# NEUROCOGNITIVE PROCESSING IN DYSLEXIC CHILDREN: AN EVENT RELATED POTENTIAL (ERP) STUDY

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**By**

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| | |
|---|---|
| n | Number of subjects |
| Hz | Hertz |
| KHz | Kilohertz |
| SD | Standard Deviation |
| µV | Microvolts |
| *p*-value | Significance level |
| S | Significant |
| NS | Non-significant |
| ms | Milliseconds |
| < | Less than |
| > | More than |
| NA | Nano ampere |
| L | Left-brain hemisphere |
| R | Right-brain hemisphere |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADHD | Attentional Deficit Hyperactivity Disorder |
| ASSR | Auditory Steady State Cortical Response |
| BA | Brodmann Area |
| BDA | British Dyslexia Association |
| CLARA | Classic LORETA Recursively Applied |
| CPT | Continuous Performance Test |
| dB HL | Decibels Hearing Level |
| dB SPL | Decibels of Sound Pressure Level |
| DD | Developmental Dyslexia |
| DSM-V | American Psychiatric Association's Diagnostic and Statistical Manual Fifth Edition |
| EEG | Electroencephalography |
| ERP | Event Related Potential |
| fMRI | Functional Magnetic Resonance Imaging |
| FOCUSS | Focal Underdetermined System Solver |
| HUSM | Hospital Universiti Sains Malaysia |
| IDA | International Dyslexia Association |
| ISC | Inter Dyslexic Subject Correlation |
| ISD | Instrument Senarai Semak Disleksia/ Dyslexia Screening Instrument |
| ISI | Inter stimulus Interval |
| JPN | Jabatan Pendidikan Negeri/State Education Department |
| KCI | Potassium Chloride |

| | |
|---|---|
| LGN | Lateral Geniculate Nucleus |
| LH- | No Familial Risk of Dyslexia |
| LH+ | Familial Risk of Dyslexia |
| LI | Lateralization Index |
| LINUS | Malaysian National Screening Instrument |
| LLI | Language and Learning Impairment |
| MEG | Magnetoencephalography |
| MMN | Mismatch Negativity |
| MMSE | Mini Mental State Examination |
| MOE | Ministry of Education |
| MRI | Magnetic Resonance Imaging |
| ms | Milliseconds |
| PET | Positron Emission Tomography |
| PSP | Postsynaptic Potential |
| RAP | Rapid Auditory Processing |
| RAVLT | Rey Auditory Verbal Learning Test |
| RT | Reaction Time |
| RTE | Redundant Target Effect Paradigm |
| SLD | Specific Learning Disorder |
| sLORETA | Standardized Low-Resolution Brain Electromagnetic Tomography |
| SNR | Signal to Noise Ratio |
| SSW | Standard Spondaic Word Test |
| UPSR | Ujian Penilaian Sekolah Rendah |
| vMMN | Visual Mismatch Negativity |

| | |
|---|---|
| vOT | Ventral Occipital Temporal Cortex |
| VWFA | Visual Word Form Area |
| VWM | Verbal Working Memory |

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# PROSES NEUROKOGNITIF DALAM KALANGAN KANAK-KANAK DISLEKSIA: KAJIAN *EVENT RELATED POTENTIAL* (ERP)

## ABSTRAK

Kanak-kanak disleksia dikatakan mempunyai defisit dalam fungsi daya tumpuan neurokognitif yang menyebabkan kebolehan mereka memproses stimulasi sensori terganggu. Namun, mekanisma daya tumpuan yang terlibat dalam fungsi pemprosesan stimulasi ini masih tidak diketahui secara jelas. Oleh itu, kajian ini dijalankan bagi menyiasat mekanisma pemprosesan dan sumber aktiviti otak bagi daya tumpuan neurokognitif dalam kalangan kanak-kanak disleksia terhadap stimulasi auditori dan visual, menggunakan teknik *Event Related Potential* (ERP). Seramai 24 kanak-kanak sekolah rendah direkrut bagi kumpulan disleksia (n = 12) dan kawalan (n = 12). Jaring sensor kanak-kanak 128-EEG digunakan untuk kajian ERP ini. Empat jenis paradigma ransangan digunakan sebagai stimulasi; Pendengaran ganjil, padanan *audio-visual*, padanan imej kongruen, dan perkataan-perkataan pseudo. Komponen-komponen ERP iaitu *Mismatch Negativity* (MMN), P300 dikaji bagi paradigma yang bercirikan pendengaran iaitu bagi paradigma pertama dan kedua. Manakala, komponen N200 dan P300 dikaji bagi paradigma selebihnya yang bercirikan visual. Nilai perbezaan gelombang antara rangsangan sasaran/ganjil dan ransangan biasa diukur dalam kedua-dua kumpulan menggunakan sistem EEG 10-20 pada 19 elektrod. Ujian statistik Mann Whitney U test diguna pakai dalam mencari perbezaan signifikan bagi amplitud dan latensi setiap komponen antara kumpulan kajian. Pencarian sumber aktiviti bagi setiap komponen ERP dalam semua paradigma menggunakan kaedah *Standardized Low-resolution Brain Electromagnetic Tomography* (sLORETA) dalam

