

Visual Processing in Reading and Dyslexia

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SUMMARY

Reading is a very important part of our everyday life and can be defined as the act of flawlessly processing written information, with a limited number of mistakes, in order to derive meaning from written text. The present work summarizes the findings from two different types of population: (1) Dyslexics (reading-disabled children) and (2) Illiterates (adults who cannot read). In order to compare our results, we have also used a literate group (educated adults) and a control group (normal reading children). The major difference between the first two groups mentioned above is that, despite an adequate learning environment, training and being considered of-normal intelligence, dyslexics have problems while reading, whereas the other set group has never been to school and, therefore, are unable to read or write due to the lack of training and learning environment.

Chapter 2 describes Event-Related Potential (ERP) differences in controls and dyslexics using the mental rotation paradigm with visually dissimilar letters. Mental rotation is a classic paradigm through which the capabilities of dyslexics can be defined. In this study, we have examined the time course differences and respective differences in ERP between controls and dyslexics. Dyslexics showed a delay in processing letters in comparison to controls. As compared to controls, dyslexics did not show an inverse relation of increasing angular disparity with potentials (Rotation Related Negativity, RRN).

In Chapter 3 we used visually similar letters to compare dyslexics and controls on a symmetry generalization task with letters in two different contrast conditions (low and high). The similarity was defined on the basis of rotation or reversibility. Dyslexics showed a similar pattern of response, but were overall slower in responding to the task in comparison to controls. Dyslexics showed an impaired response pattern in low contrast conditions, which is thought to be the function of (or controlled by) the Magnocellular pathway (M-pathway). Furthermore, the results were interpreted within the framework of the Functional Coordination Deficit (Lachmann, 2002).

Chapter 4 reflects the importance of the Magnocellular (M-pathway) deficit in dyslexia. Malfunctioning of the M-pathway could be one of the major problems of dyslexia. Due to this problem, dyslexics are impaired in responding to low contrasts, motion detection, low spatial and high temporal frequencies (ground perception). This could be one of the major causes of the problems related to adequate reading. In this study, responses were taken from a motion lexical task (motion word recognition task) using two different colors (red and green) of a different wavelength, set as a background. Dyslexics were impaired in responding to the word recognition task as reflected by response time. Using red background decreases M-pathway activity, making it more difficult to identify letters and this effect made it worse for dyslexics since their M-pathway is weaker. Hence, the reaction times with red background were longer than those with green background.

In Chapter 5 comparisons were made between the illiterate and literate sample groups. This study was designed to understand the mechanism behind analytic and holistic approaches in responses to letters and shapes. This study was a follow-up to that originally performed by Lachmann & van Leeuwen, (2004, published in the Journal of Perception and Psychophysics). Results from the literate group replicated the findings of the previous study. Illiterates showed an analytic approach to responding to letters as well as on shapes. The analytic approach does not result from an individual capability to read, but is a primary base of visual organization or perception.

Key Words

Dyslexia, Mental Rotation, Angular Disparity, Rotation Related Negativity (RRN), Late Positivity, Laterality, Magnocellular (M pathway), Parvocellular (P pathway), Symmetry generalization, Grapheme, Phoneme, Congruence, Incongruence, Isolated, Motion detection, Figure-Ground, Low spatial frequency, High spatial frequency, Contrast, Color, Holistic approach, Analytic approach. Static reversal, Kinetic reversal, Reversal Errors, Symmetry.

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CHAPTER 1

Introduction

General Introduction

The different sights and sounds of letters combined for meaningful information is termed as reading. When beginning to read, each letter is processed individually, resulting in a meaningful word. Different words are then combined together to understand the meaning of a sentence. These skills are acquired or learned over a period of time (beginners); the process subsequently becomes automated and the skilled readers read the word as a whole. Word is read as a whole because the orthographic structure of the letter, and later the perception of the word, is fully developed or automated. These readers are then capable of reading faster than beginners. Another reason why reading is faster for skilled readers is because they construct meaning from the dynamic interaction between their existing knowledge and the information suggested by the text (Wixson, Peters, Weber, & Roeber, 1987); when the reader falls below the standard level of processing of the written information, and then the reading level is considered subpar.

Reading is a complex and multi-dimensional process. A number of components were identified that need to be considered while reading (Waldron, 2012). In general, to perform reading in an adequate manner, the following skills and strategies must be implemented: an establishment of a rich vocabulary base, the development of phonological and visual skills, discovering and developing an individual comprehension style, placing a focus on reading fluency, adequate motivation to undertake the task, and also enjoyment while reading. According to Goodman (1969; 1967; 1988), while reading, basic visual sensory

information is transformed to the deeper levels of cognitive processes, that is to say moving from optical to perceptual to syntactic, and then the meaning is then driven. He also describes the five major processes that employ reading: (i) recognition (ii) prediction (iii) confirmation (iv) automated correction and (v) completion of the reading act. Visual recognition is about understanding the configuration and orthographic information present in written form, which includes language comprehension, as well as phonological, semantic and syntactic decoding. The interaction of the recognition of visual form and the acquisition of orthographies allows us to access the meaning directly in combination with the good phonological skills required to differentiate between familiar and unfamiliar languages, using the knowledge of the letter-sound conversion rule (visual and phonological information, Lachmann & Geyer, 2003). Prediction of strategies is considered to be the most efficient way of reading (Smith, 1975; Goodman, 1997; Palincsar & Brown, 1984). Predictions are mostly used when readers make use of their existing knowledge; context dependent cues help the readers to generate an anticipated meaning of the text. Once the prediction is made, the efficient reader will go back and check the information presented in the text (Collins, Brown, & Larkin, 1980). Predictions are trained interpretations about what will happen in the text and skilled readers are able to make correct predictions for the current text through the strategy of prior knowledge exposure. On the other hand, failure in monitoring predictions can cause miscomprehension due to incorrect prior knowledge because the person is incapable of remembering the learned cues, or has/had minimal prior exposure to similar text. Prediction strategies have a very important role in the theories of reading (Collins & Smith, 1982). Confirmation is the tendency for people to seek information from the cues which confirm their tentative belief. When the brain predicts, it also looks for evidence to verify those predictions. In terms of what is expected, the brain monitors for acceptance or non-

acceptance of the given input. When confirmation is biased or incorrect, then a person tends to apply automated correction and, if the brain decides for inconsistency, then that particular action is discontinued. Termination of the reading task will only happen in three different conditions: (i) the task is successfully completed and meaning is known (ii) when there is no meaning or only partial meaning is constructed and (iii) when the information is not at all useful.

Causal factors affecting reading: the modern era

Reading involves different visual and phonological processing strategies compared to object processing, while reading each and every letter is processed in a different manner, therefore, the strategies used for letter and object perception are different. While reading the recollection of the reading process is initiated, visual representation is established, and then phonetic, semantic, as well as syntactic information is generated. According to Lachmann & Geyer (2003), reading involves two major processes: (i) visual decoding of the text in a written form, which includes feature analysis (configurational structure), orthographical representation of the word form and (ii) language comprehension, which includes the phonological, semantic, and syntactic decoding (Friederici & Lachmann, 2002; Lachmann, 2002) of written information. According to them, adequate reading is a result of the successful interaction of these two processes. This complex process is further guided by working memory and long-term memory while attention processes also plays an important role (Friederici & Lachmann, 2002). Further, reading is an automated and complex process which includes much parallel processing. Dyslexia has been accepted as a language related disability showing differences in its occurrences. The most common problems affecting dyslexics are: phonological impairments, letter reversals, differentiating between similar rhymes, and wrong spellings. These common problems are most often

tested at the most commonly at the behavioral level and may also be tested at the neurological level.

