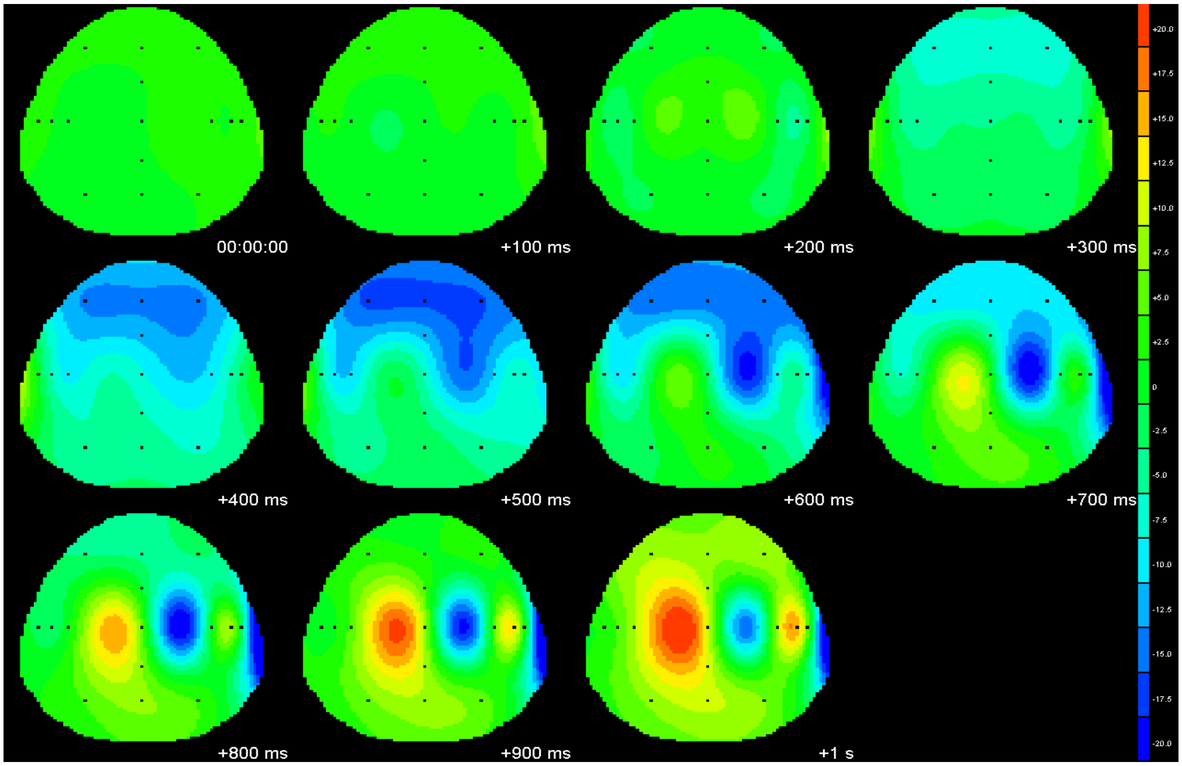

Figure 4.7 Scalp distribution of N400 peak from 0 to 1000 ms for non-words in TDC

The significant N400 effect for amplitude was seen in the frontal (F3, Fz, F4), fronto-central (FCz), coronal (Cz, C4, C3, C5), and parietal (CPz, Pz, P3, P4) channels, which is consistent with the previous researches (Byrne et al., 1999; Friedrich & Friederici, 2006; Holcomb & Neville, 1990; Kutas & Federmeier, 2000; Kutas & Van Petten, 1998; Landi & Perfetti, 2007; Lau, Almeida, Hines & Poeppel, 2009; McCleery et al., 2010; Lau, Philips & Poeppel, 2008). But along with these channels, the N400 effect is also seen in temporal channel (T7). This might be because of the only auditory mode used for presentation of the stimuli. The previous studies have either used visual stimuli or both auditory and visual stimuli for presentation of words (Connolly et al., 1995; Byrne et al., 1995a, 1995b; Byrne et al., 1999; McCleery et al., 2010). Figure 4.8 shows activation of different scalp areas at the N400 peak comparing for word and non-word in TDC.

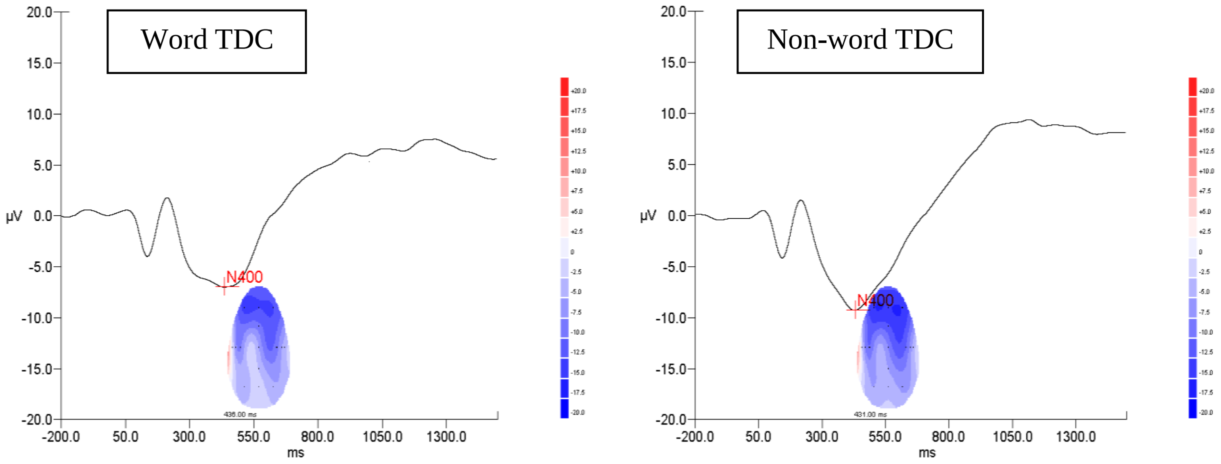

Figure 4.8 Scalp distribution at N400 peak comparing for words (left) and non-words in TDC

The results were analysed further to examine the amplitude of N400 peak at different channels for words and non-words separately. The qualitative analysis of results (Table 4.3) revealed that the mean peak amplitude of N400 was greatest at frontal channels such as Fz, F3, F4, FCz for both words and non-words. The coronal channels (Cz, C3, C4, C5, C6) and temporal channels (T7, T8) showed lesser mean N400 peak amplitude compared to frontal channels. The parietal channels such as P3, P4, Pz and CPz had the least N400 mean peak amplitude. These differences can be evidenced in Figure 4.9.

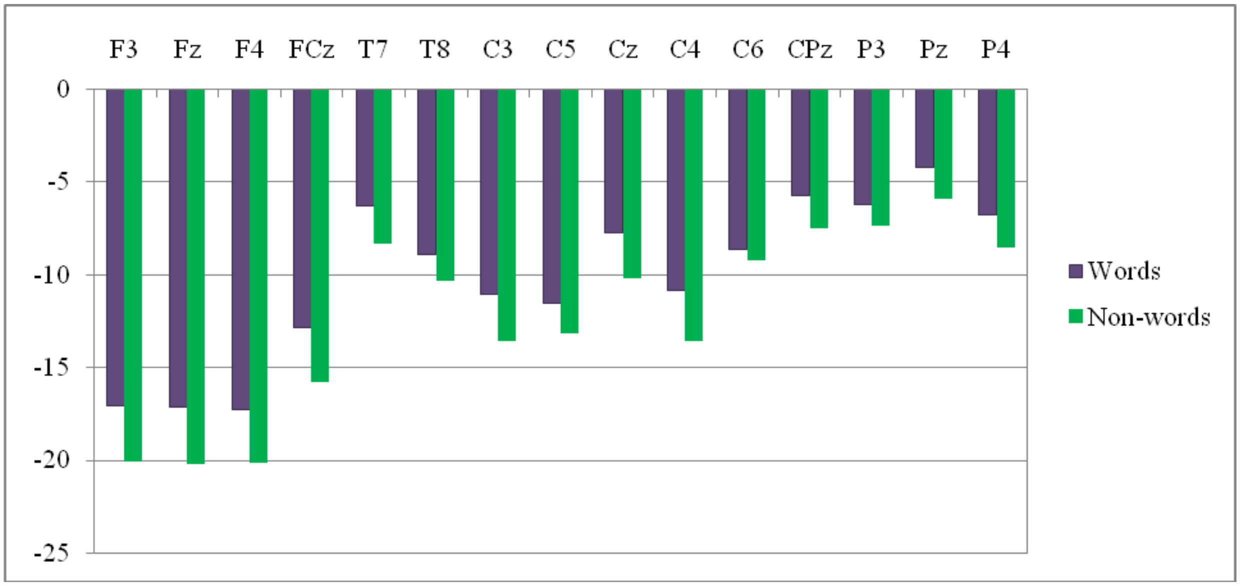

Figure 4.9 Mean N400 peak amplitude for words and non-words at 15 different channels in thirty TDC.

One-way repeated measure ANOVA was done to compare the amplitude of N400 peak across different channels for words. The results indicated a significant difference across the channels [F(14,406)=41.790, at p<0.01] for words. Post hoc analysis using Bonferroni's multiple pairwise comparison revealed the significant channels in which the amplitude of N400 was different for words. The following channels were significantly different from each other when amplitude of N400 for words was considered (at α<0.05): Frontal channels (F3, Fz, F4) were significantly different from coronal channels (C3, C4, C5, C6), parietal channels (P3, Pz, P4), temporal channels (T7, T8), central channels (FCz, CPz, Cz) and coronal channels (C3, C4, C5, C6) were significantly different from parietal channels (P3, P4, Pz). Similarly, One-way repeated measure ANOVA was also done to compare the amplitude of N400 peak across different channels for non-words. The results revealed a significant difference across the channels [F(14,406)=60.288, at p<0.01] for non-words. Post hoc analysis using Bonferroni's multiple pairwise comparison was done to compare the amplitude of N400 across channels for non-words. The results revealed a significant difference between frontal channels (F3, Fz, F4) and coronal channels (C3, C4, C5, C6), parietal channels (P3, Pz, P4), temporal channels (T7, T8), central channels (FCz, CPz, Cz) [$\alpha<0.05$].

When N400 peak amplitude across channels was compared for words and non-words separately, there was significant difference across the channels. For words, as shown in Figure 4.8, the activity was less at parietal channels than in coronal channels and frontal channels. Thus, frontal channels were significantly different from coronal channels, temporal channels and parietal channels and also coronal channels were different from parietal channels. But when non-words were examined (in Figure 4.8) the spread of activity is more towards the parietal channels compared to words. Thus, the results though showed a significant difference of frontal channels from rest of the channels, there was no significant difference in coronal and parietal channels. Holistically this indicates that processing of word in TDC is simpler and involves lesser areas in brain compared to processing of non-word. During word processing there is discrete steps involving frontal areas maximally and coronal areas, where as in non-word processing there might be greater steps involved showing additional and discrete activity in parietal areas too. This greater steps and additional areas in processing of non-word is reflected in the increased peak amplitude of N400 for non-words when compared to words.

In the present study greatest amplitude was observed in the frontal regions which indicate an increased activity in the frontal cortex. This is indicative of the fact that frontal regions are actively involved in the strategic and executive aspects of semantic processing. This means that the frontal regions facilitate semantic/phonological judgements of stimuli in children. This finding is in accordance with the previous studies which have used neuro-imaging techniques to study semantic processing in children (Fiez, 1997; Poldrack, Wagner, Prull, Desmond, Glover &. Gabrieli, 1999) and have opined that the frontal cortex is responsible for strategic and executive aspects of semantic processing. More specifically, few other researchers have observed activation of the left inferior frontal region (Broca's area) during auditory word processing for phonological judgements on auditory stimuli (Demonet, Chollet, Ramsay, Cardebat, Nespoulous, Wise, et al.,1992; Demonet, Price, Wise & Frackowiak, 1994; Zatorre, Evans, Meyer & Gjedde 1992), for the retrieval of words (Wise, Chollet, Hadar, Friston, Hoffner & Frackowiak, 1991; Warburton, Wise, Price, Weiller, Hadar, Ramsay, et al., 1996), for semantic judgements on heard words (Demonet et al., 1994; Warburton et al., 1996) and silent 'repetition' of non-words with three repetitions per stimulus (Warburton et al., 1996). However, all these tasks require auditory-verbal short-term memory to remember the auditory stimuli when the phonological or semantic decisions have to be made. It has been found that the activity in the Broca's area increases during auditory-verbal short-term memory tasks (Paulesu, Frith & Frackowiak, 1993) and its role during these tasks may be attributable to phonological rehearsal. Also it has also been reported that the phonological stages of spoken word recognition are supported by neural systems in the superior temporal lobe bilaterally, mainly superior temporal gyrus (STG) and superior temporal sulcus (STS).

In the present study, it was found that the frontal regions were activated to a greater extent followed by the temporal cortex. According to Lau, Philips and Poeppel

(2008) the temporal regions are involved in the selection process of semantic information and the frontal cortex is involved in the controlled retrieval of semantic information based on top down processing. This implicates that greater amplitude of N400 for nonwords than words in the regions of the frontal cortex facilitates activation of non-words which are processed in a sequential manner. These nonwords are categorized as non-meaningful in the posterior temporal cortex but however the realization of each of the phonemes in nonwords requires controlled processing (which is a function of frontal cortex) unlike words which are processed more automatically (in the temporal cortex). In neuroimaging studies, listening to speech bilaterally activated the superior temporal lobe which was largely symmetrical (Binder, Frost, Hammeke, Bellgowan, Springer, Kaufman, et al, 2000; Binder, Rao, Hammeke, Yetkin, Jesmanowicz, Bandettini, et al, 1994; Mazoyer, Tzourio, Frak, Syrota, Murayama, Levrier, et al,1993; Price, Wise, Warburton, Moore, Howard, Patterson, et al, 1996; Schlosser, Aoyagi, Fulbright, Gore & McCarthy, 1998). In the present study we can see the activation of temporal areas which is in accordance with these studies.

Latency of N400

The N400 peak latency at 15 different channels was analysed in Group 1 and Group 2 of typically developing children for both word and non-word. The mean and SD of N400 peak latency for both word and non-word in Group 1 and Group 2 at 15 different channels are shown in Table 4.4.

Table 4.4

Mean and SD for peak latency of N400 for words and non-words in two groups of typically developing children at 15 different channels

	Word (Latency in ms)				**Non-word (Latency in ms)**			
	Group 1 (8-9 years)		**Group 2 (9-10 years)**		**Group 1 (8-9 years)**		**Group 2 (9-10 years)**	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
F3	480.53	45.55	478.13	41.02	535.80	62.30	529.20	72.96
Fz	481.87	44.22	480.40	45.50	529.20	61.29	526.27	69.69
F4	481.67	44.55	485.60	42.49	526.07	59.95	526.00	69.61
FCz	469.93	43.39	470.40	31.85	490.47	57.26	500.73	62.21
T7	542.87	41.21	532.40	39.33	583.47	70.14	579.33	61.83
T8	541.20	67.16	526.47	46.72	565.53	57.70	572.53	69.07
C3	487.60	32.93	475.13	40.36	515.53	50.99	511.60	63.70
Cz	452.13	42.08	465.13	33.14	481.73	47.16	488.73	64.49
C4	495.07	58.27	460.60	37.84	525.67	59.98	489.27	75.07
C5	512.60	37.43	512.80	49.16	562.87	62.19	548.93	65.43
C6	491.00	41.71	462.07	32.45	531.87	60.29	507.53	65.99
CPz	455.40	34.91	459.07	35.72	460.20	134.84	491.13	68.99
P3	482.13	35.94	478.13	32.75	469.47	137.45	494.07	58.43
Pz	447.73	34.18	455.40	45.45	458.80	133.96	483.80	69.35
P4	457.47	29.28	468.67	45.60	461.80	137.15	487.07	66.01

Analysis of results from Table 4.4 revealed that the mean peak latency of N400 was greater for non-words when compared to words in both the groups of typically developing children. But there was no particular trend seen or there was no difference between the two groups of typically developing children with respect to the mean peak latency of N400, either for words or non-words which can be evidenced in Figure 4.10. It also revealed that the standard deviation is greater for non-words, evident only for the Group 1 i.e., 8-9 year old typically developing children only in the parietal channels such as Pz, CPz, P3 and P4.