perisian Stesen Net. Dalam ransangan **paradigma pendengaran ganjil**, amplitud MMN jauh lebih tinggi (4 lokasi) dan latensi berpanjangan (1 lokasi) dalam kalangan disleksia berbanding dengan kawalan. Amplitud P300 jauh lebih besar di 2 lokasi, sementara latensi P300 secara signifikan lebih pendek dan berpanjangan (masing-masing di 2 lokasi) dalam kanak-kanak disleksia berbanding kanak-kanak kawalan. Sumber aktiviti kedua-dua komponen ERP dalam disleksia dilihat lateral ke hemisfera kanan dengan MMN (BA18) dan P300 (BA9). **Dalam rangsangan padanan *audio-visual***, terdapat latensi P300 (2 lokasi) yang jauh lebih pendek dalam kalangan disleksia yang dilihat kedua-dua komponen ERP aktif di hemisfera otak kiri semasa MMN (BA3) dan P300 (BA19). **Dalam rangsangan gambar padanan habitat haiwan**, pemanjangan latensi N200 yang signifikan (2 lokasi) dan latensi P300 yang lebih pendek (1 lokasi) dalam kalangan disleksia berbanding kawalan. Sumber aktiviti otak dilihat di lobus oksipital kiri BA 18 (N200) dan BA19 (P300) di kawasan disleksia. **Untuk paradigma rangsangan kata-pseudo**, amplitud N200 (1 lokasi) dan P300 (2 lokasi) jauh lebih besar beserta latensi yang lebih pendek dari kedua-dua komponen (1 lokasi) dilihat dalam disleksia. Walau bagaimanapun, sumber aktiviti komponen N200 dan P300 dalam disleksia dikesan di kawasan BA39 dan BA19. Sebagai kesimpulan, penemuan ERP menunjukkan bahawa terdapat peningkatan fungsi kognitif tumpuan dalam semua paradigma pendengaran dan visual dalam kalangan disleksia berbanding kawalan, yang menyarankan pemprosesan mekanisma neuron yang berbeza dalam kumpulan disleksia dalam mengatasi defisit yang belum ditentukan secara pasti, dan dapatan ini juga disokong dengan aktiviti sumber saraf yang beralih.

# NEUROCOGNITIVE PROCESSING IN DYSLEXIC CHILDREN: AN EVENT-RELATED POTENTIAL (ERP) STUDY

## ABSTRACT

Dyslexic children have been reported to have an attentional neurocognitive deficit in processing sensory stimulations. Due to that, this study was aimed to investigate the neurocognitive attentional processing of dyslexic children comparing to the healthy control children in different auditory and visual stimuli paradigms by using the Event-Related Potential (ERP) technique. A total of 24 primary school-aged children were recruited for the dyslexic (n=12) and control (n=12) groups. 128-EEG child sensor net was used for the ERP study. There were four different stimulus paradigms were used in this study which was; auditory oddball, paired audio-visual, visual image congruency, and pseudo words/true words. For the first two paradigms, the MMN and P300 ERP components were analysed for the auditory and shifted attention. Alternatively, the N200 and P300 were analysed for visual attentional processing in the other two paradigms. The values of difference wave between target and standard stimuli were measured in both groups in the 10-20 system at 19 electrodes. Then, the Mann Whitney U test statistical analysis was used to analyse the mean difference amplitudes and latencies for each ERP component between dyslexic and control groups. Besides, source localizations of MMN, N200, and P300 ERP components were done for all paradigms using the Standardized Low-Resolution Brain Electromagnetic Tomography (sLORETA) method in Net-station software. For the result findings, during the auditory oddball paradigm, MMN amplitudes were significantly higher (4 sites) and prolonged latency (1 site) in dyslexics compared with the control. P300 amplitudes were significantly larger at 2 sites, whilst the P300 latencies were significantly shorter and prolonged (in 2 sites each) in the dyslexic children than control children. The source activities of both ERP components in dyslexics were seen lateralized in the right hemisphere with MMN (BA18) and P300 (BA9). In audio-visual paired stimuli, there were significantly shorter P300 latencies (2 sites) among dyslexics which seen both ERP components activated in the left hemisphere during MMN (BA3) and P300 (BA19). In visual image congruency stimuli, significant prolongation of N200 latencies (2 sites) and significantly shorter P300 latency (1 site) among dyslexics than the controls. The source activities were seen in the left occipital lobe of BA 18 (in N200) and BA19 (in P300) areas in dyslexics. For the pseudo word/true words stimuli paradigm**,** significantly larger amplitudes of N200 (1 site) and P300 (2 sites) with shorter latencies of both components (1 site) were evoked in dyslexics. However, the source activities of N200 and P300 components in dyslexics were located in the BA39 and BA19 areas, accordingly. In conclusion, the ERP findings showed that there were a betterment and enhancement in attentional cognitive function in all auditory and visual task paradigms among dyslexics than the controls, suggested on different neuronal mechanism processing among dyslexics in overcoming the undetermined deficit that was also supported with shifted neural source activities.

**Keywords:**

P100, MMN, N200, P300 ERP component, attentional processing, auditory oddball, audio-visual, visual images, orthographical lexicon, dyslexia

# CHAPTER 1

# INTRODUCTION

This chapter discussed the background of the study starting from the introduction to dyslexia follows by the definition of dyslexia from a different view. The epidemiology, theories, and etiologies of dyslexia were also discussed. Then, the subtypes of dyslexia are briefly related to the theories of dyslexia. ERP technique in the study of neurocognitive studies among dyslexics was also discussed. Besides, the objectives, research hypothesis, and significance of this study were presented.