Neuronal activations while reading

The neuronal processes involved in reading begin when visual information is received by the eyes, which is imaged on both maculae (the region of the eye surrounding the retina which has the maximum visual acuity). The information is then sent to both left and right cerebral cortex. Within the cerebral cortex, the information is transmitted to Ganglion cells and the Lateral Geniculate Nucleus. The area which receives the information is known as primary visual cortex (Brodmann's area 17 or V1); this area is responsible for word-related processing. Depending upon the visual attributes of the stimuli (size, colour and brightness), information is further processed bilaterally by different areas of the occipital lobe - V2, V3, V4 or V5. The bilateral activations from the occipital lobe are then transmitted to the angular gyrus (area 39). The angular gyrus is the central hub of reading and is responsible for processes such as hearing, speech and vision. In this area, the nature of the written word is comprehended, i.e., the transformation of written information into its relevant speech sound. The auditory form of the word is further comprehended in Wernicke's area (responsible for speech articulation). All of these processes make reading a complex process; when reading is significantly slower due to the presence of such symptoms as poor coordination, left-right confusions and poor sequencing, it could also be characterized as a neurological syndrome because such problems can also be affected by biological causes e.g.: genetic anomaly, malfunctioning of temporal lobe, Jackson & Coltheart, 2001). Stein (2001) found that 5 - 10% of school-attending children (Diagnostic and Statistical Manual of Mental disorder, DSM – IV, 1994), particularly boys, despite being of adequate intelligence, were considered dyslexics.

Evolution in the understanding of the occurrences of reading problems

In the last few years, developmental dyslexia has been one of the most important and interesting area of scientific research. Developmental dyslexia is considered to be a disorder associated with reading difficulty and being off-adequate intelligence level and having appropriate learning environmental conditions. Despite the appropriate educational background and a supporting environment, children affected with dyslexia are unable to perform adequately and it is the most prevalent learning disability in schools. The epidemiology and theoretical causes of this disorder differ considerably between countries, and even regions within countries (Shaywitz, Shaywitz, Fletcher, & Escobar, 1990; Miles, 1995; Schulte-Körne, Deimel, Bartling, & Remschmidt, 2001). One of the main causes of developmental dyslexia is associated with the malfunctioning of the parietal and occipital regions of the brain. The neurons found in these regions do not function properly when compared to normal children; which results in more errors and taking a significantly longer duration in responding to lexical tasks. Delayed responses are considered to be the common measure to compare dyslexics with normal readers. The problem also leads to difficulty in processing lexical information presented in auditory and well as visual form.

According to the relevance of the current set of experiments, dyslexia could also be attributed to an inappropriate processing of 'letters' in appropriate environmental conditions, despite the required training for language learning (we had tested dyslexics on the visual processing of letters). A German physician Oswald Berkhan, (1881) first confirmed the existence of reading disability (dyslexia) and later Rudolf Berlin, (1887) an ophthalmologist practicing in Stuttgart, Germany. The word dyslexia comes from the Greek words "dys", which means difficulty and Lexis; (which means word or speech) the translation would be difficulty related to the language processing. According to Berlin, it is

a disorder related to the processing and understanding of speech. During the year 1896, W. Pringle Morgan, described about a reading-specific learning disorder and his work, which was published in the British Medical Journal, "Congenital Word Blindness". In this article, he described a 14-year-old boy, named "Percy", who experienced reading difficulties, to which he defined 'congenital defects' as the major cause. During the 1890's and early 1900's, James Hinshelwood also published a series of articles in medical journals where description about the similar cases of congenital word blindness was made. In his 1917 book, "Congenital Word Blindness", he emphasized that this problem originates from the distorted visual representations of words and letter perception. In addition, he described symptoms such as letter reversals and difficulties with spelling, writing, and reading comprehension. In the year 1925, Samuel T. Orton determined that a syndrome unrelated to brain damage makes learning to read difficult or complicated. According to his theory, the complexity associated with reading difficulty was termed as 'strephosymbolia'. Furthermore, Orton observed that visual deficits could not be the only cause of reading deficits in dyslexia. He believed that the failure to establish hemispheric dominance in the brain may cause reversal errors. Later, Orton also worked with a psychologist and an educator named "Anna Gillingham", to develop an educational intervention program that involved the use of simultaneous multisensory instructions. In addition to this, Dearborn, (1932) considered erroneous guidance of the seeing mechanism to be the cause of such reading related problem. In the year 1970's, a new hypothesis of dyslexia evolved which rooted as a problem related to the phonological processing or difficulty in recognizing spoken words. According to the findings, studies suggested the importance of phonological awareness as the major cause of dyslexia. Medieval coroners (Hunnisett, 1962) examined the post-autopsy brains of dyslexics. Their findings have shown the differences in the anatomical activations of the language areas of the dyslexic brain compared to non-

dyslexics; later similar work was done by Cohen, Kosslyn, Breiter, DiGirolamo, Thompson, Anderson, ... & Belliveau, (1996) who suggested that the cause of dyslexia could be an “abnormal cortical development” which could have occurred before or during the sixth month of fetal brain development. Neuroimaging technologies developed during the year 1990’s, investigations related to reading disability research made a significant progress using new cognitive methodologies like; positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) which have shown the neural activations of the brain parts of adults (non-dyslexics) while performing reading tasks (e.g. Fiez & Petersen, 1998; Turkeltaub, Eden, Jones, & Zeffiro, 2002). Many approaches and experimental paradigms (e.g. the detection or judgment of rhymes, non-word reading and implicit reading) have been able to localize the inappropriate phonological processing in dyslexia (e.g. Poldrack, Wagner, Prull, Desmond, Glover, & Gabrieli, 1999; Gelfand & Bookheimer, 2003) dominant in left-hemisphere perisylvian regions. These activations shifts from left to right according to the alphabetic writing system (Left to Right or Right to left writing system, Eden & Zeffiro, 1998; Paulesu, Démonet, Fazio, McCrory, Chanoine, Brunswick,... & Frith, 2001). It has also been demonstrated that in the non-alphabetic script, where reading is more demanding the integration of visual-orthographic information about the language in dyslexics are associated with decreased activity in the left/middle frontal gyrus (Siok, Perfetti, Jin, & Tan, 2004).