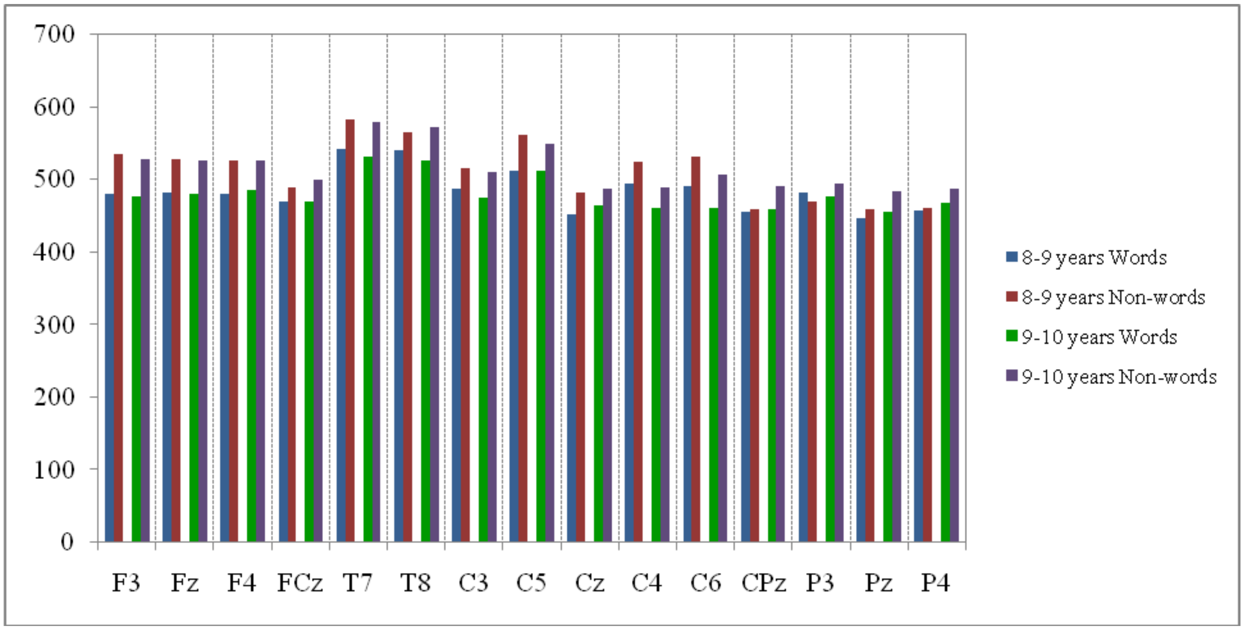

Figure 4.10 Mean N400 peak latency in 8-9 year and 9-10 year old TDC for words and non-words at 15 different channels

Mixed analysis of variance (ANOVA) was carried out to see the interaction of groups (Group 1, Group 2) with stimuli (word, non-word) and channels (15 channels) as independent variables and N400 peak latency (in milliseconds) as the dependent variable. The results indicated that there was a significant main effect for stimuli [F(1,28)=15.127, at $p<0.01$)] and channels [F(14, 392)=19.064, at $p<0.01$]. A significant interaction effect was found between stimuli and channels [F(14,392)=1.814, at $p<0.05$]. There was no significant difference across groups [F(1, 28)= 0.006, at $p>0.05$]. As there was no significant difference across the two groups, these groups were combined to form one group of typically developing children and was analysed further.

Paired Sample t-test was done to compare the latency of N400 for words and non-words at each channel since mixed ANOVA showed a significant difference across stimuli. The results indicated a significant difference between latency of N400 for words and non-words at channels F3, Fz, F4, T7, C3, Cz, C4, T8, C5, C6 (t=-4.89, -4.87, -4.12, -3.50, -3.08, -2.97, -2.88, -2.87, -4.19, -4.20 respectively, at $p<0.01$) and at channel FCz (t=-2.71, at $p<0.05$).

From the above figures (Figure 4.3 & 4.4), even though it is not evident that there is any latency difference between word and non-word, there was significant difference noted in N400 peak latency for word and non-word at frontal (F3, Fz, F4, FCz), coronal (C3, C4, Cz, C5, C6) and temporal channels (T7, T8). The latency difference was not evident in the parietal channels. The longer N400 peak latencies at these channels for non-words suggests that the processing at these sites takes place for longer time for non-words involving lexical decision. As the N400 peak was broad and the range varied a lot, the representation of the longer latencies for non-word may not be seen in the scalp distribution or in the grand average waveforms.

The peak latency of N400 was analysed further at different channels for words and non-words separately. The mean peak latency of N400 was longer for both words and non-words at temporal channels (T7, T8) when compared to frontal (Fz, F3, F4, FCz), coronal (Cz, C3, C4, C5, C6, CPz) and parietal channels (Pz, P3, P4) (Table 4). The difference in mean peak latency of N400 for word and non-word was greater at frontal channels (Fz, F3, F4) compared to temporal, coronal and parietal channels in TDC. This can be evidenced in the Figure 4.11.

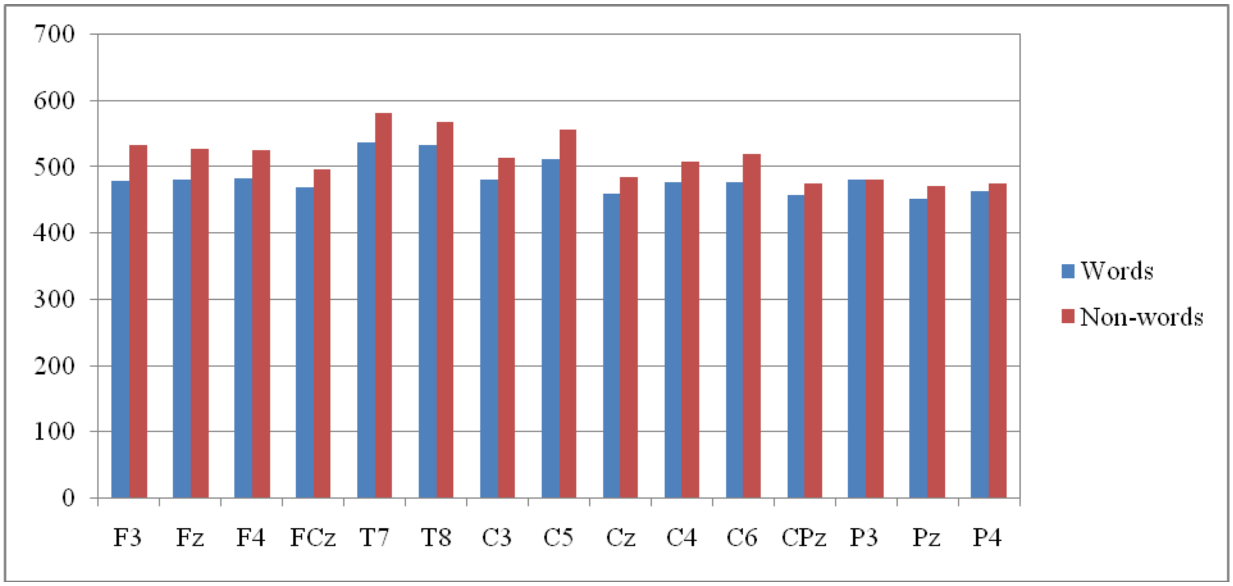

Figure 4.11 Mean N400 peak latency for words and non-words at 15 different channels in thirty TDC.

One-way repeated measure ANOVA was done to compare the latency of N400 peak across different channels for words. The results indicated a significant difference across the channels [F(14,406)=17.274, at p<0.01] for words. Post hoc analysis was done using Bonferroni’s multiple pairwise comparison to compare the latency of N400 across channels for words. The results revealed a significant difference between frontal channels (F3, Fz, F4) and temporal channels (T7, T8) [α<0.05]. Temporal channels (T7, T8) were also significantly different from central channels (FCz, CPz, Cz), coronal channels (C3, C4, C5, C6) and parietal channels (P3, Pz, P4) [$\alpha < 0.05$]. Similarly, One-way repeated measure ANOVA was also done to compare the latency of N400 peak across different channels for non-words. The results revealed a significant difference across the channels [F (14,406) =1.909, at $p < 0.01$] for non-words. Post hoc analysis using Bonferroni's multiple pairwise comparison revealed the significant channels in which the latency of N400 was different for non-words. The following channels were significantly different from each other when latency of N400 for non-words was considered (at $\alpha < 0.05$): Temporal channel (T7) was significantly different from coronal channels (C3, C4, C5, C6), parietal channels (P3, Pz, P4), central channels (FCz, CPz, Cz) and Frontal channels (Fz, F4); Temporal channel (T8) was significantly different from coronal channels (C3, C4, C6), parietal channels (P3, Pz, P4), and central channels (FCz, CPz, Cz); coronal channels (C5) was significantly different from parietal channels (P3, P4, Pz, CPz).

When N400 peak latency across channels was compared for words and non-words separately, only temporal channels differed significantly from the other channels for words. Whereas for non-words, temporal channels were different from all the other channels, but only T7 was different from few frontal channels (Fz & F4). Also, the coronal channels were different from parietal channels. This supports the lexical view of processing in N400 (Kutas & Federmeier, 2000; Federmeier, 2007). According to this theory, the difference between the effects of anomalous and predictable endings arises not because of the anomaly but because predictable words in context are easier to access from memory. Supporting context allows pre-activation of relevant lexical or conceptual features, making lexical access less effortful (Federmeier & Kutas, 1999). Although the theory explains for the amplitude differences which is seen in our study showing more activation in the frontal areas, it can be explained for the latency differences either. As it is postulated that the lexical storage and access takes place in the posterior middle temporal cortex, explains the longer latencies seen in the temporal channels compared to other channels where the processing is taking longer time. More channel differences when peak latency of N400 is considered and more activation or amplitude in processing of non-word compared to word makes it clear that more effort is needed in accessing non-word than the word during the lexical decision task.

4.2.2. Performance of children with dyslexia on ERP (N400) measures

The peak amplitude and latency of N400 was analysed for word and non-word in children with dyslexia. Figure 4.12 shows grand averaged ERP waveforms of children with dyslexia for words and non-words at 15 channels. The mean and SD of N400 peak amplitude and latency for words and non-words are shown in Table 4.5.

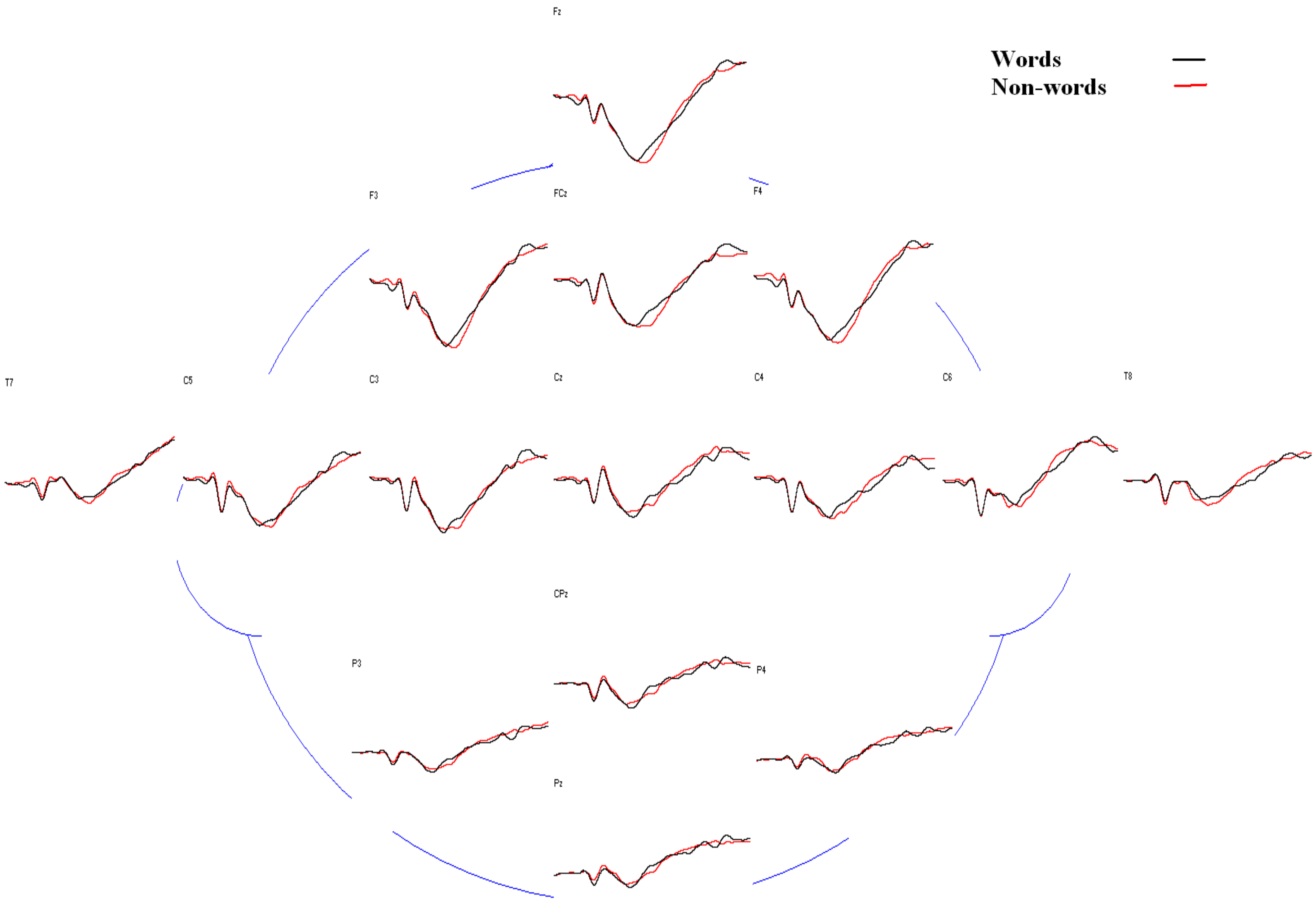

Figure 4.12 Grand average waveforms of children with dyslexia at 15 different channels for words and non-words

Table 4.5

Mean and SD for peak amplitude and latency of N400 for words and non-words in children with dyslexia at 15 different channels

	Amplitude (in µV)				**Latency (in ms)**			
	Word		**Non-word**		**Word**		**Non-word**	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
F3	-16.15	6.56	-18.05	6.66	495.80	52.18	578.47	50.78
Fz	-15.90	6.04	-17.98	5.09	495.60	56.54	573.40	61.59
F4	-15.57	6.67	-17.71	5.20	501.67	58.58	568.87	64.74
FCz	-13.74	4.21	-14.01	5.73	508.67	58.38	562.47	74.51
T7	-3.96	6.17	-5.42	6.58	512.87	67.02	589.73	66.26
T8	-4.81	5.67	-6.47	4.15	528.53	67.57	573.60	64.10
C3	-11.75	7.06	-12.85	7.23	489.20	35.17	558.00	76.86
Cz	-9.33	5.79	-9.20	4.33	472.07	42.91	535.07	76.71
C4	-9.60	5.15	-10.58	4.43	486.00	75.34	534.80	65.27
C5	-10.47	4.60	-11.56	6.10	514.60	64.95	577.33	67.63
C6	-6.92	3.84	-7.50	3.01	505.87	79.12	533.53	67.88
CPz	-7.61	5.25	-6.58	4.41	466.73	42.13	530.40	80.27
P3	-6.19	4.90	-6.53	4.37	485.60	64.26	544.20	78.40
Pz	-4.34	4.04	-3.96	3.99	468.00	38.30	530.33	77.45
P4	-4.97	5.56	-4.42	3.70	481.47	42.16	518.87	69.63

Amplitude of N400

From the Figure 4.12, it can be evidenced that there was very less difference in the mean peak amplitude of N400 for words and non-words in frontal and coronal channels. Whereas in temporal channels such as T7 and T8 the mean peak amplitude of N400 for non-words was slightly greater than that for words. But in the parietal channels, there was reversal of the trend, showing greater mean peak amplitude of N400 for word than non-words. This reversal of trend was also seen in Cz channel. Thus N400 effect was seen only in temporal channels when it is presented auditorily alone in children with dyslexia. There was not much of a difference between T7 and T8 in the amount of N400 effect seen, though the N400 peak amplitude is lesser when compared to frontal and coronal channels. It can also be seen from the Figure 6 that the N400 peak is broader and of more amplitude in frontal channels compared to other channels. In the coronal channels, C3 and C5 show greater N400 peak amplitude than the C4 and C6 channels.