## 1.1 INTRODUCTION TO DYSLEXIA

In 1877, a German physician, Adolp Kussmaul introduced a rare concept of reading failure as ‘word blindness, which was later termed as dyslexia by Rudolf Berlin in 1887. Rudolf Berlin described his patient with dyslexia mostly encountered difficulty with word reading with no possible causes were explained. Many years have passed since the early introduction of dyslexia, however, the explanations on the cause for it to happen aside from genetic factors are still inconclusive. Nowadays, as neuroscience technologies keep on advancing, many theories have been proposed to justify the causal factor of dyslexia that limits the capability to read, spell, and write. Some of the established theories are the magnocellular deficit theory, cerebellar impairment, and cognitive deficit. Recently, many neuroscientists have shifted their attention towards neurocognitive study in dyslexia as many current studies have found that the limitations of learning skill sets (reading, spelling, and writing) in dyslexia are linked to neurocognitive impairment in relating to attentional sensory processing (visual and auditory). This claim was based on many different aspects of attention that are impaired in those who are diagnosed with dyslexia (Lewandowska, Milner, Ganc, Włodarczyk, & Skarżyński, 2014).

Impairment in the aspect of sensory attention incorporated in basic visual and auditory processes causes difficulties in associating orthographical structure with its associating sound (phoneme) in word reading (Sela, 2014). Even though the studies of dyslexia are actively done, the studies of neurocognitive attentional processing are still lacking. Within the past years, many types of research primarily discussed the neurocognitive attentional deficit in sensory stimuli processing (visual and auditory stimuli) as the causal effect of learning difficulty in dyslexia (Francisco, Jesse, Groen, & McQueen, 2017; González et al., 2014; Lewandowska et al., 2014). However, inconclusive findings in neurocognitive attentional studies especially in dyslexics, provide no rational explanation on the state of attentional mechanism that happened concerning neurocognitive processing. Due to this, proper intervention for those affected with dyslexia could not be comprehensively served.

## 1.2 THE DEFINITION OF DYSLEXIA

The definition of dyslexia is widely vast, some limits on the sensory part, while some others are based on children's reading abilities. Lately, research in cognitive studies has started to relate cognitive impairment with the failure of reading and writing skills in dyslexia. Due to that reason, the definition of dyslexia is changing from time to time to allow a comprehensive description of dyslexia parallel with current findings. The British Dyslexia Association (BDA) defines dyslexia as a "specific learning difficulty that mainly affects the development of literacy and language-related skills. It is likely to be present at birth and to be life-long in its effects" (Protopapas, 2018). Anyhow, the definition by BDA does not comprehensively include any factor of neurobiology or cognitive function deficit, which does not coherently linear with the majority of recent studies in dyslexia.

The most cited and accepted definition of dyslexia was proposed by the International Dyslexia Association (IDA) in 2002, IDA has defined dyslexia as "a specific learning disability that is neurobiological in origin. It is characterised by the difficulties of accuracy and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically are the result of a deficit in the phonological component of language that is often unexpected concerning other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede the growth of vocabulary and background knowledge" (International Dyslexia Association, 2002). The definition was supported by Lyon, Shaywitz, and Shaywitz (2003), which they further defined in their literature (Lyon, Shaywitz, & Shaywitz, 2003). The acquisition of learning to read and write are the toughest challenges for the human being. It seems easy for most children but surprisingly, a large group of children is facing problems with it, even for the bright kids. Being able to read does not only comprise sensory processing, but it does highly interrelated to neuro-cognition as well, such as attention. With the advancement of neuroimaging that we have in recent years, it does significantly help in identifying the neurobiological frameworks related to neurocognitive attentional function in clearer views.

Subsequently, the definition of dyslexia is varied across the ages, and as much researches were conducted throughout the years, it has opened a wider view on dyslexia and does not limit solely on the ability to read, spell, and write, but also in arithmetic skills. The characteristics of dyslexia are following the American Psychiatric Association's Diagnostic and Statistical Manual Fifth Edition (DSM-5) that was published in 2013, which categorized dyslexia as a 'specific learning disorder' (SLD) and it has become the umbrella term for wide difficulties in reading, writing, and mathematic difficulties. Both described definitions from IDA (2002) and Lyon, Shawitz, and Shawitz (2003) do acknowledge the neurobiological impairment factor in learning difficulty among dyslexia, which parts agreeing with many findings relating dyslexia with the impairment in higher-level order of neurocognitive processing, such as attention. Due to that, studies in neurocognitive function in dyslexia related to attentional sensory processing (auditory and visual) might help us to understand the connection of neurocognitive with sensory processing.

## 1.3 EPIDEMIOLOGY OF DYSLEXIA

According to Shaywitz, Morris, and Shaywitz (2008), dyslexia occurs in all languages, despite the prevalence in different languages and orthographical language systems may have a different effect on dyslexia (Shaywitz, Morris, & Shaywitz, 2008). In the United States of America (USA), it was estimated that the prevalence of school-age children being afflicted with dyslexia was 5 % to 17 %, with approximately 40 % of them had reading scores below the grade level (Shaywitz & Shaywitz, 2003). In Asian countries such as Thailand, it was estimated that 40 000 children have a learning disability (Akiyama & Manns, 2019) that includes the prevalence of dyslexia in primary school children ranging from 5-10 % (Roongpraiwan, Ruangdaraganon, Visudhipan, & Santikul, 2002). Another Asian country such as Indonesia has reported that in 2019, they had identified 800 dyslexia cases since 2005 (Rachmawati, Soegondo, Solek, & Child, 2019).