Theories on developmental dyslexia

Orton (1925; 1928) was the first to draw attention to the symptoms of reversal errors in dyslexia and tried to explain this phenomenon through the cardinal symptom of the reading problem. During the year 1970's phonological skills were considered to be the cause of dyslexia (e.g. Liberman, Shankweiler, Orlando, Harris, & Berti, 1971; Vellutino, 1977; Bradley & Bryant, 1978). Orton believed that dyslexics have a perceptual defect; they see letters in a different orientation (the incorrect orientation) (Vellutino, Steger, & Kandel, 1972; Vellutino, 1977; 1987) but Vellutino and his colleagues found no supporting evidence of Orton's findings. They found that dyslexics and normal readers do not show a difference in the spatial-orientation of the non-language content. This brought to the in acceptance of the Orton's theory. However, Orton believed that perceptual impairments in dyslexics are not the cause of reversal errors. According to his view, these problems are due to the failure to assign an appropriate phoneme label to the correct visual representation (Corballis & Beale, 1993; Lachmann, 2002; Lachmann & Geyer, 2003). According to the Callosal Theory, Orton believed that, for normal readers and dyslexics, both, letters are represented in their normal form in one hemisphere and in a mirrored form in another hemisphere. When a normal reading child processes the visual information, then one hemisphere is activated. Activity in the other hemisphere is automatically suppressed; he believed that this mechanism in dyslexics is not automatic and the representation is equalized in both the hemispheres. This could lead to confusion while labeling the grapheme with a unique phoneme code because both the hemispheres are equally active. There is a high possibility that the grapheme materials may be different for dyslexics and normal readers, even if no differences are found in the non-grapheme material. In addition to phonological problems, the visual aspect of information processing in dyslexia cannot

be ignored (Boder, 1973; Willows & Terepocki, 1993; Badian, 2005; Becker, Elliott, & Lachmann, 2005).

The Phonological Theory

As stated above, dyslexia is a specific difficulty in learning to read. This theory defines dyslexia in the frame of phonological processing of the letter. Phonological theory explains the letter representation function which is responsible for grapheme–phoneme representation. Dyslexics have problems in representing, storing, and correct retrieval of the phonemes. Learning to read and storage of the alphabetical system requires learning the correlation between letters and constituent sounds of speech. In dyslexics, these sounds are poorly represented, which results in the inappropriate retrieval of the learned alphabetic system (Bradley & Bryant, 1978; Vellutino, 1979; Snowling, 1981; Brady & Shankweiler, 1991). Therefore, the phonological theory seeks to connect and explains the links between the neurological causes and behavioral latencies. At the neurological level, it is also assumed that this problem arises from the congenital dysfunction of the Left Hemisphere Perisylvian areas dominant for the phonological representations, which builds the connection between phonology and related orthographic representations (Paulesu, Frith, Snowling, Gallagher, Morton, Frackowiak, & Frith, 1996; Shaywitz, Shaywitz, Pugh, Fulbright, Constable, Mencl, ... & Gore, 1998; Brunswick, McCrory, Price, Frith, & Frith, 1999; McCrory, Frith, Brunswick, & Price, 2000; Pugh, Mencl, Shaywitz, Shaywitz, Fulbright, Constable, ... & Gore, 2000; Paulesu et al., 2001; Temple, Poldrack, Salidis, Deutsch, Tallal, Merzenich, & Gabrieli, 2001; Shaywitz, Shaywitz, Pugh, Mencl, Fulbright, Skudlarski, & Gore, 2002; Ramus, Pidgeon, & Frith, 2003). The theory gives a clear indication about the response latencies for dyslexics who performed poorly on tasks requiring phonological awareness, which, in turn, requires the manipulation of speech

and conscious segmentation. Dyslexics were unable to segment short-term memory problems and slower responses to verbal naming tasks also lead people to accept phonology as the greatest cause of reading problems (Snowling, 2000).

The Visual Theory

Another aspect of dyslexia is explained by the visual theory. The visual theory does not exclude a phonological deficit, but the main emphasis is in giving a visual contribution to reading problems. This theory describes the visual impairments which give rise to difficulties in processing of letters, words and sentences (Lovegrove, Bowling, Badcock, & Blackwood, 1980; Livingstone, Rosen, Drislane, & Galaburda, 1991; Stein & Walsh, 1997). Reasons could include increased visual crowding effect, (Spinelli, Luca, Judica, & Zoccolotti, 2002) poor vergence and unstable binocular fixation (Cornelissen, Munro, Fowler, & Stein, 1993; Stein & Fowler, 1993; Eden, Stein, Wood, & Wood, 1994). The Magnocellular (dorsal visual pathway, M pathway, or M cells) and Parvocellular (ventral pathway, P pathway or P cells) are the two parallel pathways responsible for two distinct types of visual processing. Evidence for the Magnocellular pathway (M pathway) dysfunction comes from anatomical studies showing abnormalities of the M layers of the Lateral Geniculate Nucleus (LGN, Livingstone et al., 1991). In some dyslexic's brain, M pathway mainly runs through the posterior parietal cortex, and even the pathway is disrupted, leading to deficiencies in visual processing of letters. Further, these problems also lead to the reading and spelling errors which has been explained in the Magnocellular Theory section of Chapter 4.

Functional Coordination Deficit (FCD Model)

Lachmann (2002) proposed a functional-coordination deficit (FCD) model. This model explains that failures in suppressing symmetry generalization cause reversal errors while

reading. This means that a letter has symmetrical attributes even if rotated; rotation does not alter visual material, and symmetry generalization is understood as an evolutionary process, such as a child developing into an adult. For this reason, symmetries are vital to the holistic representation of the visual field. The child could hold a mental representation of a symmetrical pattern, when in fact, it is an asymmetrical pattern. This may generate mirror images of the pattern in their original form and orientation, storing them together in a category. Object recognition under different-orientation symmetry generalization can also facilitate perception (Lachmann & van Leeuwen 2005) and thus, symmetry is the preferred perceptual secret for holistic images. Such a representation creates an obstacle while learning to read and beginners (in reading) convert graphemes to phonemes on a one-to-one basis. For more fluent readers, the image of the familiar word and unfamiliar word could be differentiated, and the irrelevant image would be suppressed. When there is a failure to suppress the visual and phonological relation between these two, then an unambiguous relation is created which may disturb the functional coordination of the phoneme and grapheme codes and may in turn negatively affect reading (Lachmann, 2002). This may disturb the functional coordination between phoneme and graphemes; which causes problems in learning to read. Further, the reason behind the reversal problem (e.g., confusion between b and d) could also be due to the ambiguous relation between visual and phonological codes of individual letter perception (Lachmann, 2002). Reversal errors are not necessarily a result of problems while processing objects, spatial information, nor symbols, but, are due to the inability to functionally coordinate between grapheme and phoneme representation. The problem may occur when a letter (grapheme) is presented in different orientations (rotated or normal/mirrored), such as “b” and “d” having different phonemes. Further, FCD model is only a functional-level theory and not a brain model like Orton’s or Corballi’s.

The Rapid Auditory Processing Theory

This theory claims that the auditory deficit is the primary and the phonological is the secondary cause of individuals affected with dyslexia. This problem occurs when the verbal information is too short or the sounds are rapidly varying; this makes the task more difficult and results in defective or incorrect perception (Tallal, 1980; Tallal, Miller, & Fitch, 1993; Mody, Studdert-Kennedy, & Brady, 1997; Hazan, 1998; Serniclaes, Sprenger-Charolles, Carre, & Demonet, 2001). Dyslexics are affected by the fast changes in syllables and related sounds and this causes difficulty in processing auditory information, e.g. ba/da/sa/ga/ma, which also leads to poor categorical perception. In addition, dyslexics also show below average performance in auditory tasks, including frequency discrimination (McAnally & Stein, 1996; Ahissar, Protopapas, Reid, & Merzenich, 2000) and temporal order judgement tasks (Tallal, 1980; Farmer & Klein, 1995; Nagarajan, Mahncke, Salz, Tallal, Roberts, & Merzenich, 1999; McArthur & Bishop, 2001; Steinbrink, Groth, Lachmann, & Riecker, 2012). According to the above-mentioned explanations, auditory deficits are the most important elements in the course of phonological deficits, and thus, results in reading difficulty and learning to read.