The analysis of results from Table 4.5 shows that, the mean peak amplitude of N400 was greater for non-word compared to word at most of the channels except Cz, CPz and Pz. This can be evidenced in the Figure 4.13. It can also be evidenced that the greater amplitude is seen in frontal channels followed by coronal, temporal and parietal channels.

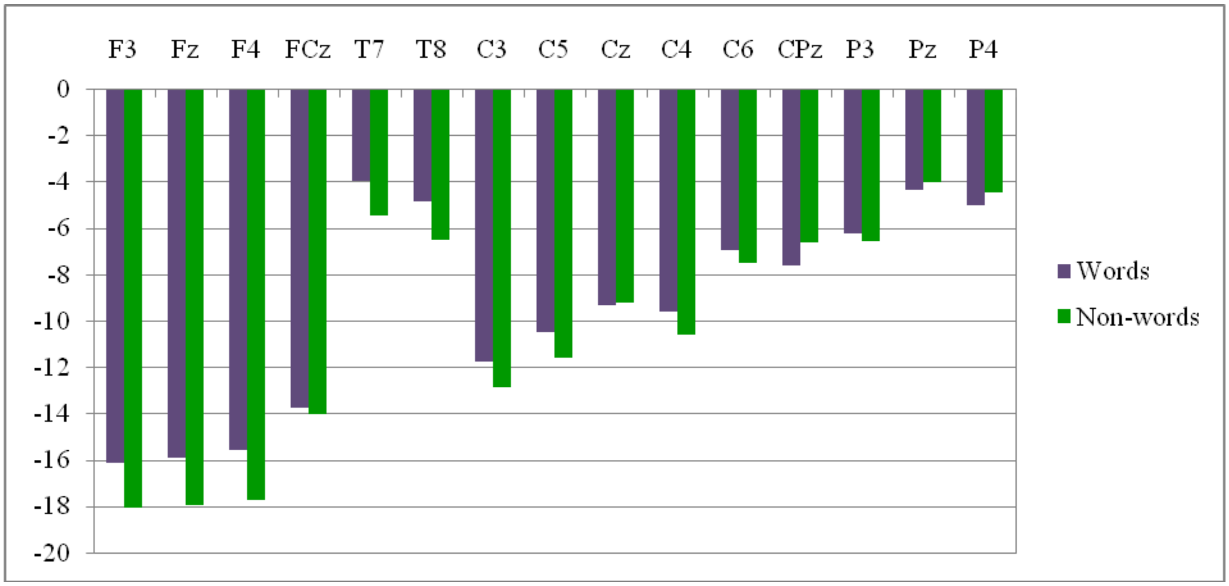

Figure 4.13 Graph showing mean N400 peak amplitude for words and non-words at 15 different channels in children with dyslexia.

Two way repeated measure ANOVA was carried out with stimuli (word, non-word) and channels (15 channels) as repeated measures variables and N400 peak amplitude (in microvolts) as the dependent variable. The results indicated that there was a significant main effect for channels [F(14,196)=29.785, at p<0.01]. A significant interaction effect was not found between stimuli and channel [F(14,196)=1.209, at p>0.05].

To compare the peak amplitude of N400 between word and non-word at each channel, paired sample t-test was done. The results indicated a significant difference at channels Fz & T8 (t=2.29 & 2.53 respectively, p<0.05). The earlier studies have also found absent N400 effect in children with dyslexia using different types of stimulus such as primed words, pseudo-words, sentences (Torkildsen et al., 2007; Araujo et al., 2012; Meng et al., 2007; Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988; Helenius, Salmelin, Service, & Connolly, 1999). This was interpreted to be because of the inability of the children with dyslexia to use semantic memory appropriately during linguistic comprehension.

One-way repeated measure ANOVA was done to see the effect of N400 peak amplitude across channels for words and non-words separately. The results revealed a significant effect across channels for both words [$F(14,196)=17.321$, at $p<0.01$] and non-words [$F(14,196)=32.258$, at $p<0.01$]. Bonferroni's multiple pairwise comparison was done as post hoc analysis to arrive at significantly different channels for words and non-words separately. For words, there was significant difference between the following channels [$\alpha<0.05$]: temporal channels (T7, T8) from frontal channels (F3, F4, Fz, FCz); frontal channels (F3, F4, Fz, FCz) from Parietal channels (P3, P4, Pz, CPz) and coronal channels (Cz, C4, C6). For non-words, the following channels were significantly different [$\alpha<0.05$]: frontal channels (F3, F4, Fz, FCz) from temporal channels (T7, T8), Parietal channels (P3, P4, Pz, CPz), and coronal channels (Cz, C4, C6); coronal channels (Cz, C4, C5, C3) from Parietal channels (P3, P4, Pz, CPz).

The topographical scalp distribution of activity from 0 ms to 1000 ms (1sec) in 100 ms interval is shown in Figure 4.14 and Figure 4.15 for words and non-words respectively. From the Figure 4.14, the activity was seen more in the frontal area at 400 ms, spreading towards the coronal areas more towards right at 500 ms, when considered for words.

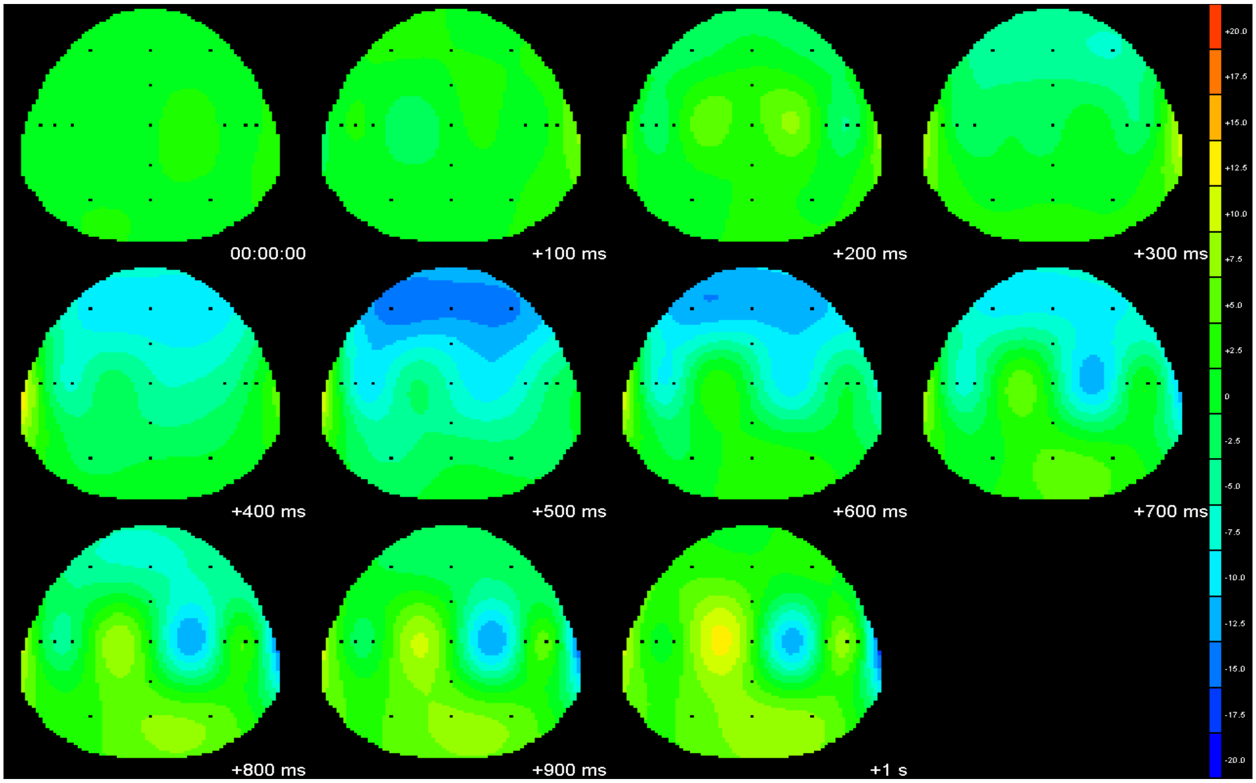

Figure 4.14 Scalp distribution of N400 peak from 0 to 1000 ms for words in children with dyslexia

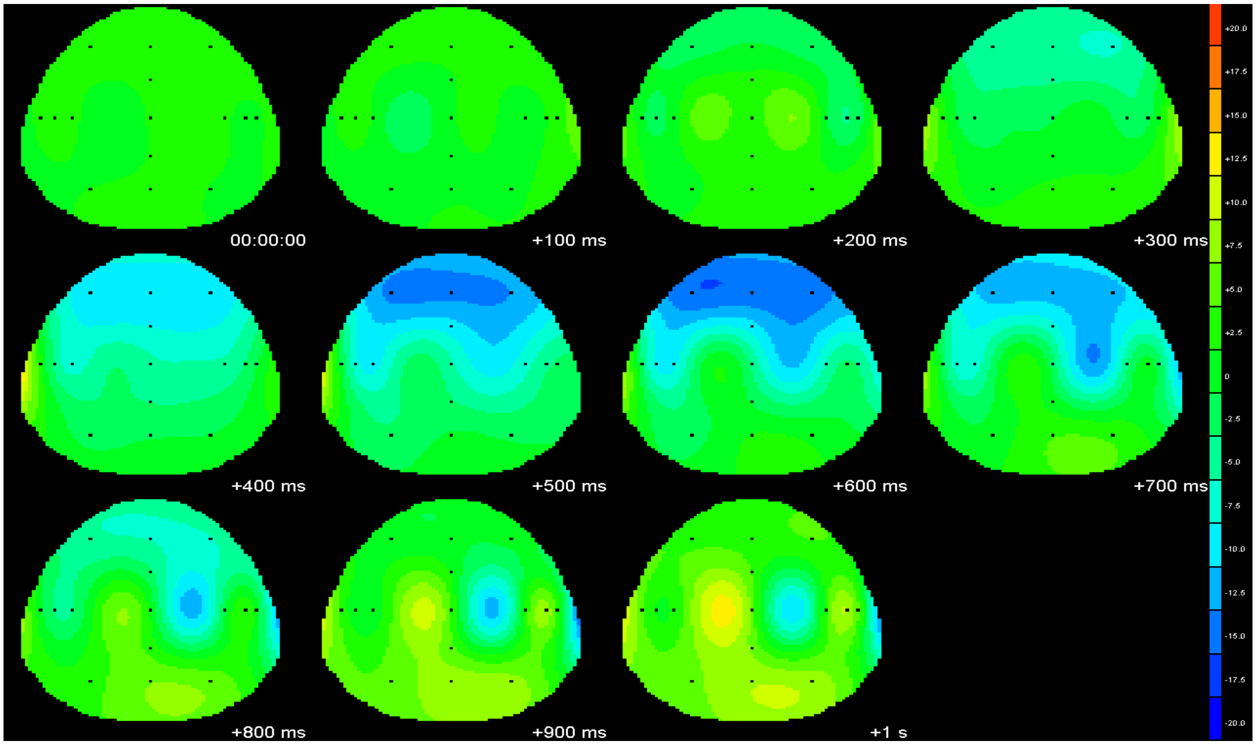

Figure 4.15 Scalp distribution of N400 peak from 0 to 1000 ms for non-words in children with dyslexia

There is very less amount of activity seen in the parietal areas for both words and non-words (Figure 4.14 & 4.15). When non-words are considered in Figure 4.15, the activation follows the same pattern as for words, but there is more activity and spread of activation than words. The greater spread of activation for non-words compared to words can be evidenced from 600 to 700 ms. Thus indicating that the processing of non-words occurs for longer time in children with dyslexia. Though there is no N400 effect seen in the waveforms, more activity for non-words in scalp distribution (from Figure 4.14 & 4.15) compared to words indicates more amount of processing taking place during recognition of non-words in children with dyslexia. Irrespective of word or non-word, there is more activation towards right hemisphere than left hemisphere. This is in accordance with the studies showing that the brain areas involved in phonological processing such as left perisylvian cortices, left middle and inferior temporal cortex have been found to be dysfunctional in adults and children with dyslexia (Helenius, Salmelin, Service, Connolly, Leinonen & Lyytinen 2002; Rumsey, Andreason, Zametkin, Aquino, King, Hamberger, et al, 1992). But when the coronal channels are compared the peak amplitude in the left hemisphere channels are more compared to right hemisphere channels. Overall the N400 responses can be seen widespread in the frontal, coronal and temporal regions. This result is in conjugate with the previous studies done on children with dyslexia (Araujo et al., 2012; Sabisch et al., 2006). These studies have reported N400 responses which were widespread across both right and left hemispheres in children with dyslexia. Figure 4.16 shows activation of different scalp areas at the N400 peak comparing for word and non-word in children with dyslexia.

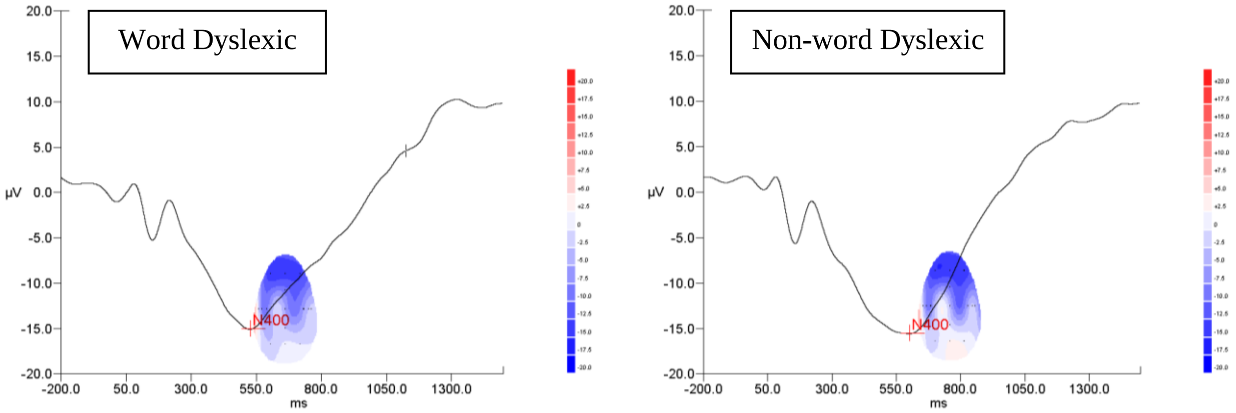

Figure 4.16 Scalp distribution at N400 peak comparing for words (left) and non-words in children with dyslexia

When N400 peak amplitude across channels was compared for words and non-words separately, there was significant difference across the channels. For words, as shown in Figure 4.16, the activity was less at parietal channels than in coronal channels, temporal channels and frontal channels. Thus, frontal channels were significantly different from coronal channels, temporal channels and parietal channels. But when non-words were examined (in Figure 4.16) the spread of activity is more specific with almost no activity in the parietal channels. Thus, the results also showed a significant difference between parietal and coronal channels along with the similar differences as seen for words.