Statistically, more males are commonly found among dyslexics as compared to females (Rachmawati et al., 2019; Roongpraiwan et al., 2002) with no convincing reasons for such differences across genders. Some have claimed that the differences are portrayed as sampling bias in a school identified samples (Quinn & Wagner, 2015; S. E. Shaywitz & Shaywitz, 2003), while some others claimed on prominent neuro-genetic of hormones between genders has a potential explanatory factor in dyslexia imaging studies (Krafnick & Evans, 2019; Ramus, 2003). But one thing that has been agreed to many is that dyslexia is inheritable and familial (Kirkpatrick, Legrand, Lacono, & McGue, 2011), which significantly helps in predetermined potential dyslexics with familial risk for early detection.

## 1.4 THEORIES OF DYSLEXIA

Since the early recognition of dyslexia as a learning difficulty. Many theories have been proposed regarding the potential causes and deficits manifested in spelling, reading, and writing difficulties. As reported by Nicholson and Fawcett (2019), there are three-level of explanations that need to be considered when discussing theories of dyslexia. The three levels are behavioral, brain levels, and cognitive (Nicolson & Fawcett, 2019). The behavioral level in dyslexia is regarded as the manifestation of reading-related symptoms as the secondary effect of the genetic impairment. For instance, the deletion impairment of specific DCDC2 genes in dyslexia which responsible for motion perception (Cicchini, Marino, Mascheretti, Perani, & Morrone, 2015). But the underlying causes for the genetic impairment are still early to be concluded. The second level is the brain level processing that relates to the sensory and cerebellar deficit theory. For the sensory impairment processing, it was hypothesized that the cause of learning difficulties in dyslexia is might be due to impaired development of the transient/magnocellular system of the visual brain system as proposed by John Stein (Stein, 2019; Stein, 2018; Stein, 2001) who believed that the phonological deficit among dyslexics was caused by the magnocellular impairment. This deficit eventually defects the temporal sequencing of visual input which is supposed to be automatic in normal readers.

Meanwhile, for the cerebellar deficit theory, it was raised in cognitive studies considering the large portion of its structure that consists of neurons and actively involves in the acquisition of cognitive and sensory processing; which seemly impaired among 80 percent of dyslexics (Nicolson, Fawcett, & Dean, 2001). The active brain areas that involve in automatic reading are the Broca's area, parieto-temporal region, and occipito-temporal region. Broca's area is the one involves in articulation and word analysis, while the other two regions are responsible for word analysis and fluent reading, respectively (Christodoulou et al., 2014). As compared to the normal readers, the dyslexic readers among adults displayed significantly low activation in several areas of the brain, which were in the left prefrontal and left superior temporal regions. Both regions are related to the retrieval of semantics and phonological inputs (Christodoulou et al., 2014).

The third level is the cognitive impairment theory. Referring to the definition of dyslexia by International Dyslexia Association (IDA) in 2002 (Refer subchapter 1.2), the definition does not limit to the behavioral output of reading, writing, or spelling difficulties, but also on the phonological deficit, as the secondary effect in learning and poor cognitive abilities. Evaluating from these three different levels of theories, all of them create a subtle relation of the phonological deficit with the cognitive processing that involves reading difficulties, agreeing with a theory proposed by Bowers and Wolf in the double deficit theory of dyslexia. Bowers and Wolf (1999) have hypothesized that the dyslexic children have deficits in two essential skill for reading which is phonological and rapid naming speed deficit (Wolf & Bowers, 1999), supported with a functional MRI (fMRI) study in which the study reveals on less neural activation in the fronto-parietal reading network among dyslexics when compared to a child with typical reading skill and single deficit children. Besides, the bilateral prefrontal areas that function in bridging the phonological awareness and rapid naming associations were abnormally functioning in dyslexics with a double theory deficit (Norton et al., 2015). These abnormalities might be the possible reason for the common confusion and mistakes among dyslexics in reading/pronounce almost similar phonemic sounds and graphemes, for example in the common mirror reflected letters such as ‘b-d’, ‘u-n’, m-w’, and ‘p-q’ (Ramus et al., 2003).

## 1.5 ETIOLOGIES OF DYSLEXIA

There are three different etiologies of dyslexia: trauma, developmental, and primary dyslexia. Trauma dyslexia or acquired dyslexia is developed by a form of brain injury that gives a direct or indirect impact on the reading and writing processing part of the brain. This etiology of dyslexia is rarely being discussed in the literature, as in PubMed lists of articles, there were no articles that discussed trauma dyslexia in specific detailing. Trauma dyslexia is a reading disorder that occurred to literate individuals who lost well-developed reading skills due to brain injury or certain infections (Kuerten, Mota, & Segaert, 2019). A speculated cause of trauma dyslexia is quite unsettled, as some postulated that it can also be triggered by the infectious diseases of cold, flu, and ear infection which eventually give direct impairment to the auditory phonological processing development. The other etiology of dyslexia is primary dyslexia, which remains permanent and cannot be developed or improved throughout maturity and age. It is a type of inheriting disability in reading and can be passed from one generation to another. As for the third one, developmental dyslexia

(DD) is a result of the congenital impairment of the brain caused by improper neuronal development at fetal stages. The child with DD can develop skills needed for learning according to maturity and age. Hence, the reading ability among those with DD can be improved linearly with their age with proper intervention and learning rehabilitation as children with DD have normal or above-average intelligence. It is important to bear in mind that dyslexia is not a disease but a lifelong condition and the learning difficulty symptoms are variable across dyslexic children. In clinical settings especially in Malaysia, most children with dyslexia are commonly diagnosed with DD, and it is easily detected at the early age of pre and primary school by going through screening in learning abilities (reading, writing, and calculations) (Yuzaidey et al., 2018). From here onwards, developmental dyslexia will be termed as dyslexia for the rest of this thesis writing.