The Cerebellar Theory

The Cerebellar Theory (Nicolson & Fawcett, 1990; Nicolson, Fawcett, & Dean, 2001) offer another viewpoint on dyslexia. The cerebellum plays an important role in motor control and therefore, is also responsible for speech articulation; it is shown that retarded or dysfunctional articulation could lead to faulty phonological representation. The cerebellum also plays a vital role in the automatization of over-learned tasks, such as driving skills, reading and writing. A malfunctioning of the cerebellum would have a

massive effect on such over-learned tasks and even on grapheme-phoneme correspondence, resulting in inadequate reading. Poor performances of dyslexics has been evidenced (Fawcett, Nicolson, & Dean, 1996) in several motor tasks, including time estimations while performing non-motor tasks (Nicolson, Fawcett, & Dean, 1995) and even impaired automatization of balance (Nicolson & Fawcett, 1990). Many studies have also shown anatomical, metabolic and activation differences in the cerebellum of dyslexics (Rae, Lee, Dixon, Blamire, Thompson, Styles, ... & Stein, 1998; Nicolson, Fawcett, Berry, Jenkins, Dean, & Brooks, 1999; Brown, Eliez, Menon, Rumsey, White, & Reiss, 2001; Leonard, Eckert, Lombardino, Oakland, Kranzler, Mohr, ... & Freeman, 2001).

The Magnocellular Theory

This theory integrates the major findings associated with developmental dyslexia (Stein & Walsh, 1997). According to the theory, reading related dysfunctions is not only restricted to the visual processing, but are generalized to other modalities; including auditory, tactile and even motor. According to the findings of the theory, temporal processing in all above mentioned systems seemed to be impaired in dyslexia (Stein & Walsh, 1997). The M cell abnormalities are associated in the medial as well as the Lateral Geniculate Nucleus (LGN) of the dyslexic brain (Livingstone et al., 1991; Galaburda, Menard, & Rosen, 1994); can be observed behaviorally by the poor performance of dyslexics in the tactile domain (Grant, Zangaladze, Thiagarajah, & Sathian, 1999; Stoodley, Talcott, Carter, Witton, & Stein, 2000), as well as the co-occurrences of visual and auditory impairments (Witton, Talcott, Hansen, Richardson, Griffiths, Rees, ... & Green, 1998; Cestnick, 2001; van Ingelghem, Wieringen, Wouters, Vandenbussche, Onghena, & Ghesquiere, 2001). For further details refer to Magnocellular Theory section of Chapter 4.

CHAPTER 2

Group differences for Rotation Related Negativity (RRN) while Reading

Introduction

Mental rotation is the ability to rotate objects mentally or to identify novel spatially matched configurations. Mental rotation also refers to the cognitive process of imagining how an object would look, if rotated from the angle of perception in which individuals are prone to perceive (Shepard & Metzler, 1971). Mental rotation is a cognitive process in which the parietal cortex plays a salient role (Jordan, Heinze, Lutz, Kanowski, & Jancke, 2001).

In mental rotation paradigm, characters are presented in a number of different orientations from their regular format to clock wise/anti-clockwise reversals. The time to decide upon the parity of the character increases linearly with the angular displacement (disparity) from the upright position (Shepard & Metzler, 1971). This process is typically studied in making comparisons in same versus different tasks using letters, or 3D figure discrimination tasks (Cooper & Shepard, 1973a; b). In a pioneering study, Shepard & Metzler (1971) instructed participants to discriminate between novel 3D figures and their mirror images with different orientations. They found that response time increased linearly with the difficulty level associated with the angular disparity from the upright position (Heil, 2002). In another paradigm, Cooper & Shepard, instructed subjects to decide whether rotated alphanumeric characters were in their normal or mirrored or if they were reversed. They replicated the same result, being that response time varied linearly as a function of the

difficulty level associated with the angular rotation (Cooper & Shepard, 1973a; b; Rusiak, Lachmann, Jaskowski, & van Leeuwen, 2007).

The behavioral properties of mental rotation are now well defined (Shepard & Cooper, 1982) but corresponding neuronal activations still remain to be poorly understood. Studies show that mental rotation was found to be salient for patients with brain lesions in the posterior right hemisphere (Ratcliff, 1979; Farah & Hammond, 1988; Ditunno & Mann, 1990). These lesions are often large with a significant involvement of the parietal lobe. Further, a study by Ditunno & Mann (1990) also demonstrated mental rotation deficits to be localized to the right parietal lobe. Thus, the results are consistent with other findings of parietal involvement in spatial cognitive task (De Renzi, 1982; Stein, 1991). The parietal lobe has been suggested as a potential substrate for a domain-specific representation of quantities and it is also found to have greater activations for the tasks related to verbal, spatial, and attentional functions; which may contribute to functions related to calculation as well (Cohen et al., 1996; Richter, Andersen, Georgopoulos, & Kim, 1997; Alivisatos & Petrides, 1997; Kosslyn, Digirolamo, Thompson, & Alpert, 1998; Heil et al., 2000; Jordan et al., 2001; Heil & Rolke, 2002; Dehane, Piazza, Pinel & Cohen, 2003; Milivojevic et al., 2003; Nunez-pena & Aznar-Casanova, 2009). Heil (2002) further indicated the importance and involvement of the parietal lobes in different processing stages, including stimulus identification, mental rotation, parity judgment, response selection and motor processes.

The effect of mental rotation in children was first studied by Mamor (1975; 1977) whose study evidenced that 4-year-old children can respond to mental rotation tasks based on 2-dimensional images. In addition, it was successfully proved that reaction times decrease as age increases and that a child of age 8 respond twice faster compared to the child of age 4.

Speed is an important factor associated with mental rotation tasks. It was also evidenced that age and the response times are inversely related; as the age increases, the time taken to respond on various cognitive tasks decreases (visual search, memory search, mental rotation), ranging from primary school children up to adolescence (Kail, Pellegrino & Carter, 1980; Kail, 1988; 1991). Such pattern of results, suggest that, some general mechanism (or processing resource) exists which obstruct performance on cognitive tasks during childhood and performance gets better with an increasing effect of age (Kail, 1988). Developmental changes, related with mental rotation, cannot be understood without incorporating qualitative developmental changes (Heil & Jansen-Osmann, 2008). Typically, it is found that reaction times increase linearly with an increasing difficulty of angular disparity (from upright position 0° - 360°). The process involves different processing stages Heil, (2002) mentioned in the above paragraph.