There was less activity seen at the parietal regions in children with dyslexia. This is in correspondence with the previous studies. Horwitz, Rumsey and Donohue (1998) found lack of coherence between measurements in the angular gyrus and parieto-temporal regions, suggesting functional disconnection between the brain regions involved in the phonological analysis process at the initial stages of phonological decoding. They investigated the angular gyrus and its connections during phonological processing. Pugh, Mencl, Shaywitz, Shaywitz, Fulbright, Constable et al (2000) also found functional disconnections between the angular gyrus and parietal regions in the left hemisphere specific to the phonological processing during fMRI in dyslexic brain .

Latency of N400

The mean peak latency of N400 was longer for non-words than words in children with dyslexia (Table 4.5). This was evidenced in all the 15 channels which are shown in Figure 4.17.

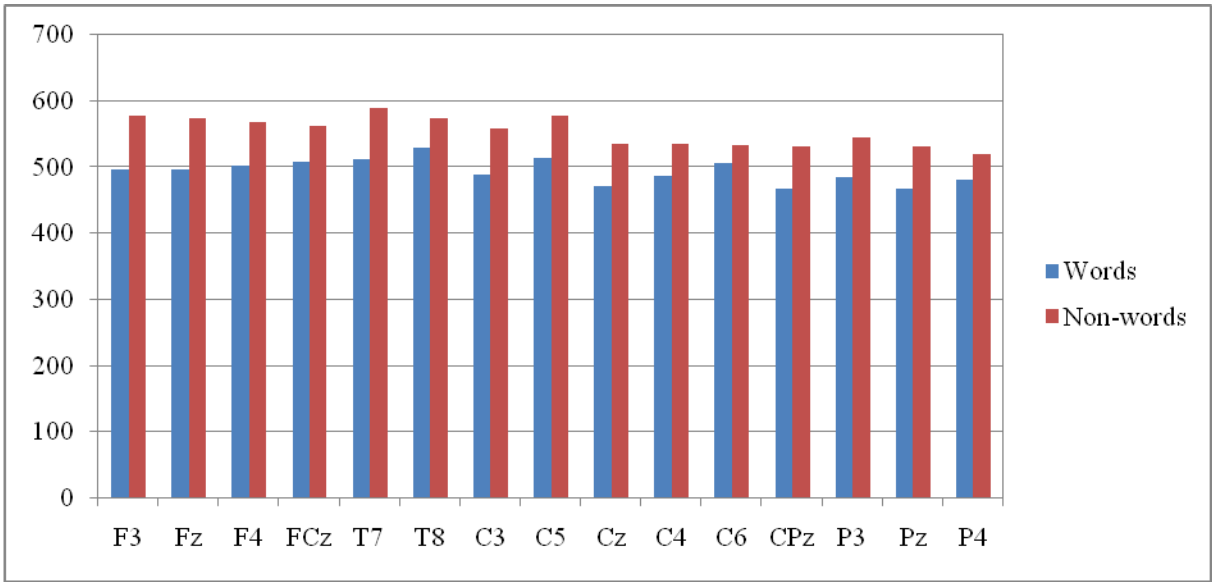

Figure 4.17 Graph showing mean N400 peak latency for words and non-words at 15 different channels in children with dyslexia.

Two-way repeated measure ANOVA was done with stimuli (word, non-word) and channels (15 channels) as repeated measures variables and N400 peak latency (in milliseconds) as the dependent variable. The results indicated that there was a significant main effect for stimuli [F(1,14)=45.352, at $p<0.01$] and channels [F(14,196)=4.512, at $p<0.01$]. There was no significant interaction between stimuli and channel [F(14,196)=1.495, at $p>0.05$]. Paired Sample t-test was done to compare the peak latency of N400 for words and non-words at each channel. The results revealed a significant difference at all the channels such as F3 (t=-6.56, p=0.00), Fz (t=-6.50, p= 0.00), F4 (t=-5.72, p=0.00), FCz (t=-2.75, p=0.016), T7 (t=-4.55, p=0.00), C3 (t=-4.95, p=0.00), Cz (t=-4.34, p=0.001), C4 (t=-2.87, p=0.012), T8 (t=-3.44, p=0.004), CPz (t=-4.48, p=0.001), P3 (t=-5.50, p=0.00), Pz (t=-4.31, p=0.001), P4 (t=-2.36, p=0.033), C5 (t=-4.19, p=0.001), except C6 (t=-1.45, p=0.170) .

To examine the effect of N400 peak latency across channels for words and non-words separately, one-way repeated measure ANOVA was carried out. The results indicated a significant effect across channels for both words [F(14,196)=2.292, at $p<0.01$] and non-words [F(14,196)=5.442, at $p<0.01$]. Post hoc analysis was done using Least Significant Difference to arrive at the channels which were significantly different for words and non-words separately. The results revealed that temporal channels (T7, T8) were significantly different from parietal channels (CPz, Pz, P3, P4) and coronal channels (C3, Cz) [$\alpha<0.05$] for words. Frontal channels (F4, FCz) were also significantly different from Parietal channels (Pz, CPz, P4) and Cz [$\alpha<0.05$] for words. But for non-words, frontal channels (F3, Fz, F4, FCz) were significantly different from coronal channels (Cz, C4, C6) and parietal channels (Pz, P3, P4, CPz) [$\alpha<0.05$]. The temporal channels (T7, T8) were seen to be significantly different from parietal channels (Pz, P3, P4, CPz) [$\alpha<0.05$]. The coronal channels were found to be significantly different among themselves and with T7 [$\alpha<0.05$].

From the above figures (Figure 4.12, 4.14, 4.15 & 4.16), it is evident that there is N400 peak latency difference between words and non-words. The N400 peak latency for non-words is longer when compared to words in frontal, coronal and temporal channels (Figure 4.12). The N400 peak latency difference was not evidenced in the parietal channels. The longer N400 peak latencies at these channels for non-words suggests that the processing at these sites takes place for longer time for non-words involving lexical decision. Comparison of Figure 7 and 8 also shows increased activation in the time window from 500 to 600 ms for non-words than words implying prolonged latency for non-words compared to words. Though there are very less studies reporting on the latency differences as the N400 is a broad negativity, few of the previous researches has reported longer latencies during priming tasks which is in accordance with the present study (Jednorog et al., 2010; Russeler et al., 2007). Jednorog et al., 2010 generally reported longer latencies of N400 in children with dyslexia, while Russeler et al. (2007) reported a shorter N400 peak latency of 401 ms in control subjects when compared to children with dyslexia showing 493 ms in a priming task involving visually presented words.

4.2.3. Comparison of performance on ERP (N400) measures between typically developing children and children with dyslexia

The typically developing children were compared with children with dyslexia on peak amplitude and latency of N400 across 15 channels. The two groups of typically developing children were combined together to form one group of thirty children, as there was no significant difference between the groups. The grand average waveforms for words and non-words comparing TDC and children with dyslexia at Cz channel and 15 channels are shown in Figure 4.18 and Figure 4.19 respectively.

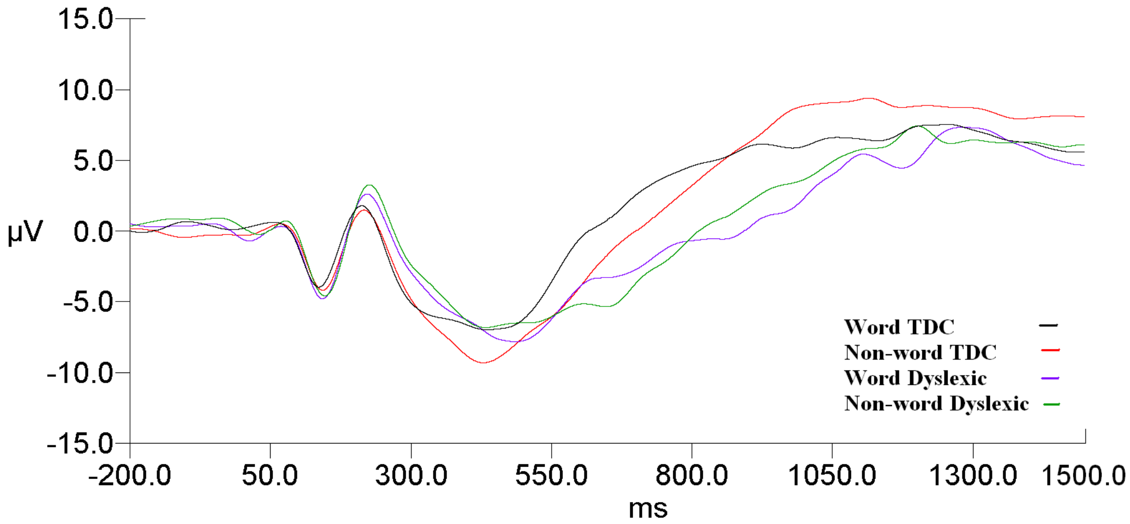

Figure 4.18 Grand average waveform for words and non-words at Cz channel in TDC and children with dyslexia

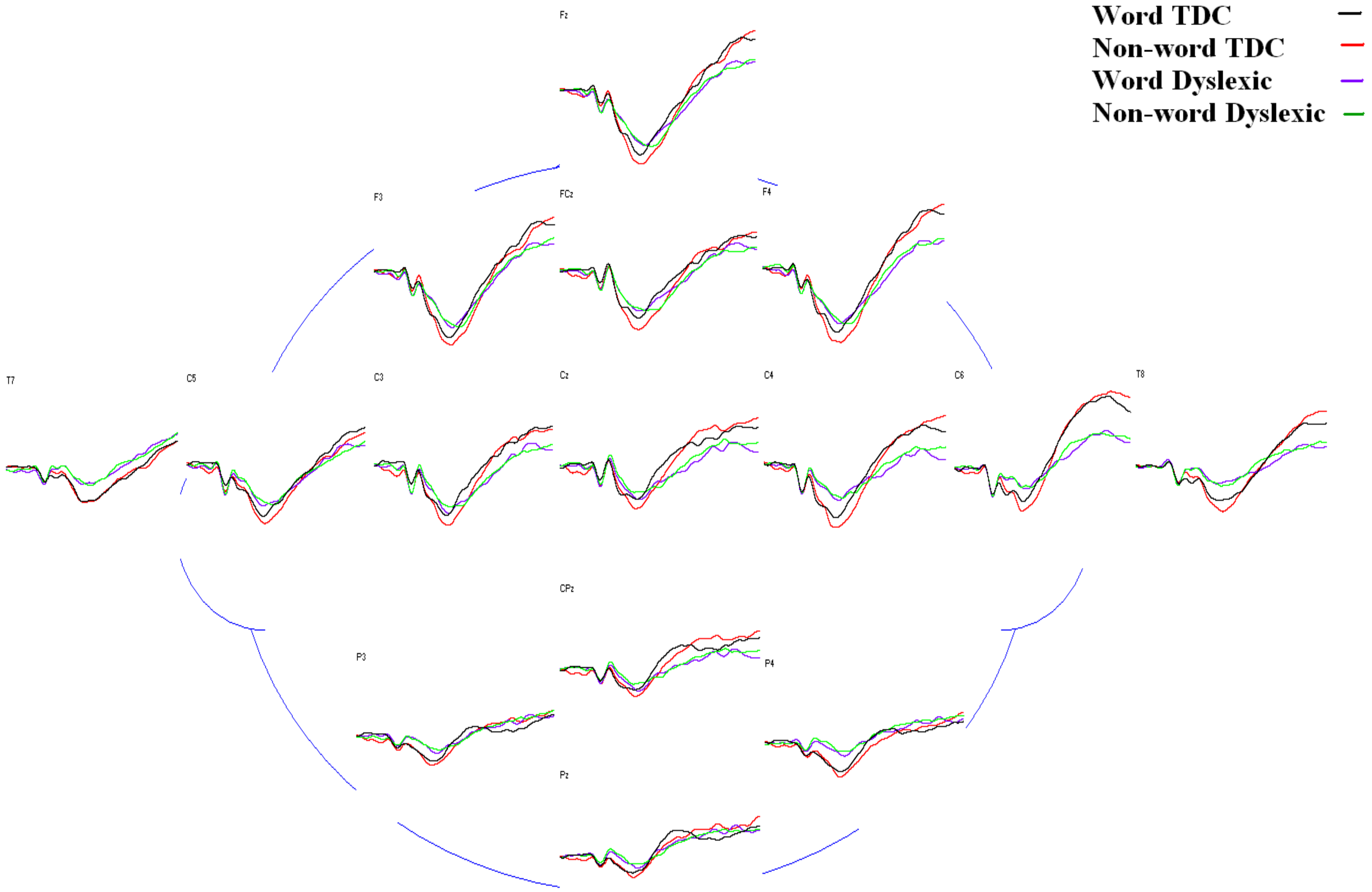

Figure 4.19 Grand average waveforms of TDC and children with dyslexia at 15 different channels for words and non-words

Amplitude of N400

The mean peak amplitude of N400 was compared between TDC and children with dyslexia for words and non-words at 15 different channels which is shown in Figure 4.20.

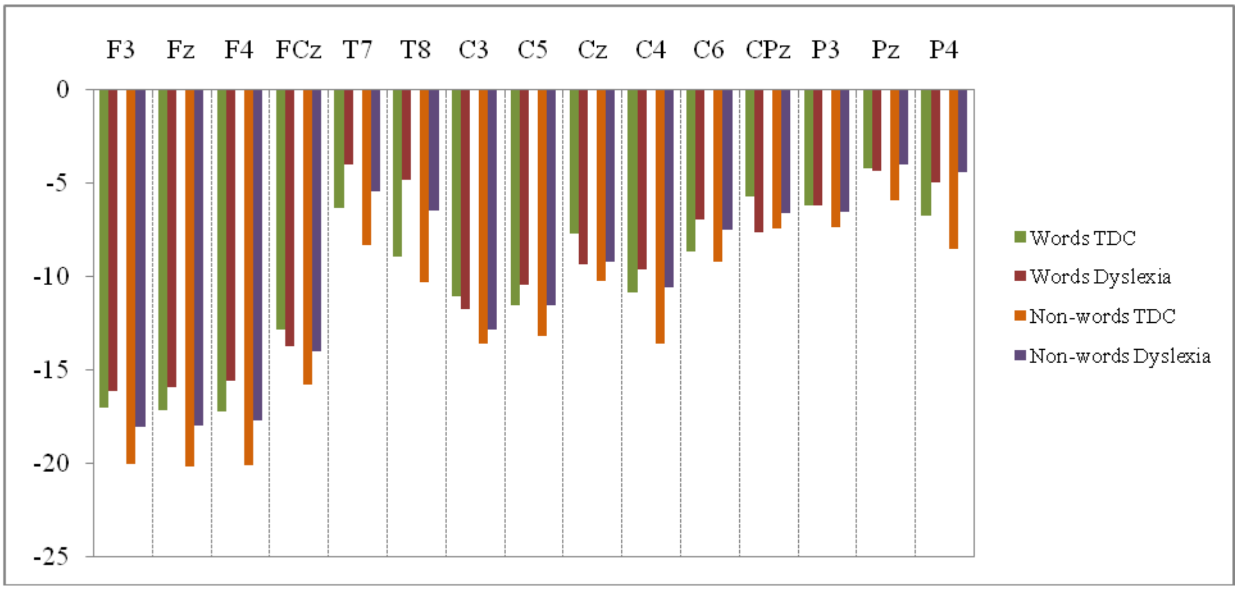

Figure 4.20 Mean N400 peak amplitude at 15 different channels comparing TDC and children with dyslexia for words and non-words

The result from Figure 4.19 shows that the mean N400 peak amplitude in TDC is higher than children with dyslexia at all the 15 channels for non-words (Figure 4.19). Even for words, mean N400 peak amplitude in TDC is higher than children with dyslexia except at channels FCz, C3, Cz, CPz and Pz. Mann-Whitney U test was done to compare between 30 typically developing children and fifteen children with dyslexia on N400 peak amplitude for words and non-words separately at 15 channels. When peak amplitude for words was considered, there was significant difference between groups in channel T8 (Z=-2.31, p<0.05). But when peak amplitude of N400 for non-words was examined, significant difference between the groups was noted in P4 (Z=-2.38, p<0.05) along with T8 (Z=-2.58, p<0.05).