## 1.6 SUBTYPES OF DYSLEXIA & ITS RELATION TO THEORIES OF DYSLEXIA

Different dyslexic children may display different reading abilities. Due to that, the classification of subtypes has been proposed to identify the homogenous reading abilities across the dyslexia population (Zoubrinetzky, Bielle, & Valdois, 2014). The subtypes of dyslexia are classified into the surface and phonological subtypes. Surface subtype dyslexia has poorer ability in reading exception words compared to pseudo words or non-words, while phonological subtype dyslexia has the opposite pattern of surface dyslexia.

The phonological subtype is related to the theory of phonological awareness impairment, whereby the children with this subtype have difficulty in pronouncing the sound of phonemes due to the inability to store phonological sound in their owns awareness. Inability to store phonological sound in owns awareness causes incapability to connect and manipulate each phonemic sound in word reading. Due to that factor, it is common for dyslexic children with phonological subtypes to have poor reading skills in unfamiliar word structures such as pseudo words or non-words. Among normal readers, the lexico-semantic and direct reading routes allow the discrimination and identification of whole word structures and activate the semantic meaning giving a pathway for direct pronunciation (Temple, 2006). In dyslexia with phonological subtype, the poor mastery of phonemic awareness or phonological skills can be seen in the lexical and non-lexical routes whereby they have difficulties in converting letters/words into sounds (Al-Shidhani & Arora, 2012; McAnally, Castles, & Stuart, 2000). Many theories on the causes of learning difficulties in dyslexia have been proposed directing the phonological failure indirectly to the sensory perception (Prestes & Feitosa, 2016), which goes for both visual and auditory neurocognitive processing related to attention (Heiervang & Hugdahl, 2003; Heiervang, Stevenson, & Hugdahl, 2002; Van der Lubbe, de Kleine, & Rataj, 2019).

For the subtype of surface dyslexia, there is an association of poor orthographical word reading to attentional deficits theory that indicates lexical route abnormality (Zoccoloti et al., 1999). The lexical route allows the pronunciation, and silent reading of non-words outside of reading and grammar rules (unfamiliar), while the non-lexical route operates by grapheme-phoneme rules that have access to the semantic word system. According to Heim et al., (2008), the role of attentional deficits theory is manifested with the poor encoding of letters and visual word forms in the lexical route pathways which then resulting confusion during word reading (Heim et al., 2008). This reading confusion is seen in dyslexia children that have intact ability to read unfamiliar pseudo word or non-words structures but having difficulties in reading irregular words due to poor orthographic coding skills. The irregular words refer to words that are spelled differently from the phonemic sound, for example, the word ‘answer’ or ‘island’. Hence, that is the reason why it is also termed visual dyslexia.

In general, both subtype dissociations provide evidence that the mastery of phonological awareness and grapheme-phonemic conversion in word reading involves dual routes of lexical orthographical reading and non-lexical phonological routes (Peterson, Pennington, & Olson, 2013). However, there is little consensus regarding the specific mechanisms underlying the lexical and non-lexical route in dyslexia. Furthermore, there is evidence indicating that dyslexia may have neurocognitive impairment in processing different sensory stimulations, be it auditory or visual (A. Facoetti, Turatto, Lorusso, & Mascetti, 2001; Vidyasagar & Pammer, 2009). Thus, the current study aimed to reveal the neurocognitive processing of visual and auditory processing among dyslexia by using different sensory task paradigms.

## 1.7 STUDIES ON DYSLEXIA IN MALAYSIA

In Malaysia, even though the study of dyslexia is still in its infancy due to limited studies have been performed in the Malaysian population, the understanding of dyslexia has grown over the past years. In Malaysia, 314 000 children are being diagnosed with dyslexia (Oga & Haron, 2012), with the number keeps on increasing. According to Ramli et al., (2019), there was a possibility for the increment of dyslexia cases that were mostly diagnosed at a later age (primary school) was due to the lack of knowledge among preschool teachers in identifying dyslexia among their preschool-age students, whereby it was discovered through questionnaire studies that most of the preschool teachers acknowledged on the general information on dyslexia but lack of essential knowledge in the aspect of symptoms, diagnosis, behavioral and the treatment (Ramli et al., 2019). Consistent with a report by the New Straits Times (NST) in 2018 which stated that there was only one percent of the school teachers in Malaysia have been trained on dealing with dyslexic students (Muhamading, 2018). This eventually causes incapability in detecting early age dyslexia at a younger age.