In Mental rotation task (Cooper & Shepard, 1973a; Shepard & Metzler, 1971) individuals spatially match the transfigured image with the way they are naturally prone to perceive. According to the task, the material is presented simultaneously or one after the other; the participant must decide if the material presented is same/different by pressing different keys, without keeping track of the angles of rotation. As can be seen in the resulting reaction times, there is a linear increase in reaction times as the angle of rotation increases from the material's normal (upright) position. This has also been used in two-dimensional representations of three-dimensional images (Shepard & Metzler, 1971). Since then, the paradigm has been used for a varied amount of stimuli and different tasks, including letters, cubes, or figures (Ruthruff, Miller, & Lachmann, 1995; Cohen et al., 1996; Kosslyn et al., 1998; Harris, Egan, Sonkkila, Tochon-Danguy, Paxinos, & Watson, 2000; Jordan et al., 2001). Orton's brain model was rejected due to the findings of mental rotation experiments. In a study by Corballis, Macadie, & Beale, (1985a); Corballis, Macadie,

Crotty, & Beale, (1985b) dyslexics of an average age of 12 and normal reading children of the same age group were tested on letter naming tasks in which the letters were either normal or mirrored (horizontal rotation) and were presented either in the right/left visual fields. The participants responded by pressing two different keys, and their judgments were based on if the letter was normal/mirrored, regardless of the angles of rotation. According to the findings, no differences between mean reaction times and error rates were found between the normal reading and dyslexic children. No preference for the normal letter over the mirrored letter was found. Further, no interaction between visual fields and rotation angles was present. Corballis et al., (1985b). He concluded that, reading disabled children do not show equilibrium for left and right hemispheres and the findings were against the model proposed by Orton. The group differences (dyslexics and normal reading children) for the mental rotation letter naming task was absent in the Corballis et al., (1985a) study; this was explained with the help of the FCD model proposed by Lachmann, (2002). According to the FCD model, the letter naming task does not require mental rotation. Ruesseler, Scholz, Jordan, & Quaiser-Pohl, (2005) found that dyslexics were impaired on the mental rotation tasks involving letters, shapes, and pictures, in comparison to normal reading children. In an another study by Rusiak et al., (2007) a total of 28 participants, including 16 dyslexics and 12 normal reading aged-matched polish children participated in the study. Their stimuli consisted of five letters (G,F,R,e,k), and were presented in normal as well as mirrored form, starting from the upright rotation angle 0° - 180° (clockwise multiples of 45°). The participant's responded to normal and mirrored letters with a different key press, irrespective of rotation angles. They found a linear increase in the reaction times as the angle of rotation increased from the upright position. These findings replicated the results of earlier studies using mental rotation task (Shepard & Cooper, 1982; Jordan et al., 2001; Harris & Miniussi 2003). Dyslexic children showed the same

trend of reaction times, the difference being that they were significantly slower than normal reading children (769 ms versus 648 ms). The results supported the FCD model by Lachmann (2002). Corballis et al., (1985a) also found the same effect of the mental rotation even for the symmetrical letters “b” and “d”; they further explained that these effects are not limited to symmetrical letters, but also true for non-symmetrical letters; It is a generalized effect which is restricted to letters. They suggested that visuo-spatial capabilities are intact in dyslexics because they followed the same trend of rotation, except that they showed some delayed effects in information processing of mental rotation tasks for letters.

The present study extends the work of Corballis et al., (1985a); Rusiak et al., (2007) in which dyslexics and age-matched normal reading children performed mental rotation tasks with letters. The classical paradigm, discovered by Cooper & Shepard (1973a; b) was one in which letters were shown in isolation in the normal or mirrored form. According to the predictions of the FCD model, dyslexics are predicted to perform equally well while rotating the letters; requiring a mental process. However, dyslexics will have problems in decision making with the orientation of the letter (normal/mirrored). For this reason, dyslexics will show a delayed response in the mental rotation of letters, i.e., dyslexics will be delayed in information processing while decision making (pressing response keys). According to the FCD approach, the symmetry generalization problem occurs only while responding to graphemes, but it is not only true for symmetrical letters such as “b” and “d”; hence, we have used letters which are symmetrically dissimilar (letter, G, F, and R). In order to further investigate the nature of perceptual strategies used for the mental rotation task of letters by dyslexics, neurophysiological (EEG/ERP) methods must be applied (Goswami, 2004; Rusiak et al., 2007).

Neurophysiological methods (EEG/ERP) and mental rotation

Mental rotation is a cognitive process which is difficult to explain because it is one of many cognitive processes which are processed unconsciously. Hence, there is a need to combine neurophysiological methods to fully understand the underlying mechanisms and the temporal processing involved. Therefore, this study adopted event-related potentials (ERPs) as a neurophysiological method. ERP is a procedure to measure the electrical activity of the brain through the scalp (Rugg & Coles, 1995). Previous neurophysiological research has suggested that humans show similar trends while responding to tasks such as recognition, identification, mental rotation and problem solving (Cicconetti, Priami, Sagrafoli, Tafaro, Ettore, Donadio, ... & Marigliano, 2007; Lai, Chiu, Gadow, Gau, & Hwu, 2010). For example, when humans respond to a mental rotation task, the greater the angle (greater the angle of rotation) of the stimulus, the larger the rotation-related negativity (the positive waveform decreases as the angle of rotation becomes more complex, Heil & Rolke, 2002; Milivojevic, Clapp, Johnson, & Corballis, 2003).

This mental rotation process is reflected as a modulated, delayed, positive waveform ranging between 300 to 1000 ms and has an inverse relation to the rotational angle of the stimulus; the waveform becomes more negative as the complexity associated with the angles of rotation increases (Peronnet & Farah, 1989; Heil, Rauch, & Hennighausen, 1998; Heil & Rolke, 2002; Heil, 2002). The gradual decrease in amplitude (as the angle of rotation becomes more complicated) is thought to be caused by a superimposed negativity on the simultaneously prevailing P300 complex (Peronnet & Farah, 1989; Wijers, Otten, Feenstra, Mulder, & Mulder, 1989), which is why it is referred to as Rotation Related Negativity (RRN) (Nunez-Pena, Aznar, Linares, Corral, & Escers, 2005; Lust, Geuze,

Wijers, & Wilson, 2006; Nunez-Pena & Aznar-Casanova, 2009). The RRN is an electrophysiological correlate of the mental rotation process recorded by the cerebral activations of the functioning brain (Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Heil, 2002; Heil & Rolke, 2002). RRN as a result of increasing complexity, was present during the mental rotation of both letters and objects (Thayer, Johnson, Corballis, & Hamm, 2001; Heil, 2002; Lust et al., 2006; Thayer & Johnson, 2006; Tao, Liu, Huang, Tao, Yan, & Teeter, 2009). Mental rotation is a well-known task and is essentially dominant in the parietal cortical regions; the task is also associated bilaterally in the middle occipital gyrus, left superior temporal gyrus, medial frontal gyrus, and in the right superior and inferior parietal lobes. The larger mean amplitudes of the rotation-related negativity indicate that the participants used less mental rotation to complete the task than the baseline; this means that the task was easier. Less mean amplitude shows that; more cognitive abilities are required for the task and the task is difficult. According to the recent framework of the literature, rotation-related negativity is prominent in mental rotation tasks and is found in the parietal electrodes. Therefore, in the current study, we analyzed the ERP data from the parietal electrodes (P3, Pz and P4).

Aim of the study

The behavioral results of the mental rotation tasks of letter perception collected thus far indicate that group effects in mental rotation tasks occur later, in the decisive stage of information processing (Rusiak et al., 2007). Behavioral data, however, provide only limited information on the time course of the information processing. In order to evaluate the hypothesis of a failure in suppressing symmetry generalization in letter perception, psychophysiological methods need to be applied. We designed a mental rotation task with

Latin letters, where all letters were visually and phonologically dissimilar. Heil (2002) and his colleagues were able to locate the effects of Mental Rotation in the time course of processing using event related potentials (ERP) of the electroencephalogram (EEG). Latencies, amplitudes, and locations were defined as representing the performance of the mental rotation process.