The previous studies are in accordance with this finding where the N400 effect was reduced in children with dyslexia (Meng et al., 2007; Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988; Helenius, Salmelin, Service, & Connolly, 1999). Jednorog et al. (2010) and Russeler et al. (2007) found no differences in N400 amplitude between congruent and incongruent conditions in children with dyslexia when compared to control group. Torkildsen et al. (2007) also found that N400-like response was attenuated or absent in children at-risk for dyslexia, which was prominent in the control group. They suggested that deficiencies in young children at-risk for dyslexia are not only restricted to perceptual and lower-level phonological abilities, but also affect higher order linguistic skills such as lexical and semantic processing.

The topographical scalp distribution of N400 peak for words and non-words comparing TDC and children with dyslexia is shown in Figure 4.21.

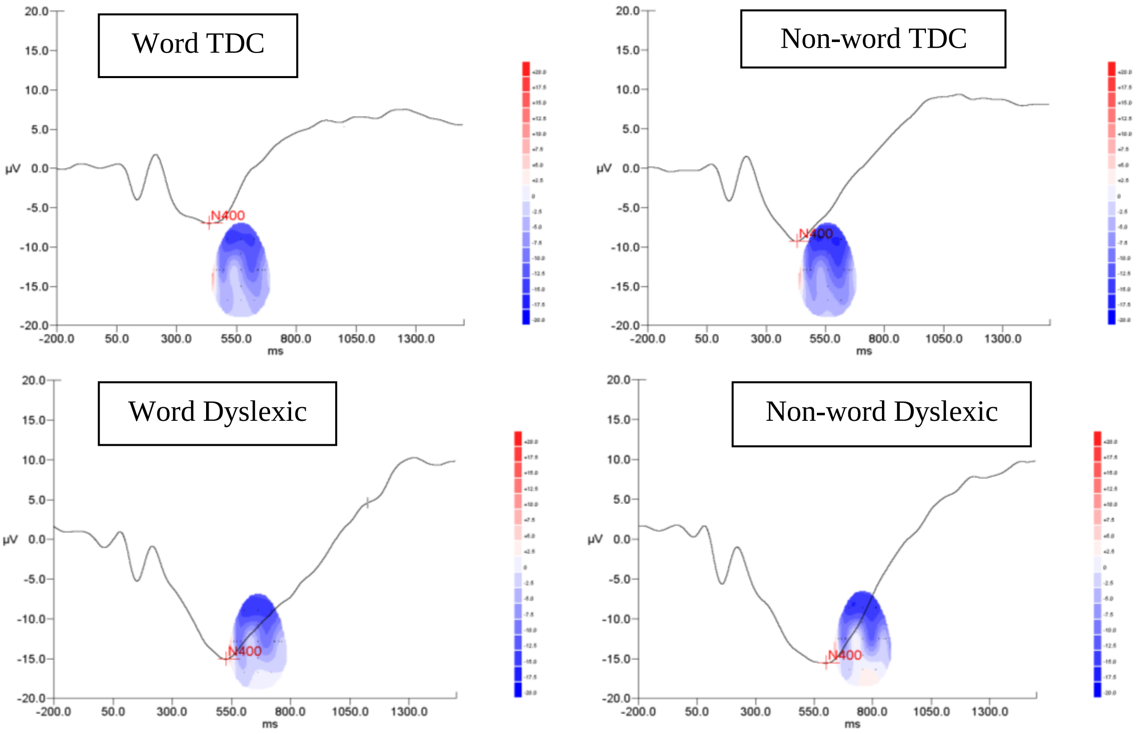

Figure 4.21 Comparison of topographical distribution of N400 peak for words (left) and non-words in TDC (above) and children with dyslexia (below).

From Figure 4.21, it can be evidenced that there is more spread of activation and is widely spread across the scalp in TDC for both words and non-words when compared to children with dyslexia. In TDC, there is some amount of activity in parietal region, which is absent in children with dyslexia for both words and non-words. The pattern in which there is spread of activation from frontal region to the parietal region owing more towards the right hemisphere is similar both in TDC and children with dyslexia. This is in contradicting to the findings of the previous studies where the topographical differences showed lateralization towards the left hemisphere in control group when compared to children with dyslexia in whom it was widespread across the scalp (Araujo et al., 2012; Georgiewa et al., 2002). But these studies have used visual mode of stimuli presentation with semantic priming. When visual stimuli were used, the studies also report of more centro-parietal distribution in control subjects than children with dyslexia (Meng et al., 2007). Sabisch et al. (2007) found widely distributed N400 across both the hemispheres which was of centro-parietal origin in control group using auditorily presented sentences. They reported a left anterior negativity referring to N400 in children with developmental dyslexia, whereas both right and left anterior negativities were found in control subjects. They hypothesized that the involvement of right hemisphere in control group suggests the established prosodic processes in linguistic comprehension which might be absent in children with developmental dyslexia. However in the present study, it cannot be hypothesized as using prosodic processes as the stimuli used are isolated words.

In a PET study by Paulesu, Firth, Snowling, Gallagher, Morton and Frackowiak (1996) the activation of Broca’s area, Wernicke’s area and the insula was seen in both rhyming task and short-term memory task, whereas phonological memory task specifically activated parietal operculum in normal control subjects. In individuals with dyslexia only a subset of brain regions were activated in phonological processing which involved Broca’s area during rhyme judgment and left temporo parietal cortex during short term memory demands. The insula of the left hemisphere was not at all activated in individuals with dyslexia. Paulesu and his collegues (1996) in their study suggested that the left insular cortex is crucial in the conversion of whole word phonology (temporo parietal regions) to segmented phonology (inferior frontal regions). They speculated that there might be a weak connectivity between anterior and posterior language areas in dyslexia which results in phonological deficits. Because of these deficits in neural connections in children with dyslexia there was lesser activation in the parietal areas seen when compared TDC. To overcome this deficit the children with dyslexia takes more duration in processing involving various other brain areas which are not otherwise used in normal phonological processing.

Latency of N400

The TDC were compared with children with dyslexia considering mean peak latency of N400 for words and non-words at 15 different channels which is depicted in Figure 4.22 and Table 4.5.

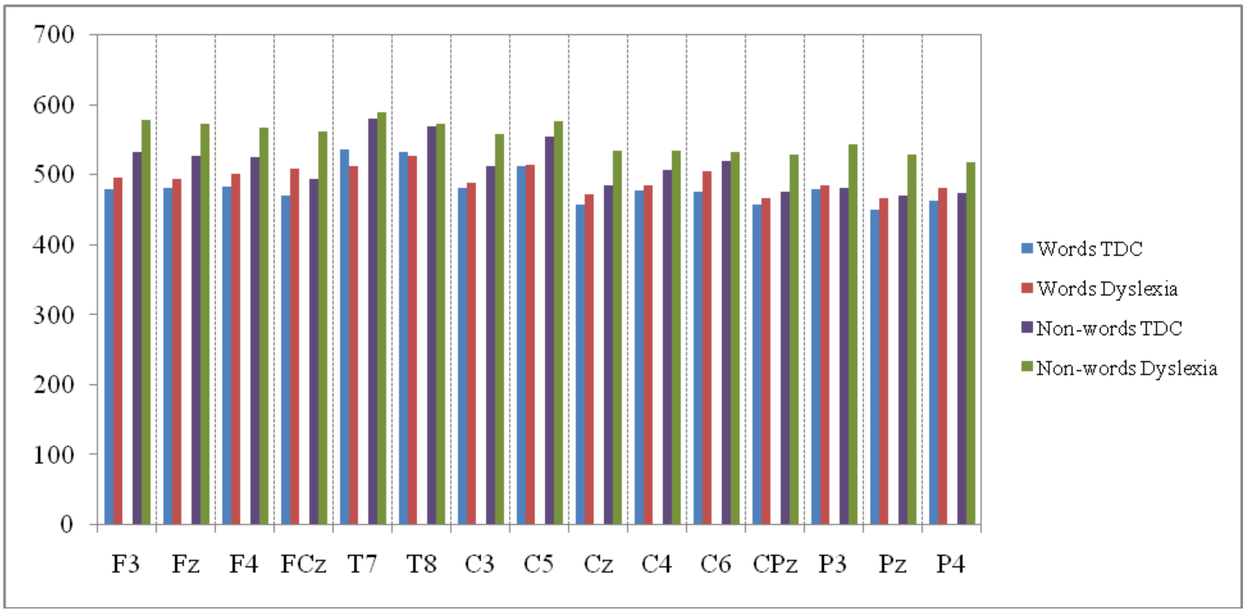

Figure 4.22 Mean N400 peak latency at 15 different channels comparing TDC and children with dyslexia for words and non-words

As it is evident from Figure 4.22, when peak latency of N400 was compared between TDC and children with dyslexia, it indicates longer latency in children with dyslexia than TDC for both words and non-words at all the channels except at T7 and T8 for words (Figure 4.18 & 4.19). Few studies reported longer latencies during incongruent conditions in children with dyslexia compared to control group (Jednorog et al., 2010; Russeler et al., 2007) which is in congruence with the present study. But these studies have used priming tasks which was not used in the present study.

Mann-Whitney U test was done to compare between 30 typically developing children and fifteen children with dyslexia on N400 peak latency for words and non-words separately at 15 channels. The peak latency of N400 for words was significantly different between the groups at only FCz (Z=-2.13, p<0.05). The results showed that there was no difference in the performance of TDC and children with dyslexia in processing words at other channels other than FCz. Whereas for non-words, the significant difference between groups on peak latency of N400 was found at channels F3 ($Z=-2.18$, $p<0.05$), Fz ($Z=-2.20$, $p<0.05$), F4 ($Z=-2.19$, $p<0.05$), Cz ($Z=-2.81$, $p<0.05$) and P3 ($Z=-2.08$, $p<0.05$) along with FCz ($Z=-2.01$, $p<0.05$). These findings revealed that there was difference in processing of non-words in children with dyslexia when compared to TDC at the channels-F3, Fz, F4, Cz, P3 and FCz.

The results indicated that there was no difference in the N400 peak amplitude for words and non-words in children with dyslexia (as seen in TDC). It was also observed that there was a difference in N400 peak latency for words and non-words in children with dyslexia. This suggests that the non-word processing is different from word processing in children with dyslexia which indicates involvement of different processes in non-word processing in them compared to TDC.

4.3. Relationship between behavioural tasks and ERP (N400) measures in typically developing children (TDC) and children with dyslexia

Karl Pearson’s correlation was done to study the relation between behavioural measures (RT & accuracy) and N400 measures (peak amplitude & latency) for words and non words in typically developing children and children with dyslexia.

In TDC, there was significant positive correlation of RT and N400 peak amplitude for words at the channels T8 ($r= 0.391$, at $p<0.05$) and C6 ($r= 0.431$, at $p<0.05$). But when reaction time was correlated with N400 peak amplitude for non-words, there was no significant correlation at any channels. The reaction time neither significantly correlated with N400 peak latency for words or for non-words.

Similarly, there was no significant correlation when the accuracy was correlated with N400 peak latency for both words and non words at any channels. Also, there was no significant correlation between accuracy and N400 peak amplitude for words at any channel. But when accuracy was correlated with N400 peak amplitude for non-words, there was significant positive correlation only at Cz ($r= 0.401$, at $p<0.05$).

In children with dyslexia, when words were considered, there was no significant correlation found between N400 peak latency and RT, N400 peak latency and accuracy, N400 peak amplitude and RT, or between N400 peak amplitude and accuracy. But when non-words were considered, there was a significant positive correlation of peak latency with reaction time at channels Fz ($r=0.591$, at $p<0.05$), F4 ($r=0.591$, at $p<0.05$), FCz ($r=0.609$, at $p<0.05$), Cz ($r=0.624$, at $p<0.05$), C4 ($r=0.572$, at $p<0.05$), CPz ($r=0.531$, at $p<0.05$), Pz ($r=0.546$, at $p<0.05$), and P4 ($r=0.669$, at $p<0.05$), whereas, no significant correlation was found with accuracy. The N400 peak amplitude neither significantly correlated with RT or with accuracy for non words. This suggests that the prolonged N400 latency for non-words in children with dyslexia showed poorer performance on lexical decision task showing longer reaction times for non-words indicating temporal processing deficit in children with dyslexia (Tallal & Piercy, 1973; Tallal & Piercy, 1974; Tallal & Piercy, 1975). This correlation is true for the right hemisphere and midline channels.

A stepwise multiple regression analysis was done to examine the potential predictors in N400 peak latency and amplitude separately for each behavioural measure (reaction time & accuracy) for words and non-words in children with dyslexia. The regression analysis was done considering the word RT and non-word RT as dependent variables and the N400 peak latency and amplitude at 15 channels for both words and non-words as independent variables. The results revealed no significant predictors among N400 peak latency (R^2 = 0.993, p>0.05) and amplitude (R^2 = 0.963, p>0.05) for words at 15 channels, when word RT was considered as dependent variable. Even when the non-word RT was considered as dependent variable, there were no significant predictors found among the peak amplitude of N400 for non-words at 15 channels (R^2 = 0.990, p>0.05). But among the N400 peak latency for non-words, the P4 channel was a significant predictor (R^2=0.473, p<0.01), that predicted 47.3% of the time. The scatter plot for non-word reaction time and N400 peak latency is given in Figure 4.23.