Fundamentally, detection of dyslexia at an early age reciprocally helps in the betterment of early intervention. Malaysia is a multiracial community that stands of Malay, Chinese, Indians, and many other ethnicities that comprises different languages and use of dialects. A recent study by Lee, Yusoff, Ong, Nordin, and Winskel (2020) proposed a reading assessment test battery for multilingual Malaysia in a way to support early detection of dyslexia in Malaysia population with multiracial society. As the authors stated that in Malaysia, there is no comprehensive reading assessment available yet to multiracial society, which is currently only limited to the Malaysian national screening instrument (LINUS) to identify children at risk of reading difficulty. Hence, the study by Lee et al., (2020) in providing a multi-component approach in assessing different reading assessments in time measures of Letter Name Frequency, Rapid Automatized Naming (RAN) Digits, Word Reading Efficiency, and Oral Reading Fluency provides another angle of assessment for early detection. Eventually, when Lee and his team made a comparison of concurrent validity with LINUS, it was revealed that both assessments had moderate to strong correlation suggesting the shared construct of validity and reliability (Lee et al., 2020).

As far as we have noted, the research of dyslexia in Malaysia is mostly restricted to social and educational studies with no research on neurocognitive studies has been performed on the local population. One case study of dyslexia students in a local population of Kelantan among 5 dyslexics was performed in evaluating literacy difficulty which manifested in letter reversal, inaccurate naming of alphabet letters, unable to perform spelling test, and difficulty in pronouncing the words during reading. Based on the literacy findings, the authors concluded that the method of teaching for dyslexics should explicitly advance in grapheme-phonemic knowledge, phoneme manipulation, and syllable segmentation to improve reading skills (Wan Norudin & Baba, 2018). Another aspect of local studies on dyslexia has been performed in the preliminary assessment of dyslexics in copying Jawi handwriting (Arabic alphabet writing incorporated onto Malay language system) by Rahim et al., (2015). The study found that dyslexics had no difficulty in writing Jawi handwriting, but needed more time as compared with the healthy control group (Rahim, Kahar, Khalid, Salleh, & Hashim, 2015). No linkage of dyslexia to neurocognitive impairment has been found in all of the local studies.

## 1.8 COGNITIVE FUNCTIONS

Cognitive function is defined as mental processes that allow mental capabilities in solving problems, thinking, speech, and making decisions. Cognitive function also serves as an essential component in the development of memory and attention (Roy, 2013). Cognitive function is interchangeably terms with neurocognitive function wherein relates to the specific neural pathways or neural network connections that are easily influenced by neural processing in different medical conditions (Sharafkhaneh & Grogan, 2015). Medical conditions that are related to neural impairment that caused cognitive deficit are aging effects, psychiatric disorders, and learning difficulty disorders. Thus, from here onwards, the cognitive function will be termed as neurocognitive processing throughout this dissertation. Neurocognitive functions do cover the daily life cognitive functioning in concept formation, memory, and working memory, planning, information processing, learning, and attention (Cervantes, Rosales, Lo, & Ramos, 2017; Cowan, 2015; Roy, 2013).

Learning to read is an integrative neurocognitive process that requires accurate recognition of letters combinations in word forms and associated it with correct phonemic sound before the grapheme-phonemic decoding stage (Menghini et al., 2010). Children with dyslexia have been widely acknowledged for having difficulty in processing the phonological inputs in the grapheme-phonemic word decoding stage. Grapheme-phonemic is a correspondence relation between the sound (phoneme that utilized phonological awareness) and letter structure (orthographical structure). Phonological awareness deficits in dyslexia are supported by a wide corpus of studies that reported on abnormalities exclusively exhibited in dyslexia (Ramus, Marshall, Rosen, & Van Der Lely, 2013) by having impairment in temporal duration discrimination (Gooch, Snowling, & Hulme, 2011), neurocognitive functions (Menghini et al., 2010; O. Moura et al., 2016) and abnormality in functional neuroimaging which has less neural activity in the brain area specified for phonological awareness (left inferior frontal and inferior parietal regions) (Norton et al., 2015).

Although the underlying neurocognitive deficits in dyslexia are still in debates, it has occasionally been argued that the failure in phonological awareness development was due to the neurocognitive processing deficit related to sensory attentional processing of auditory and visual stimuli, with cascading effects on reading acquisition processes of grapheme-phonemic decoding and orthography processing. Reading acquisition is an attention process demand. From the neurocognitive side of view, attentional top-down control of auditory and visual information processing is important as a prerequisite for effective reading (Verhoeven, Reitsma, & Siegel, 2011). Phonological input decoding in learning a novel word in pre-reading age relies on the ability to associating orthography information with its phonemic sound, which requires an efficient multi-type of sensory neurocognitive that might be raised from attentional mechanisms related to auditory and visual sensory tasks. The sensory neurocognitive attentions are auditory attention (Herrmann & Knight, 2001; Stavrinos, Iliadou, Edwards, Sirimanna, & Ludwig, 2018), visual-spatial attention (Andrea Facoetti, Zorzi, Cestnick, & Lorusso, 2006), visual attention, and audio-visual shifted attention. For this current study, we shall examine the neurocognitive function in the attentional mechanism of dyslexic children with auditory, visual, and audio-visual stimuli utilizing an electrophysiological technique of Event-Related Potential (ERP).

## 1.9 EVENT-RELATED POTENTIAL (ERP)

As neurocognitive attentional studies involve a study of brain mechanisms at the neural activity level, a very powerful tool that has high temporal features in capturing neural activity changes to certain task stimuli is needed. This feature is provided by ERP that can reflect neurocognitive processing events at the speed of milliseconds (ms) which are rarely offered in other neuroimaging tools. The implementation of ERP, an electrophysiological subset tool under the electroencephalogram (EEG) technique is based on the capability of the ERP in reflecting changes in the brain's electrical activity by time locking the neural changes in response to any task stimulations (Sokhadze et al., 2017a; Sur & Sinha, 2009).