- Using this method allows us to check when the group effect in mental rotation tasks occurs. Dyslexics and controls process the letters at the same time or are dyslexics earlier or later in information processing, this means that dyslexics show a late or an early ERP component.
- We expect an overall group effect (dyslexics and controls) on reaction times and on amplitudes (ERP).
- We also expect rotation related negativity (RRN), which is prominent in mental rotation tasks and to be found in parietal electrodes ranging between 400 – 1000 ms (Heil, 2002). Are there any differences between the left and right parietal electrodes (laterality)?
- The larger mean amplitude of rotation-related negativity (RRN) will indicate that the participants used more mental rotation to complete the task than the baseline. Here we expect that dyslexics will show less RRN (less positive amplitude) in comparison to controls, as they have a critical problem in understanding and making decisions about rotation tasks with letters.

Method

Participants

There were 30 children from primary schools and after-school care in Kaiserslautern, Leipzig, and Saarbrücken (all major German cities) participating in the study, with 13 diagnosed with developmental dyslexia (mean age = 10.6; two females) and 17 grade

matched controls (9.8 males; 7 females). All participants were right-handed and had normal or corrected--to-normal vision. Each participant received a gift voucher of a toy shop equivalent to 15 Euros as a reward for participation. Before participation, parents signed a letter of informed consent for every child. All participants performed the Salzburger Lese-und Rechtschreibtest (SLRT – Landerl, Wimmer, & Moser, 1997) reading test and Ravens Standard Progressive Matrices Test' in German (Heller, Kratzmeier, & Lengfelder, 1998). The Salzburger Lese test measure consists of five different sections: (1) frequent word reading; (2) chain word reading; (3) long or short comprehension reading (children up to grade 2 read short comprehension and from grade 3, children read long comprehension); (4) pseudo word reading (pronounceable non-word reading); and (5) non-word reading. Participants were to perform in all the above-mentioned sections of reading by reading aloud. Reaction times (using a stopwatch) and the total number of errors were noted by the native examiner for every section. All scores of the SLRT were computed. A control child had to perform within the norm of their reference group, i.e. above the percentage rank of 20 (rank >20 in each subtest). Dyslexic participants were expected to perform below percentage rank 5 (rank < 5), in at least two subtests, particularly for frequent and non-word reading (Lachmann, Berti, Kujala, & Schroger, 2005) of the above-mentioned subtests. Five subjects did not meet the criteria and did not participate in the experiment. Six participants met the criteria for the dyslexic group, but parents did not sign the letter of consent for the EEG experiment; these participants were excluded. All children were of normal intelligence and performed within the criteria of $IQ < 75$.

Material and Procedure

The experiment was performed using the 'Presentation Programming Language' for the stimulus presentation and the portable 'Neuroscan' for the ERP data acquisition. For all participants, EEG and behavioral responses were recorded from 360 trials in twelve blocks of 30 trials each. Before the experimental blocks, each participant had to participate in 30 practice trials. The experiment was performed on a 15" laptop, positioned approximately 50 cm from the participant, resulting in a visual angle of 2.9 degrees, without head fixation. Participants were instructed to minimize body and eye movements during the experiment. The experiment was performed in a dimly lit room, with minimal environmental noise.

Three capital letters G, F, and R, were used for the experiment. The letters were presented in black against a white background. First, a fixation cue was presented, followed by a visual feedback: '+' as correct and '-' as an incorrect response. Participants were supposed to respond to choice reaction tasks by a key press, left arrow key for normal letters, and right arrow key for mirrored letters (see Figure. 2.1). The target was presented until a response was given; the inter-trial interval was either 500 ms, 600 ms, or 700 ms (because the participant should not predict the occurrence of the next stimuli) and a target letter was presented either in a normal or mirrored orientation with a rotation of about 30° , 330° , 90° , 270° , 150° or 210° (see Figure. 2.2). All trials were completely randomized.

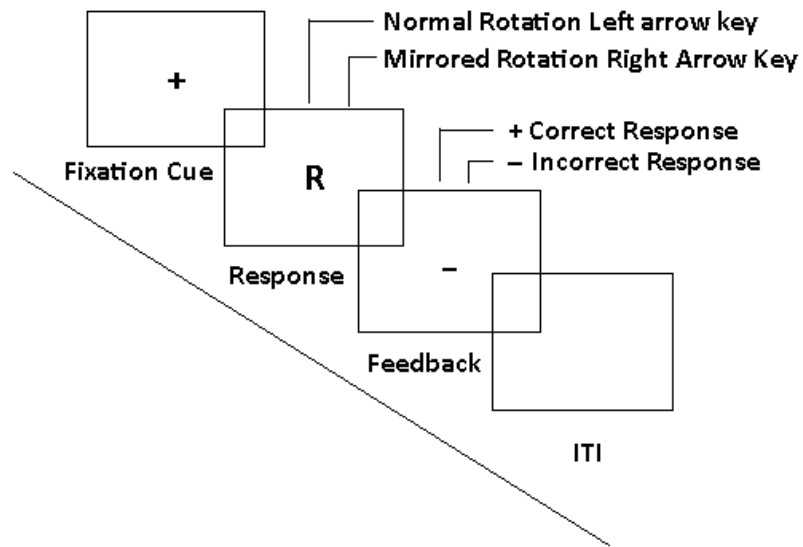


Figure. 2.1. Sequence of stimulus presentation.

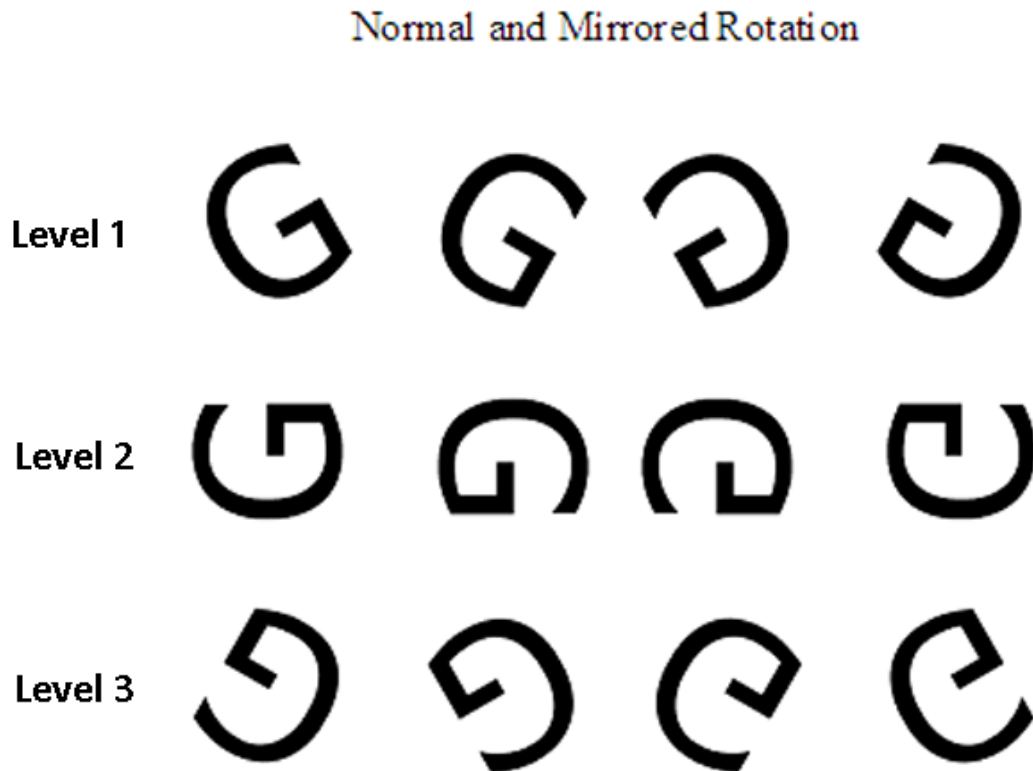


Figure. 2.2. Angles of rotation used in the experiment.