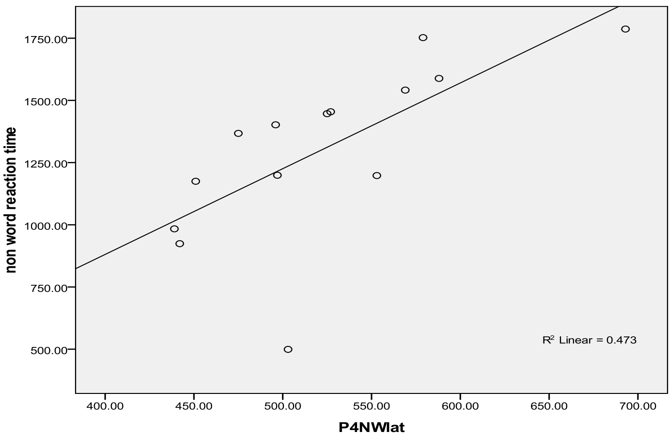

Figure 4.23 Scatter plot of non-word RT with N400 peak latency at P4 in children with dyslexia

For accuracy of words, the latency of N400 peak for words at FCz (R^2=0.134, p<0.05), T7 (R^2=, p<), C4 (R^2=0.09, p<0.05) and T8 (R^2=0.042, p<0.05) were potential predictors which predicted 13.4%, 9% and 4.2% of the time in that order. The scatter plots for the same are shown in Figure 4.24

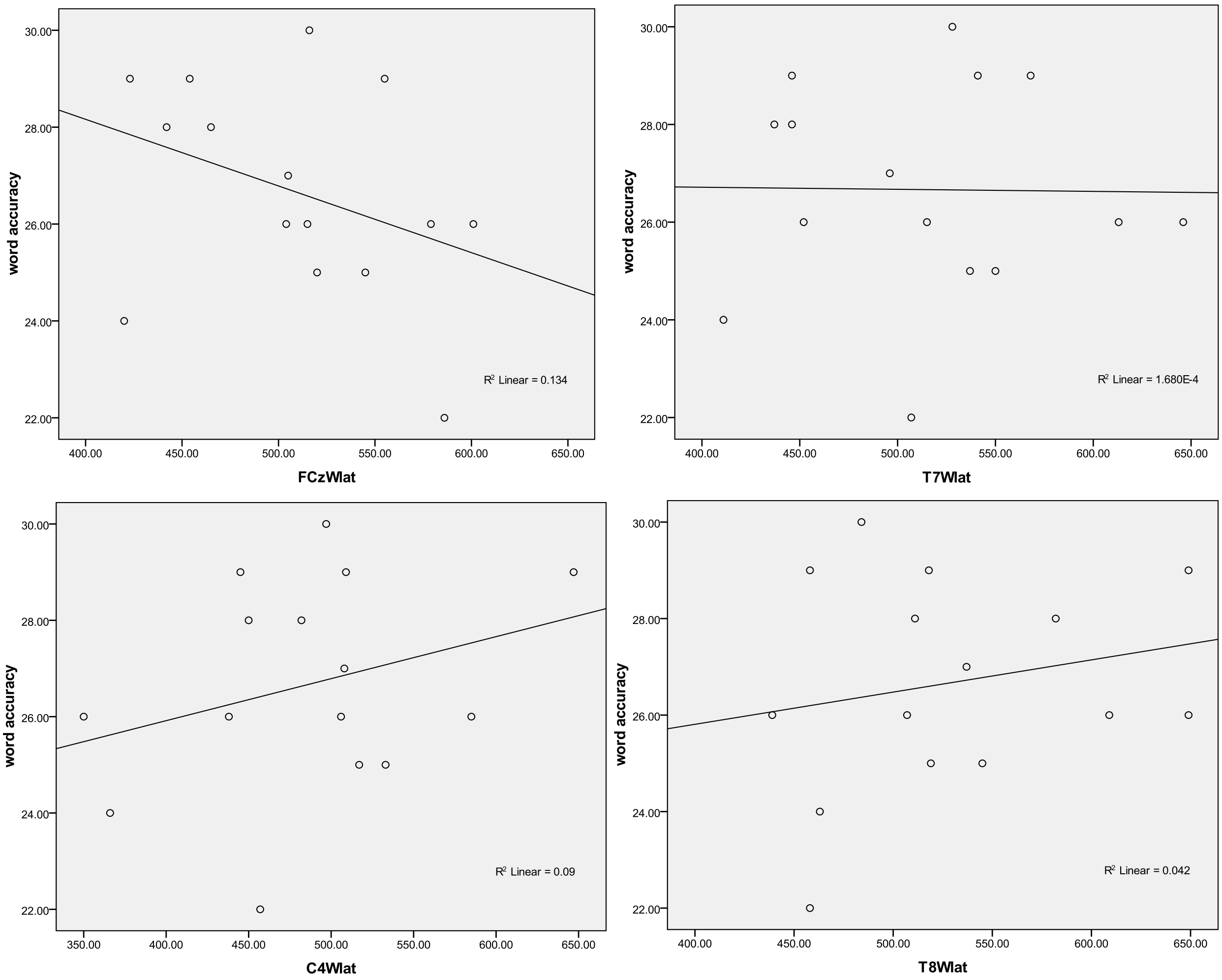

Figure 4.24 Scatter plot of word accuracy with N400 peak latency at FCz, T7, C4 & T8 in children with dyslexia

. But there were no potential predictors when peak amplitude of N400 for words and peak latency of N400 for non-words was considered for word accuracy (R^2 =0.783, p>0.05) and non-word (R^2 =0.917, p>0.05) accuracy respectively. When peak amplitude of N400 for non-words was considered, the potential predictors among the 15 channels were Fz (R^2=0.037, p<0.01), F4 (R^2=0.041, p<0.01), FCz (R^2=0.018, p<0.01), T7 (R^2=, p<0.01), C3 (R^2=0.027, p<0.01), C4 (R^2=0.084, p<0.01), CPz (R^2=0.011., p<0.01) and P3 (R^2=0.092, p<0.01), which predicted 3.7%, 4.1%, 1.8%, , 2.7%, 8.4%, 1.1% and 9.2% of the time in that order when non-word accuracy was considered. The scatter plots for the same are shown in Figure 4.25.

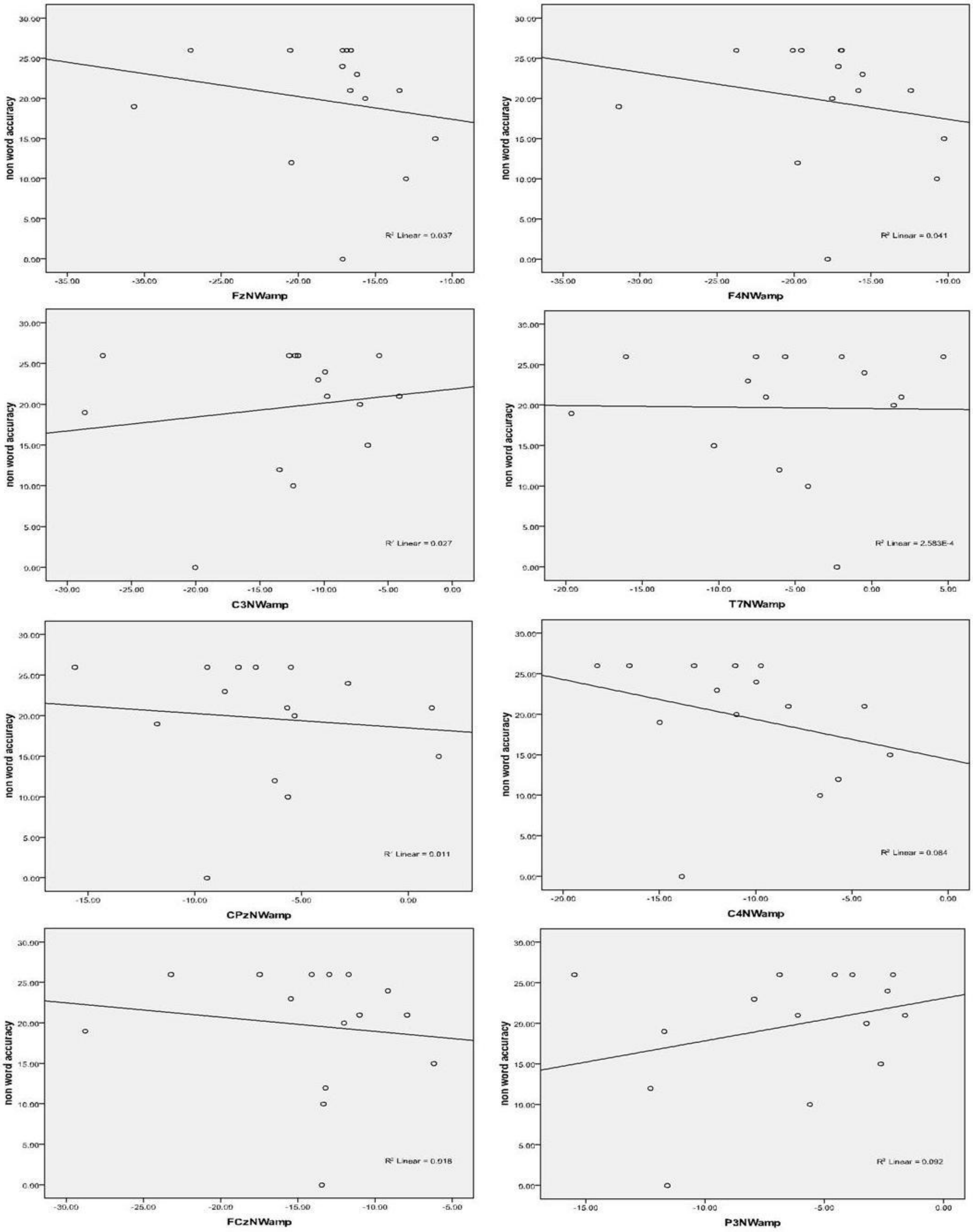

Figure 4.25 Scatter plot of non-word accuracy with N400 peak amplitude at Fz, F4, CPz, T7, C3, C4, FCz & P3 in children with dyslexia

4.4. Sub typing of dyslexia using behavioral and N400 measures

Discriminant function analysis was carried out to predict the group membership for TDC and children with dyslexia. Discriminant function analysis assesses the relationship between a group of predictors (in the present study for e.g., reaction time, accuracy, amplitude & latency measures) and a grouping variable (e.g., dyslexic & TDC).

Both behavioral and ERP data were subjected to discriminant function analysis considering all the variables such as reaction time, accuracy, peak amplitude and latency for both words and non-words across two groups of TDC (including both 8-9 year & 9-10 year old) and children with dyslexia. The results revealed two canonical discriminant functions, DF1 and DF2. The Discriminant Function 1 (DF1) had an eigen value of 162.59 with a correlation coefficient of 0.997 and the Discriminant Function 2 (DF2) had an eigen value of 10.22 with a correlation coefficient of 0.954. Thus, both the functions showed good correlation. But DF1 accounted for the 94.1% of the total variance, whereas DF2 accounted only for 5.9% of the total variance. Wilk's Lambda showed significant DF1 when the data was analyzed across the variables at 0.001, χ^2 (84)=161.580, $p<0.001$. However, DF2 was found to be not statistically significant (χ^2 (41)=51.987, $p>0.001$, Wilk's $\lambda=0.089$). Thus, the DF 1 is important in distinguishing the groups. When the functions of group centroids was examined, the 9-10 year old TDC group performed significantly different from the 8-9 year old TDC and children with dyslexia (Table 4.6). When DF2 was considered, 8-9 year old TDC was different from 9-10 year old TDC and children with dyslexia, but was not significant. The predictor variables contributing to two discriminant functions are shown in Table 4.7.

Table 4.6

Functions at group centroids for tasks (overall: words and non words)

Groups	Function	
	1	2
8–9 years TDC	1.395	-4.354
9-10 years TDC	-15.736	1.874
Dyslexics	14.341	2.480

Table 4.7

Structure matrix of predictors contributing towards the discriminant functions overall

	Function	
	1	2
C6Wlat	.027*	-.011
T7Wamp	.021*	-.006
PzNWamp	.019*	-.005
C5NWlat	.014*	.005
F4Wamp	.012*	.002
C5Wamp	.009*	.005
FzWamp	.009*	.002
F3Wamp	.008*	-.006
P3Wlat	.005*	.001
T7NWlat	.005*	.004
FCzNWlat	.029	.106*
word reaction time	.045	.084*
FCzWlat	.026	.074*
P4Wlat	.009	.071*
CzWlat	.005	.065*
T7Wlat	-.011	-.065*
T8Wamp	.026	.058*
PzWlat	.009	.057*
FzNWlat	.023	.057*

F3NWlat	.025	.052*
C4Wlat	.015	-.051*
C3Wamp	.002	-.044*
F4Wlat	.010	.041*

	Function	
	1	2
ord accuracy	.015	.040*
on word reaction time	.025	.037*
T8Wlat	.002	-.034*
CzWamp	-.006	-.033*
CPzWlat	.006	.032*
P3Wamp	.005	-.031*
P4Wamp	.010	.031*
F3Wlat	.012	.025*
CPzWamp	-.012	-.024*
C6Wamp	.013	.024*
C4Wamp	.014	-.023*
FzWlat	.010	.022*
non word accuracy	-.010	-.022*
C3Wlat	.013	-.019*
T8NWlat	.000	.018*
FCzWamp	-.004	-.015*
C5Wlat	.001	.004*

*. Largest absolute correlation between each variable and any discriminant function

Note: W=word, NW=non-word, lat=latency, amp=amplitude

The groups separated according to DF1 and DF2 are shown in the Figure 4.14. Results from Figure 4.26 revealed that the groups were separated apart from each other when DF 1 was considered. The analysis based on DF1 showed that group centroids for children with dyslexia were better than children with TDC.

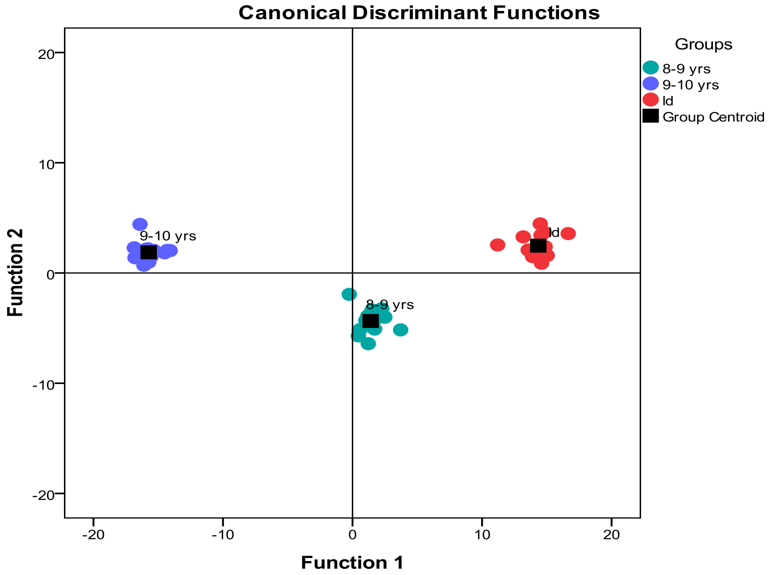

Figure 4.26 Group plot for canonical discriminate functions for combined behavioral and ERP measures for words and non words

Based on discriminant functions for overall tasks (performance on words & non words in both behavioral & ERP measures) classification was made to quantify predicted group membership. The results revealed that 100% of the 8-9 years old TDC, 9-10 years old TDC and children with dyslexia performed as their respective groups as shown in Table 4.8.

Table 4.8
Classification of TDC and dyslexics for discriminant functions (overall: both words & non words)

		Predicted group membership			
	Groups	8-9 years TDC	9-10 years TDC	Dyslexics	Total
Original	8-9 years TDC	15	0	0	15
Count	9-10 years TDC	0	15	0	15
	Dyslexics	0	0	15	15
	8-9 years TDC	100.0	.0	.0	100.0
%	9-10 years TDC	.0	100.0	.0	100.0
	Dyslexics	.0	.0	100.0	100.0

When analysis was done considering both word and non-word data, it was found that group centroids for children with dyslexia were better than children with TDC (Figure 4.26). This indicated that a combination of word and non-word could not differentiate the TDC and the dyslexia group. Hence a second step of analysis was done to remove the influence of word stimuli type for grouping TDC and dyslexia groups. In the second step of analysis, word stimuli were removed and group membership was studied only for the performance of children on non-word stimuli. On this analysis, two discriminant functions were derived for predicting group membership using reaction time, accuracy, peak amplitude and latency for only non-words. DF1 had an eigen value of 3.967 with a canonical correlation coefficient of 0.894 and the DF2 had an eigen value of 2.209 with a canonical correlation coefficient of 0.830. Both the discriminant functions showed similar correlation. DF1 accounted for the 64.2% of the total variance, whereas DF2 accounted only for 35.8% of the total variance. But when Wilk's Lambda was analyzed, both DF1 (χ^2 (64)=73.372, p>0.001, Wilk's λ=0.063) and DF2 (χ^2 (31)=30.897, p>0.001, Wilk's λ=0.312) were not statistically significant. The functions at group centroids (Table 4.9) for DF1 showed that 8-9 year old performed different from 9-10 year old TDC and children with dyslexia, showing more negative function for children with dyslexia than 9-10 year old TDC. When DF2 was considered, 9-10 year old TDC performed different from children with dyslexia. Thus the predictors on DF1 differentiated 8-9 year old TDC from children with dyslexia, while predictors on DF2 differentiated 9-10 year old TDC from children with dyslexia. The predictor variables contributing to two discriminant functions are shown in Table 4.10.