The ERP technique is used in assessing neurocognitive function via the evaluation of the physical features of amplitudes and latencies by the time of certain peak ERP components after stimulation. It is a non-invasive electrophysiological technique that is safe to be used in a wide range of ages including infants and children. Hence, this technique has been widely used in clinical or experimental settings. Other than that, ERP does not have any conduction delay in recording the postsynaptic (PSP) brain activity inside the head and the potential recorded in the scalp. Thus, it minimizes the loss of the voltage potential recorded (Woodman, 2010). The waveforms produced in ERP are a product of postsynaptic voltage neural activity in visualizing the neurocognitive processes, in a sequence of positive and negative voltage deflection. The voltage deflection is known as ERP waveform components or ERP peak, forming two different polarities of ERP (negative and positive) which we see as neural waveforms (Luck, 2014).

The ERP waveform components were named based on the polarity and the latency of components that emerge during certain neuro-cognition processes. For instance, the P300 component is labelled based on its peak component that has positive polarity wave deflection and emerged at the latency range of 300 ms post stimuli. The ERP waveforms are divided into two different categories which are exogenous and endogenous. The exogenous or also known as the early waves are roughly emerged within the first 100 ms post-stimulation, such as in P50 and N100. It was characterized as exogenous due to its nature that is sensitive to the physical parameters of task stimulations, for instance, the shape, colour, sound pitch, etc. In contrast, the endogenous or late wave components are normally evoked later than 100 ms post-stimuli. Endogenous ERP components do not easily affect by the physical parameters but instead highly follow the neuro-cognition processing (Sur & Sinha, 2009). The examples of endogenous ERP components are Mismatch Negativity (MMN), N200, P200, P300, N400, and P600. Most of the ERP components are easily evoked by sensory task stimulations such as visual and auditory. As for this current study, we studied the attentional neurocognitive function which measured the endogenous ERP components of MMN, N200, and P300 components in auditory and visual stimuli.

All three ERP components representing the different functions of neuro-cognition. The MMN is a pre-attentive response towards differences of discriminable auditory stimuli such as an auditory oddball sequence (Näätänen & Paavilainen, 2007; Ungan, Karsilar, & Yagcioglu, 2019). The MMN measurement was obtained through the subtraction of the average waveform of standard stimuli from the averaged waveform of target stimuli. This measurement formed an ERP waveform that marked the MMN amplitudes and latencies in each time window. The MMN does not appear if the brain is not able to differentiate difference of standard and target auditory stimuli, even with an intact peripheral hearing system indicating the brain's ability to discriminate stimuli (Bishop & Hardiman, 2010; Naatanen, 2003), which may be influenced by automatic pre-attentional neurocognitive factor. The next targeted ERP component is N200 negative peak deflection subset known as N2b, which is commonly evoked in visual task stimuli presenting the higher-order visual cognitive processing. A study of N200 ERP component in utilizing auditory stimuli performed by Papaliagkas and his team in 2008 found that the amplitudes and latencies of N200 are the potential basis in predicting cognitive impairment (Papaliagkas, Kimiskidis, Tsolaki, & Anogianakis, 2008) such as pre-and selective attention and conscious discrimination in detecting changes in stimulations (Patel & Azzam, 2005). As for the P300 ERP component, its physical features of amplitudes and latencies indicating the attentional exertion to task stimulation. The greater amplitudes sizes of P300 reflect on the production of greater attention to task stimuli, whilst shorter latencies indicate superior mental performance than longer latencies (Sur & Sinha, 2009).

## 1.10 BRAIN SOURCE LOCALIZATION

While exploring the neuronal mechanism of sensory neurocognitive processing, neural/brain source localization could provide additional information on neurocognitive function. The brain source localization of ERP components targeted for this current neurocognitive attentional study is the extension of the ERP study technique, whereby the source generators actively involve during neurocognitive attentional processing in auditory, visual and audio-visual paired tasks stimuli represented by MMN, N200, and P300 ERP components could be revealed. The source localization provided by the ERP technique by applying the standardized Low-Resolution Brain Electromagnetic Tomography (sLORETA) method allows for the identification of neural source generators with zero localization error. As few established studies discovered on abnormalities of anatomical and functional structure in the dyslexic's brain (Eckert & Leonard, 2000; Foster, Hynd, Morgan, & Hugdahl, 2002; Galaburda & Kemper, 1979; Krafnick et al., 2014) are linked to the attentional neurocognitive function deficit in dyslexia. Hence, localizing the neural source generator that involves in neurocognitive processing during attentional-related task stimuli would be valuable in providing significant data in understanding their neural activity and neural mechanisms differences to those without dyslexia.

## 1.11 RESEARCH HYPOTHESES

### 1.11.1 General hypothesis

There is a difference in the state of auditory attention, visual attention, and shifted attentional neurocognitive processing in the dyslexic group compared with the control group when stimulated with different auditory and visual task paradigms, which can be investigated by using the Event-Related Potential (ERP) technique and the localisation of the neural source activities.

### 1.11.2 Alternative hypothesis

1. There are significantly smaller amplitudes and longer latencies of MMN and P300 ERP components in the dyslexic group compared to the control group during auditory attentional processing towards the auditory oddball task paradigm.