ERP Analysis

The data were analyzed using an EEG lab toolbox of Matlab. Monopolar EEG was recorded by AgAgCl electrodes from frontal (F3, Fz and F4), central (C3, Cz and C4), and parietal (P3, Pz and P4) electrodes. Horizontal and vertical eye movements were monitored by two different electrodes. The left mastoid served as a ground electrode. Electrode

impedance was kept at less than 5 k Ω , digitization rate was kept at 250 Hz. On average, less than 30% of the total trials were rejected. The artifacts and errors were rejected manually and ocular corrections were also done. Bandpass filters were used with a value of the high pass at 0.5 Hz and the low pass at 30 Hz. Stimulus-locked epoching was done in the time window of -100 to 1500 ms from the onset of stimulus presentation. Mean ERP amplitude analysis was done for only correct trials for the time window of 400 – 700 ms and 800 - 1000 ms from the onset of stimulus presentation, with a pre-stimulus baseline of 100 ms ERPs extracted from single-trial averaging for both groups of participants, electrodes and experimental conditions. Statistical effects were tested for the amplitudes for the time window of 400 – 700 ms using ANOVA, including ‘group’ as a between subject variable and ‘levels of rotation’ and ‘laterality’ as within subject variables.

Results

Behavioral Results

A 3 x 2 Analysis of Variance (ANOVA) was performed on correct reaction times as a dependent variable, for the within-subject variable *Rotation* (30⁰ and 330⁰ – level 1, 90⁰ and 270⁰ – Level 2, 150⁰ and 210⁰ – Level 3) and *Group* (dyslexics and controls) as a between-subject variable. The *Group* main effect was significant, $F(1, 28) = 5.597, p = 0.025$, and the main effect of *Rotation*, $F(2, 56) = 53.86, p = 0.000$, was also found to be significant. Interaction between *Rotation X Group* was not found to be significant. Dyslexics were slower (Level 1 – 1652 ms, SD = 573 versus Level 2 – 1878 ms, SD = 703 versus Level 3 – 2025 ms, SD = 600) in responding to the rotation task compared to controls (Level 1 – 1189 ms, SD = 341 versus Level 2 – 1357 ms, SD = 462 versus Level 3 – 1610 ms, SD = 541).

One-factorial within-subject ANOVAs in each group was performed. Controls $F(2, 32) = 33.58, p = 0.000$ and dyslexics, $F(2, 24) = 22.962, p = 0.000$, both showed significant main effects of the variable rotation. Adjustment for multiple comparisons was done using Bonferroni correction to perform pairwise comparisons for the variable rotation for both groups. Controls showed significant differences between Level 1 and Level 2, $p = 0.002$, Level 2 and Level 3, $p = 0.000$ and for Level 3 and Level 1, $p = 0.000$. Controls showed an increase in reaction time with an increase in the complexity of rotation (increasing angles of rotation) of letters from the upright position (see Figure.2.3). Dyslexics also showed significance for Level 1 and Level 2, $p = 0.001$, and Level 3 and Level 1, $p = 0.000$, while effects for Level 2 and Level 3, $p = 0.160$, were not found to be significant. Dyslexics showed an increase in reaction times with an increase in the complexity of the rotation of letters only for Level 1 versus Level 2 and Level 3 versus Level 1. Differences between Level 3 and Level 2 were not found to be significant because, as the angle of rotation becomes more complex, dyslexics are unable to treat both the angles differently. These results could be interpreted as floor effects. Overall, the task was more difficult for dyslexics when compared to controls, because of the symmetry generalization dyslexics have for letter perception (see Figure.2.3).

Further, error rates were also analyzed and the *Group* main effect, $F(1, 28) = 13.10, p = 0.001$ and the effect of *Rotation*, $F(2, 56) = 31.80; p = 0.000$ was significant; no interaction was found to be significant. One factorial within-subject ANOVA in each group was performed for error rates. Controls, $F(2, 32) = 12.881, p = 0.000$ and dyslexics, $F(2, 24) = 18.811, p = 0.000$, both showed significant main effects of the variable Rotation. Error rates for dyslexics on rotation for Level 1 versus Level 2, $p = 1$, Level 1 versus Level 3, $p = 0.000$ and Level 3 versus Level 2, $p = 0.005$. On the other hand, controls showed significant differences between Level 1 versus Level 3, $p = 0.005$ and Level 2 versus Level

3, $p = 0.005$ as well, while the difference between Level 1 versus Level 2, $p = 1$, was not found to be significant. Dyslexics and controls both showed the maximum percentage of errors for Level 3. Level 1 showed the minimum percentage of errors (see Figure.2.4).

Dyslexics and controls showed a proportionate increase in Error rates as there was an increase with the complexity associated with the task. In addition to this, controls were more accurate (Level 1 - 3.5% versus Level 2 - 4.3% versus Level 3 - 11.3 %) as compared to dyslexics (Level 1 - 8.91% versus Level 2 - 10.90% versus Level 3 - 20.25 %) (see Figure.2.4).