Table 4.9

Functions at group centroids for tasks (only for non words)

Groups	Function	
	1	2
8-9 years TDC	2.431	.912
9-10 years TDC	-.157	-2.027
Dyslexics	-2.274	1.115

Table 4.10

	Function	
	1	2
non word reaction time	-.115	.170*
C3NWamp	.046	.166*
P3NWamp	.031	.162*
F3NWlat	-.138	.157*
PzNWamp	-.037	.153*
C3NWlat	-.133	.138*
CzNWamp	.012	.134*
C6NWlat	.000	.128*
CPzNWamp	.010	.119*
C5NWlat	-.042	.110*
non word accuracy	.058	-.064*
T7NWlat	-.019	.038*

*. Largest absolute correlation between each variable and any discriminant function

Structure matrix of predictors contributing towards the discriminant functions for only non-words

	Function	
	1	2
FCzNWlat	-.229*	.148
CzNWlat	-.172*	.115
P3NWlat	-.161*	.056
PzNWlat	-.153*	.048
CPzNWlat	-.150*	.025
FzNWlat	-.140*	.139
F4NWlat	-.135*	.119
P4NWlat	-.125*	.021

T8NWlat	-.027*	-.013
C6NWamp	.060	.372*
T8NWamp	-.119	.299*
C4NWamp	-.022	.264*
F3NWamp	.020	.243*
F4NWamp	.006	.239*
T7NWamp	-.040	.231*
C4NWlat	-.020	.202*
FzNWamp	-.005	.200*
FCzNWamp	-.001	.174*

Note: W=word, NW=non-word, lat=latency, amp=amplitude

The discriminant functions were plotted on the graph as shown in Figure 4.27. DF1 was considered to discuss the group membership as it had accounted for more variance than DF2 though both DF1 and DF2 were not statistically significant. When DF1 was analysed from the Figure 4.27, it revealed that the children with dyslexia performed poorly than both 8-9 year old and 9-10 year old TDC.

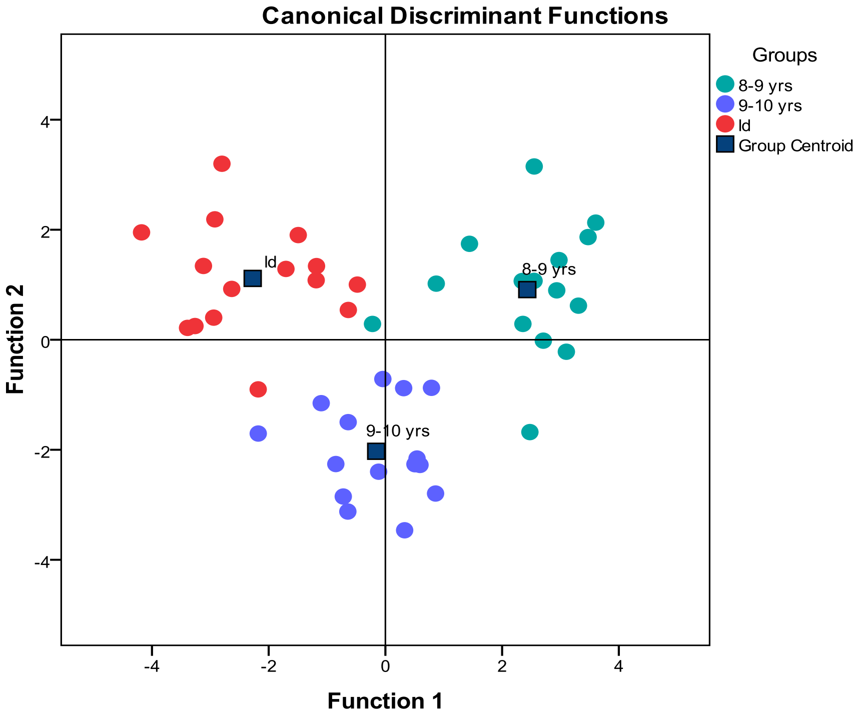

Figure 4.27 Group plot for canonical discriminate functions for combined behavioural and ERP measures only for non words

Based on discriminant functions for non-words (performance on only non words in both behavioral & ERP measures) classification was done to quantify predicted group membership. The results revealed that 93.3% of participants in 8-9 year old TDC (14/15) and 100% of participants in 9-10 year old TDC and children with dyslexia showed predicted group membership of their respective groups, as shown in Table 4.11.

Table 4.11
Classification of groups for discriminant functions (only non words)

		Predicted group membership			
	Groups	8-9 years	9-10 years	Dyslexics	Total
Original Count	8-9 years	14	0	1	15
	9-10 years	0	15	0	15
	Dyslexics	0	0	15	15
%	8-9 years	93.3	.0	6.7	100.0
	9-10 years	.0	100.0	.0	100.0
	Dyslexics	.0	.0	100.0	100.0

The results on discriminant function analysis (Figure 4.27) revealed that the group of children with dyslexia is different from that of typically developing children. This could be established using a host of functions for non-words such as FCzNWlat, CzNWlat, P3NWlat, PzNWlat, CPzNWlat, FzNWlat, F4NWlat, P4NWlat, and T8NWlat. The group plot also revealed that the group with dyslexia was not a homogenous group but a heterogenous group. Hence, subtyping of dyslexia was required. In order to carry out the subtyping, a Hierarchical cluster analysis was done. In this method, the clusters were represented in dendrograms for different tasks.

4.4.1 Subtyping of dyslexia based on behavioural measures (Nonword reaction time)

The major aim of the study was to subtype the children with dyslexia based on their performance on behavioral and ERP tasks. For this purpose hierarchical cluster analysis was done. Since discriminant analysis revealed that non words will better discriminate children with learning disability from the other two groups (8-9 year old & 9-10 year old) of TDC, performance on non words was only considered for cluster analysis. Hierarchical cluster analysis was done on children with dyslexia for subtyping them on their performance on non word reaction time. The participant 6 did not give any accurate response in recognizing non word and hence this data was eliminated from analysis. Cluster analysis on children with dyslexia revealed that for the performance on non word reaction time the participants can be clustered into two main groups, one large group (Group I) and another small group (Group II). The subjects {1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 13, 14, & 15} formed Group I and the subject {12} formed group II. (See figure 4.28)

```
 C A S E    0         5        10        15        20        25
Label Num +---------+---------+---------+---------+---------+

         1   -+
         3   -+-+
         5   -+ +-----------+
         9   -+-+           |
        15   -+             +---------------------------------+
         8   -+---+         |                                 |
        14   -+   +---------+                                 |
         4   -+   |                                           |
        11   -+---+                                           |
        10   -+                                               |
        13   -+                                               |
         2   -+                                               |
         7   -+                                               |
        12   -------------------------------------------------+
```

Figure 4.28 Dendogram representing hierarchical cluster analysis for non word reaction time in children with dyslexia

Qualitative analysis of the individual data revealed that, the participants in Group I showed poor performance and the participant in Group II showed better performance on non word reaction time. That is, the participants in Group I had longer reaction time and the participant in Group II had short reaction time in recognizing non word. Within Group I, the participants {1, 3, 5, 9 & 15} formed a cluster (Cluster I) and the participants {8, 14, 4, 11, 10, 13, 2 & 7} formed another cluster (Cluster II) (see Figure 4.28). On qualitative analysis of the individual data, it was found that the participants in Cluster I performed better than the participants in Cluster II. That is, the participants in Cluster I had shorter non word reaction time (mean ranging from 1197.17 ms - 924.13 ms) compared to the participants in Cluster II who had longer non word reaction time (mean ranging from 1786.81 ms - 1367.42 ms).

Within Cluster I, the participants {1, 3 & 5} differed from the participants {9 & 15} and thus forming separate clusters. Hence the participants {1, 3 & 5} formed the cluster (Cluster I a) and the participants {9 & 15} formed another cluster (Cluster I b). (See Figure 4.28). The clusters I a and I b differed in terms of performance on non word reaction time. The performance of participants on non word reaction time in cluster I a was poorer compared to that of participants in cluster Ib. Similarly, the participants {8 & 14} within cluster II differed from the participants {4, 11, 10, 13, 2 & 7} and formed separate clusters. Hence the participants {18 & 14} formed the cluster (Cluster II a) and the participants {4, 11, 10, 13, 2 & 7} formed another cluster (Cluster II b) (See Figure 4.28). The clusters II a and II b differed in terms of performance on non word reaction time with the participants in cluster II a performing poorer than the participants in cluster II b. Non words on which these participants performed poorly were ‘thish’, ‘lird’, ‘porse’, ‘prapes’, ‘jight’ and ‘gurse’. Analysis of Group II revealed that participant {12} performed differently forming a separate cluster (Cluster III) (see Figure 4.28). On qualitative analysis of the data, it was found that the performance of this subject on non word reaction time was good. That is this subject had shorter reaction time (499.26 ms) compared to other participants. To summarize, the participants in cluster I and II forming Group I had longer non word reaction time indicating poor performance and the participant in the cluster III forming Group II had shorter non word reaction time indicating better performance.

The results showed that dyslexia is not a homogenous group, but a heterogeneous group with existence of two major subtypes: phonological and non phonological. Children with dyslexia who fell into phonological subtype were the participants {1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 13, 14, and 15} and those who fell into non phonological subtype was the participant {12} (see Figure 4.28). Thus the present study supports the existence of heterogeneity among developmental dyslexia as suggested by various researchers (Murphy et al., 1994).

In the present study out of the 15 participants, 13 were classified as phonological sub type. Children with dyslexia who were subtyped as phonological type had poor performance on reaction time for non words and those subtyped as non phonological type had better performance on reaction time for non words. The sublexical processing is expected to be affected in children with phonological dyslexia (Castles et al, 1993; Kuppuraj et al, 2009). The sublexical processing of phonological dyslexics in the present study would have been affected and because of this these children are showing difficulty on their performance on non words. Children with phonological deficit perform poorly on tasks which require phonological awareness such as paying attention to and manipulating individual sounds (Snowling, 2000). The poor performance of children with phonological dyslexia in the present study could be attributed to this phonological deficit also.

Phonological short term memory is another manifestation of phonological deficits in children with dyslexia (Brady et al, 1991; Rack et al., 1992). This is important as the non word has to be kept in the memory while the processing takes place; the absence of which will lead to poor performance as evidenced in the present study.

Among these 13 participants there were sub groups forming different clusters. This indicates that even the children who were classified as phonological dyslexia did not form a homogenous group. Rather there was a gradation in their performances on non word reaction time, with the intermediate ones linking the extremes cases. That means to say that these children with dyslexia differed in their degree of impairment. This result is in consonance with the findings of Ellis (1985) and Ellis et al (1996) where they argued that children with dyslexia do not fall into distinct categories in terms of their word recognition skills. While some children can be characterized as surface or phonological dyslexics, these children will differ by degree of impairment and not type of impairment. The findings of Murphy et al (1994) also support the present study where they examined the word recognition abilities of sixty five children with reading disability. They strongly suggested that poor readers cannot be divided into homogeneous subgroups based on their word recognition abilities. They opined that poor readers differed primarily in terms of the severity of deficits, and not in the kind of deficits.

The one participant which formed the non phonological dyslexia showed good performance on non words. This indicates that the sub lexical processing in this child seems to be intact. The problem could be due to a non phonological deficit rather than a general phonological deficit. Individuals with surface dyslexia have good phonological decoding skills and poor exception word reading skills. In the present study exceptional words or irregular words were not considered. So, further investigation including exceptional words or irregular words is required to find out the exact nature of deficit in this particular child.

Several researchers had attempted to subtype the children with dyslexia based on their performance on phonological and non phonological tasks. They opined that there exists no homogeneous group of dyslexia. Different researchers had identified different classification system or subtypes of dyslexia (Ingram, 1964; Boder, 1970; 1973; Coltheart et al, 1980; Castles et al, 1993; Lovett et al, 1987; 1988; 1989; Kuppuraj et al, 2009; Gnanavel et al, 2009). The results of the present study are in line with Ellis (1985) where he suggested that there may be heterogeneity among poor readers in terms of word recognition strengths and weaknesses. Some children can be characterized as surface or phonological dyslexics but they may differ by degree of impairment and not type of impairment. The participants in group 1 exhibited significant impairments in word recognition speed which was indicated through longer reaction time. So these participants can also be labelled as the rate disabled subtype, a subtype of dyslexia proposed by of Lovett et al (1987, 1988 & 1989) where the children with dyslexia have marked deficit in reading rate despite grade-appropriate decoding ability. The phonological dyslexia identified in the present study is similar to the phonological type described by Coltheart et al (1980), Kuppuraj et al (2009), Gnanavel et al (2009) where they observed poor performance on phonological tasks in those participants who fell into this subtype.

4.4.2 Subtyping of dyslexia based on N400 latency and amplitude of non-words

To examine whether the latency of N400 peak for non-words can be used to group the children with dyslexia, cluster analysis was carried out. Hierarchical cluster analysis carried out to subtype children with dyslexia based on latency of N400 for non-words is shown in the Figure 4.29.

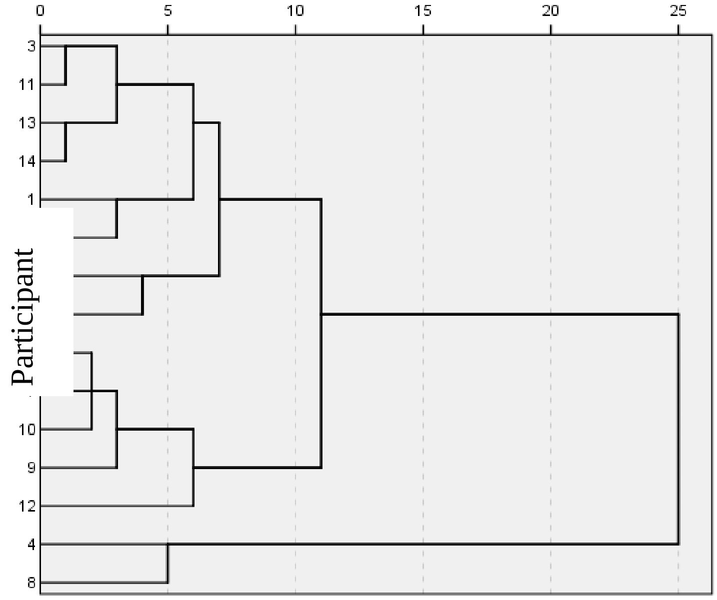

Figure 4.29 Dendogram representing hierarchical cluster analysis based on peak latency of N400 for non-words in children with dyslexia (x-axis representing the participant)

Analyzing results from Figure 4.29 revealed 2 main clusters, Cluster 1 and Cluster 2. Cluster 1 (1, 2, 3, 5, 6, 7, 9, 10, 11, 12, 13, 14 & 15) had larger number of children with dyslexia grouped in it, whereas Cluster 2 (4 & 8) had only 2 of them clustered. Examining the mean of each participant revealed that the participants in Cluster 2 had longer mean peak latencies of N400 compared to participants in Cluster 1. Thus, indicating a better performance in participants forming Cluster 1. Cluster 1 consisted of another 2 more clusters named Cluster 1a and Cluster 1b. Cluster 1a included the participants 1, 2, 3, 6, 11, 13, 14 and 15. Cluster 1b included 5, 7, 9, 10 and 12th participant. The Cluster 1a (mean ranging from 436ms to 698ms) had longer mean peak latencies of N400, revealing poorer performance, compared to the Cluster 1b (mean ranging from 434 ms to 595 ms).

The results showed that dyslexia is not a homogenous group, but a heterogeneous group with existence of two major subtypes: phonological and non phonological. Children with dyslexia who fell into phonological subtype were the participants {4 & 8} and those who fell into non phonological subtype was the participants {1, 2, 3, 5, 6, 7, 9, 10, 11, 12, 13, 14 & 15} (see Figure 4.29). Thus the present study supports the existence of heterogeneity among developmental dyslexia as suggested by various researchers.