2. There are significantly smaller MMN and P300 amplitudes, with longer latencies in the dyslexic group than the control group during shifted attentional processing throughout the paired audio-visual paradigm.

3. There are significantly smaller amplitudes and prolong latencies of N200 and P300 ERP components during visual attentional processing in the dyslexic group compared with the control group when stimulated with the different context of visual congruency matching-unmatching images.

4. There are significantly lesser amplitudes and delay latencies of N200 and P300 ERP components in the dyslexic group compared with the control group during visual

attentional processing towards different orthographical lexicon (pseudoword and true words) tasks stimuli.

5. There are distinguishable differences of MMN, N200, and P300 brain source localization in the dyslexic group comparative to the control group during auditory attention, visual attention, and shifting attention.

### 1.11.3 Null hypothesis

1. There are no significant changes in MMN and P300 amplitudes and latencies among dyslexic and control groups during an auditory oddball task.

2. There are no significant changes in MMN and P300 amplitudes and latencies in dyslexic and control groups during an audio-visual paired task paradigm.

3. There are no significant changes in the amplitudes and latencies of N200 and P300 ERP components between dyslexic and control groups during different congruency of visual images task stimuli.

4. There are no significant N200 and P300 amplitudes and latencies differences during the reading stage of different orthographical lexicon (pseudoword and true word) structures between dyslexic and control groups.

5. There are no distinguishable differences of MMN, N200, and P300 brain source localisation spotted in dyslexic and control groups during the stimulation of different auditory, visual, and audio-visual paired task stimuli paradigms.

## 1.12 RESEARCH OBJECTIVES

### 1.12.1 General objectives

To explore the neural mechanism of auditory attention, visual attention, and shifted-attention of neurocognitive attentional processing, along with their neural source localization in the dyslexic group, in comparison to the control non-dyslexic group during auditory oddball, paired audio-visual, different visual image congruency, and orthographical word task stimuli using Event-Related Potential (ERP) technique.

### 1.12.2 Specific objectives

1. To investigate the auditory attentional processing of the dyslexic group compared to the control group during the auditory oddball paradigm by exploring the amplitudes and latencies of the MMN and P300 ERP components.

2. To explore the shifted attentional processing of the dyslexic group during paired audio-visual stimuli compared to the control group by examining the amplitudes and latencies of the MMN and P300 ERP components.

3. To investigate the visual attentional processing of the dyslexic group compared to the control group during different visual images congruency task stimuli by exploring the amplitudes and latencies of the N200 and P300 ERP components.

4. To examine the visual attentional processing of the dyslexic group compared with the control group when stimulated with the different orthographical lexicon of the pseudoword/true word by exploring the amplitudes and latencies of the N200 and P300 ERP components.

5. To determine and to localise the ERP source generators involved in auditory attention, visual attention, and shifted attention indicated by the activities of MMN, N200, and P300 ERP components when stimulated to different auditory and visual task paradigms between control and dyslexic groups.

## 1.13 SIGNIFICANCE OF STUDY

The study of neurocognitive function is essential to relate the difficulty of spelling, reading, and writing (learning set) faced by dyslexics is also affected by the higher-order processing deficit. Inconsistent findings and the lack of neurocognitive studies in dyslexia limit a comprehensive understanding of the functional neural processing that caused such learning set difficulties among children affected with dyslexia particularly in different sensory task stimulation. In the aspect of education, Knight (2018) reported that most educators that involved in special education (for dyslexia) associate the failure of learning in dyslexia to visual functioning deficit instead of general sensory neurocognitive processing deficit, which might be due to inconclusive evidence on neurocognitive studies among dyslexics (Knight, 2018). Due to that, some of the rehabilitation modules used in schools targeting visual rehabilitation instead of neurocognitive enhancement generally. The learning rehabilitation that is currently provided to our dyslexic children at the school is lacking in the utilization of neurocognitive related rehabilitation due to the lack of support data on neurocognitive impairment on dyslexic children. In the aspect of neurocognitive studies, failure of learning set capabilities is associated with neurocognitive deficits such as working memory and attentional processing. However, most studies mainly focused on the behavioural and neuropsychological state without implying neural processing and its mechanisms. Furthermore, as the learning set development depends on well development and integration of sensory processing such as visual (in terms of orthographic/language symbol structure), auditory (phonemic awareness and phonemic sound), and audio-visual (associating orthographical structure and phonemic sound), which build up the neurocognitive processing abilities. Thus, a study on the neural processing state on all three sensory task processing could elucidate what is happening in the brain of dyslexics. This could be achieved through the implementation of the EEG technique of ERP that allows the capturing of neural mechanisms activity during cognitive functions. Understanding the way of the cognitive neural mechanism works in dyslexia could contribute to the betterment of providing future quality life by having a proper diagnosis, intervention, and rehabilitation.

This current study will provide information regarding the attentional neurocognitive processing at the level of neural mechanisms and its source generators that actively involve during auditory and visual task stimulations. Hence, this study may provide information on how the dyslexic brain dealing with different sensory tasks and revealing to us why they tend to face difficulty in learning compared to others. Therefore, through this study, it is worthwhile to reveal the neural mechanisms involved in attentional neurocognitive function among dyslexic children for the rehabilitation purpose to enhance the cognitive abilities of dyslexics in learning processes.