In the present study out of the 15 participants, 13 were classified as non phonological sub type. Only two of the participants were classified as phonological type. Children with dyslexia who were subtyped as phonological type had longer N400 peak latencies for non words and those subtyped as non phonological type had shorter latencies of N400 peak for non-words. The sublexical processing is expected to be affected in children with phonological dyslexia (Castles et al, 1993; Kuppuraj et al, 2009). The sublexical processing of phonological dyslexics in the present study would have been affected and because of this these children are showing longer latencies of N400 peak on non words. Phonological short term memory is a manifestation of phonological deficits in children with dyslexia (Brady et al, 1991; Rack et al., 1992). This is important as the non word has to be kept in the memory while the processing takes place; the absence of which will lead to poor performance as evidenced in the present study. Children with phonological deficit perform poorly on tasks which require phonological awareness such as manipulating individual sounds (Snowling, 2000). The poor performance of children with phonological dyslexia in the present study could be attributed to this phonological deficit also.

The subtyping of children with dyslexia based on based on behavioural non-word reaction time showed a larger phonological group and there were various groups classified among that larger group. Correlating with the behavioral subtyping, the participant 4 and 8 were classified under phonological type. Further, the subtyping based on peak latency of N400 for non-words has helped in classifying this larger phonological group reflecting the degree of phonological impairment. In case of participant 12, who was the only classified as non-phonological in behavioural subtyping, was also classified under same subtype in latency based classification. The participant 12 had the shortest mean N400 peak latency for non-words, also reflected as shorter reaction times on non-words, indicating the correlation of good performance. The other participants who had larger reaction times for non-words along with participants 4 and 8 did not show such greater impairment in the latency of N400 peak compared to participants 4 and 8. This indicates that there might be others factors such as attentional state and the processing decoding of the lexical decision into motoric responses influencing the behavioural reaction time rather than exclusively lexical decision.

Even though the latency of N400 peak for non-words correlated well with the behavioural reaction times, the amplitude of N400 peak for non-words was further utilised for subtyping to see whether it can be considered for correlating with the behavioural performances of children with dyslexia.

Hierarchical cluster analysis was carried out to examine whether the N400 peak amplitude for non-words can be used to group the children with dyslexia. The clusters based on peak amplitude of N400 for non-words are shown in the Figure 4.30.

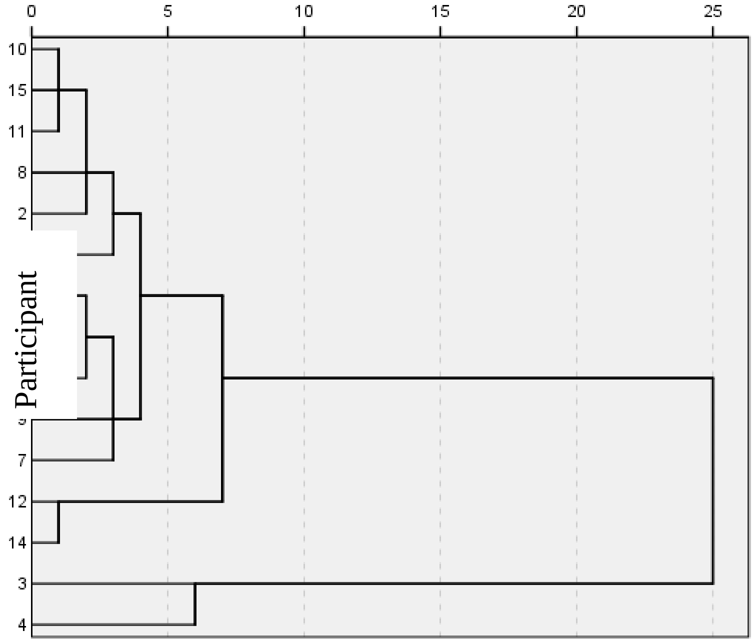

Figure 4.30 Dendogram representing hierarchical cluster analysis based on peak amplitude of N400 for non-words in children with dyslexia (x-axis representing the participant)

There were 2 main clusters observed (as shown in Figure 4.30) among children with dyslexia even when the amplitude of N400 peak was considered namely Cluster 1 and Cluster2. Cluster 1 (1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 & 15) had the maximum number of children with dyslexia grouped into it when compared to Cluster 2 (3 & 4), which consisted of only two children with dyslexia grouped. The mean data indicated that Cluster 2 had greater peak amplitude of N400 compared to the Cluster 1 indicating better performance in Cluster 2. The Cluster 1 was further grouped into 2 clusters. Cluster 1a consisted of 1, 2, 5, 6, 7, 8, 9, 10, 11, 13 & 15th participant, whereas Cluster 1b consisted of only two participants 12 & 14. The Cluster 1b (mean ranging from -13.70µV to 4.56µV) had the least mean peak amplitude than the Cluster 1a (mean ranging from -35.53µV to 4.68µV) revealing poorer performance in processing non-words.

The participants 3 & 4 forming Cluster 2 (in Figure 4.30) showed greater N400 peak amplitude for non-words, which indicates a better performance matching the processing similar to TDC. Thus these two participants can be classified under non-phonological type. But according to the behavioural subtyping and subtyping based on latency the participant 4 was classified under phonological type. Even when the Cluster 1 (in Figure 4.30) was considered, though greater number of participants were included in this group who showed lesser N400 peak amplitude for non-words, who can be classified under phonological subtype does not correlate with the types derived from subtyping using behavioural non-word reaction time or N400 peak latency for non-words. Also, there was no correlation seen between the non-word reaction time and N400 peak amplitude for non-words in children with dyslexia. It was also discussed earlier that the TDC children showed differences in N400 peak amplitude for words and non-words (that is N400 effect), where as children with dyslexia did not exhibit differences in N400 peak amplitude but showed differences in N400 peak latency for words and non-words. Thus, the subtyping based on N400 peak latency for non-words is more reliable in classifying among the children with dyslexia which was true in the present study. The subtyping based on N400 peak amplitude might be useful in classifying TDC, but might not serve as a tool to classify children with dyslexia as it is not present or exhibited in them.

To summarize the present study confirmed the heterogeneity among the children with dyslexia. Two major subtypes of children with dyslexia were identified: the phonological and the non phonological type. The subtyping based on the ERP measures such as N400 peak latency in the present study, will not only help in correlating with the behavioural measures but also will aid in differentiating the children with dyslexia based on their degree of impairment (Ellis, 1985; Ellis et al., 1996). Such a classification will help in more fine grained understanding the nature of the problem in children with dyslexia. The reality that children with dyslexia display heterogeneity and hence can be subtyped or classified on the basis of word recognition abilities has some clinical/educational validity. The treatment that has to be provided for a particular child varies depending on his/ her strengths and weakness. Subtyping and profiling the children with dyslexia will allow in better understanding of the exact nature of the problem and the development of individualized treatment plan. When appropriate treatment based on their deficits is provided, these children will definitely improve on their performance.

SUMMARY AND CONCLUSION

There is enough evidence that a sub-group of children with dyslexia or Learning disability show some form of underlying phonological deficit leading to reading difficulties. However, the focus on understanding whether these deficits are at a perceptual level, awareness level or cognitive level has been attempted through offline behavioural tasks such as metaphonological or phonological awareness tasks. It is important that an assessment of phonological processing is done at an explicit as well as implicit level in order to understand the relative difficulty of a child with dyslexia at various levels such as lexical access, decoding, phonemic categorization and awareness. An explicit and implicit level of understanding will facilitate in identifying various subtypes of dyslexia and/or atleast phonological v/s non-phonological subtype of dyslexia.

Event-related brain potentials (ERP) have been found successful in providing data that reflects processing at each millisecond from the onset of language stimuli, and multiple, differentiable cognitive operations. Previous studies have described many ERP components associated with different stages of lexical processing such as the N400 (Carreiras, Perea, & Grainger, 1997; Grainger & Jacobs, 1996; Holcomb, Grainger& O’Rourke, 2002; Kutas & Van Petten, 1994; Sears et al., 1995). It has been reported that the N400 elicited by words is particularly sensitive to the processing of semantics, and is relatively insensitive to the decision or response strategies found to influence behavioural responses. Hence, lexical processing and subtyping of dyslexia, was investigated in the present study using ERP measures as on-line measure and behavioral measures as off-line measures that occur in response to a lexical decision task in Indian children. Thus, the aim of the present study is to compare the behavioural correlates with event-related potential (ERP) correlates of implicit phonological processing during the recognition of spoken words in children with dyslexia and typically developing children and thus an attempt to subtype the dyslexia.

A total of 30 typically developing children (TDC) and 15 children with dyslexia were included in the present study. The participants were aged between 8-10 years. The TDC were divided into two groups- Group 1 included children in the age range of 8-9 year old and Group 2 included 9-10 year old children. Group 3 consisted of children with dyslexia. Reaction time and accuracy were measured on a lexical decision task as a behavioural measure. The electrophysiological correlate included the peak amplitude and latency of N400 peak, which was measured at 15 different electrode sites. The stimuli used were 30 word and non-word pair for both behavioural and electrophysiological measures. The peak amplitude (in µV) and latency (in milliseconds) of N400 was considered separately for words and non-words and was analysed. The statistical analysis was done using SPSS version 17.0.

The comparison of performance of TDC and children with dyslexia was made on behavioral measures. The findings of the present study revealed that in both the groups of TDC the reaction time was faster for words when compared to non-words. A developmental trend in the performance of TDC for both words and non-words was also observed, children with 9-10 years of age showed shorter reaction times than 8-9 year old children. Similar pattern was observed in the performance of children with dyslexia where the reaction time for non words was longer compared to words. The findings also revealed that there was no significant difference between the two groups of TDC, but a statistically significant difference between children with dyslexia and the other two groups of TDC (Group 1 & Group 2) was observed.

Results of behavioral measure indicated that the children with dyslexia required more time than the age matched TDC to recognize the word or non word. The children with dyslexia were found to have problems in phonological processing skills and decoding skills which could have led to longer time in the lexical processing. This could be attributed to the poor performance of children with dyslexia than TDC in the present study. Analysis of results on accuracy measures revealed that accuracy for non words was poorer compared to words indicating more errors for performance on non-words. Comparing the performance of children with dyslexia and TDC, the performance of the former group was better for words.

With respect to non words, the performance was poorer for children with dyslexia than TDC. The factors such as attention and verbal short term memory also may affect the outcome of the performance on accuracy measures. Children with dyslexia were as accurate as TDC of the same age in accepting words and refusing non words. Despite the fact that they were not less accurate, they were slower than age-matched peers in recognizing words and non words as observed on reaction times measure. Thus, children with dyslexia seem to be delayed and not deviant from the lexical developmental pattern.

The results on performance of TDC and children with dyslexia on ERP measures revealed that the mean peak amplitude and latency of N400 for non-words was greater and longer than that for the words respectively. The findings also indicated that the difference in mean peak amplitude of N400 for words and non-words (termed as N400 effect) is greater in children with dyslexia when compared to TDC. The difference in mean peak amplitude of N400 also varied across channels in both the groups. There was no significant difference between Group 1 and Group 2 of TDC. Hence the two groups were combined to form one group. The mean peak amplitude and latency of N400 was greater and shorter respectively in TDC when compared to children with dyslexia. The results indicated that there was no difference in the N400 peak amplitude for words and non-words in children with dyslexia (as seen in TDC). But a difference in N400 peak latency for words and non-words was observed in children with dyslexia unlike TDC. This suggests that the non-word processing is different from word processing in children with dyslexia which indicates involvement of different processes in non-word processing in them compared to TDC. Also, the deficiencies in children with dyslexia are not only restricted to perceptual and lower-level phonological abilities, but also affect higher order linguistic skills such as lexical and semantic processing. The topographical distribution of N400 peak indicated that there was greater spread of activation and is widely spread across the scalp in TDC for both words and non-words when compared to children with dyslexia. The pattern in which there is spread of activation from frontal region to the parietal region owing more towards the right hemisphere is similar both in TDC and children with dyslexia. In TDC, there was some amount of activity in parietal region, whichwas absent in children with dyslexia for both words and non-words.

The correlation of behavioral and ERP (N400) measures in TDC and children with dyslexia showed that the reaction time and peak amplitude of N400 for words correlated in TDC. In children with dyslexia correlation was seen between reaction time and peak latency of N400 for non-words. This suggests that the prolonged N400 latency for non-words in children with dyslexia showed poorer performance on lexical decision task showing longer reaction times for non-words indicating temporal processing deficit in children with dyslexia. It also suggests the underlying process in TDC during the perception of words is different (showing amplitude differences) from children with dyslexia who demonstrated latency differences.

Further, the children with dyslexia were subtyped based on non-word reaction time which revealed phonological and non-phonological subtype. The phonological subtype further had different sub groups in it. Thus, there exists no definite homogenous group among the children with dyslexia though a few similar characteristics were found between children based on which sub groups were obtained. The primary objective of the present study was to classify/subtype children with dyslexia based on N400 latency and amplitude. The subtyping based on peak latency of N400 revealed two subtypes: phonological and non-phonological types among the children with dyslexia. These subgroups correlated well with the behavioral subtypes in the present study. The subtyping based on N400 peak amplitude also revealed two groups but did not correlate with the behavioral subgroups. The TDC showed differences in N400 peak amplitude for words and non-words (that is N400 effect), where as children with dyslexia did not exhibit differences in N400 peak amplitude but showed differences in N400 peak latency for words and non-words. Also, there was no correlation seen between the non-word reaction time and N400 peak amplitude for non-words in children with dyslexia whereas the non-word reaction time correlated well with N400 peak latency. Thus, the subtyping based on N400 peak latency for non-words is more reliable in classifying among the children with dyslexia. The subtyping based on N400 peak amplitude might be useful in classifying TDC, but might not serve as a tool to classify children with dyslexia as it is not present or exhibited in them.

To summarize the present study confirmed the heterogeneity among the children with dyslexia. Two major subtypes of children with dyslexia were identified: the phonological and the non phonological type. The subtyping based on the ERP measures such as N400 peak latency in the present study, will not only help in correlating with the behavioural measures but also will aid in differentiating the children with dyslexia based on their degree of impairment. Such a classification will help in more fine grained understanding the nature of the problem in children with dyslexia and in the development of individualized treatment plan based on whether children need to follow strategies for top-down processing or bottom-up processing or both. Children with dyslexia of the phonological subtype require strengthening of bottom-up skills right from auditory discrimination skills to phonological processing skills. On the other hand children with dyslexia of the non-phonological type may require both bottom-up and top-down strategies for processing auditory information. Also, the management could focus on strengthening the phonological/lexical related skills through exercises for improving lexical access, lexical storage, sequencing, programming and execution. The treatment that has to be provided for a particular child varies depending on his/ her strengths and weakness. When appropriate management is provided based on their deficits, these children could improve on their processing skills which reflect on their reading skills. The reality that children with dyslexia display heterogeneity and hence can be subtyped or classified on the basis of word recognition abilities as shown in the present study seem to have some clinical/educational importance.

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APPENDIX 1

List of stimuli

No.	Words	Nonwords
1.	Desk	Lesk
2.	Leaf	Meaf
3.	Home	Gome
4.	Socks	Thocks
5.	Fish	Thish
6.	Phone	Thone
7.	Lion	Dion
8.	Bird	Lird
9.	Crow	Trow
10.	Pipe	Gipe
11.	Glass	Plass
12.	Bus	Dus
13.	Box	Mox
14.	Milk	Jilk
15.	Frog	Srog
16.	Girl	Shirl
17.	Bike	Vike
18.	Belt	Jelt
19.	Bench	Mench
20.	Paste	Gaste
21.	Horse	Gorse
22.	Grapes	Prapes
23.	Frock	Srock
24.	Brush	Drush
25.	Light	Jight
26.	Tail	Kail

27.	Door	Zoor
28.	Chalk	Galk
29.	Tree	Kree
30.	Mouth	Jouth