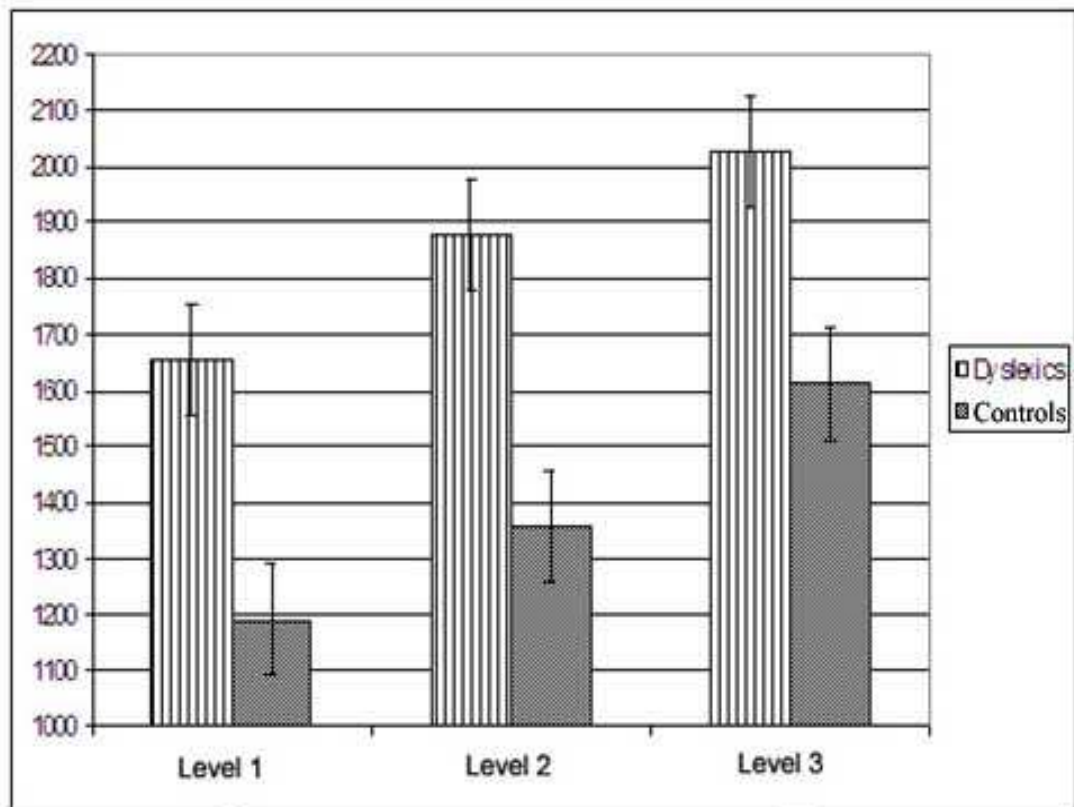


Figure.2.3. Reaction Times for both groups (dyslexics and controls). The X axis represents angles of rotation and the Y axis, reaction times.

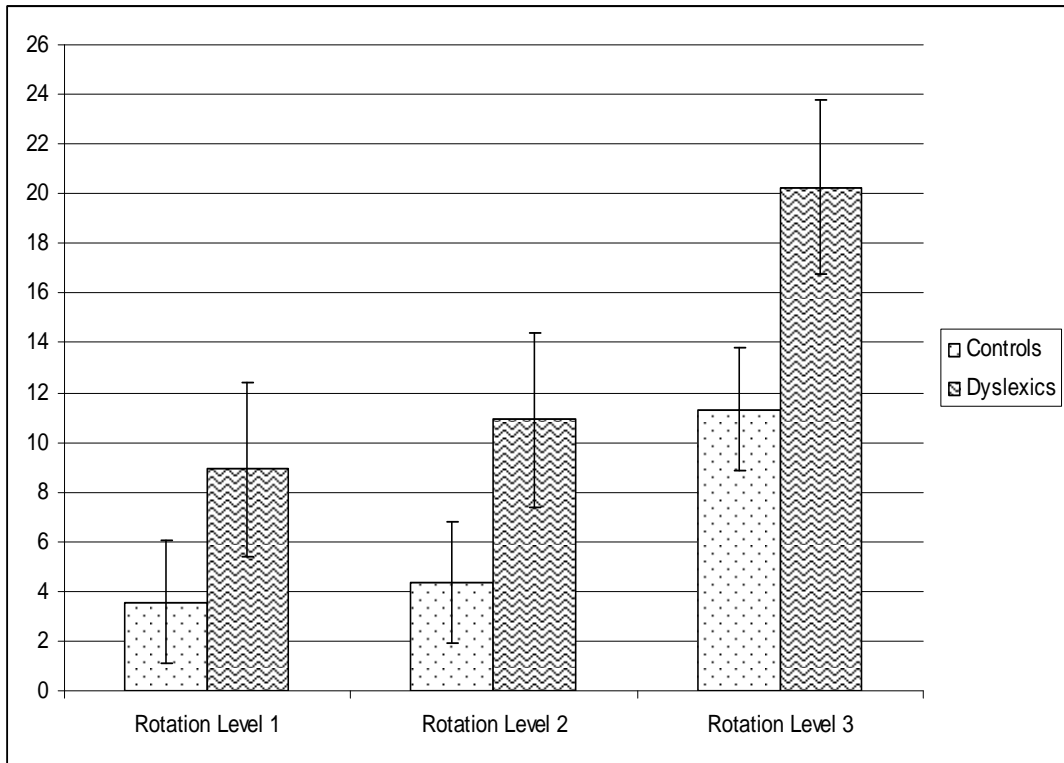


Figure.2.4. Error percentages represented as the Y axis for both groups (dyslexics and controls) and the X axis represents angles of rotation.

Mean Amplitude						
Laterality				Rotation		
	P3	Pz	P4	Level1	Level2	Level3
Dyslexics	8.827	11.115	9.396	10.138	10.0337	9.1664
Controls	10.627	13.801	9.437	13.184	11.648	9.100
Mean Standard Deviation						
	P3	Pz	P4	Level1	Level2	Level3
Dyslexics	3.237	4.660	4.946	4.139	4.391	4.372
Controls	3.900	3.868	4.981	4.004	4.356	4.005

Table 1. Mean reaction times and standard deviations (SD) (400-700 ms).

ERP Results 1

A repeated measure ANOVA was performed for amplitudes within the time window of 400-700ms (Heil, 2002) for parietal electrodes P3, Pz and P4, for the independent variables:

- *Laterality* (P3, Pz and, P4),
- *Rotation* (30^0 and 330^0 – Level 1, 90^0 and 270^0 – Level 2, 150^0 and 210^0 – Level 3) and
- *Group* (dyslexics versus controls)

The *Group* effect was not found to be significant. The main effect of *Laterality* $F(2, 56) = 19.655, p = 0.000$ and *Rotation*, $F(2, 56) = 16.861, p = 0.000$ were significant. Interestingly, an interaction between *Laterality X Group* $F(2, 56) = 3.185, p = 0.049$ and *Rotation X Group*, $F(2, 56) = 6.026, p = 0.04$ was also found to be significant, however, no triple interaction was significant (for interaction plots, please refer to Figures 2.6 and 2.7). The mean amplitude and standard deviations are shown in table 1. Adjustments for multiple comparisons were done using the Bonferroni correction (t-test) to perform the pairwise comparisons for controls and dyslexics separately by multiplying the significance value of the total number of pairwise conditions within that variable. We considered the $p = 0.05$ ERP amplitudes as very sensitive; usually a difference of $.05\mu\text{V}$ is considered to be relevant. Therefore, post-hoc analysis has been done using (i) the Bonferroni correction and (ii) without the Bonferroni, because, after applying this correction, the significance values become more stringent and even a tendency towards significance becomes insignificant.

Two factorial within-subject ANOVA in each group was performed. Controls showed significant main effects of the variables *Laterality*, $F(2, 32) = 19.562$, $p = .000$, and *Rotation*, $F(2, 32) = 28.473$, $p = .000$. No interaction was found to be significant. Further, as mentioned above, adjustment for multiple comparisons was done with and without Bonferroni correction to perform pairwise comparisons for the variables laterality and rotation. With the Bonferroni correction, significant differences were found between Level 2 and Level 3, $p = .000$ ($t(16) = 5.429$, $p = 0.000$) and Level 3 and Level 1, $p = 0.000$ ($t(16) = -8.098$, $p = 0.000$), whereas the difference between Level 1 and Level 2 was not significant, $p = .107$ ($t(16) = -2.295$, $p = 0.107$). Without the Bonferroni correction, the difference was found for the condition Level 1 and Level 2, $p = 0.036$ ($t(16) = 2.295$, $p = 0.036$). Controls showed the maximum amplitude for Level 1 in comparison to Level 2 and Level 3; the amplitude decreases as the level of rotation increases (see table 2 and Figure.2.10). Dyslexics showed no significant differences between the angles of rotation. The trend of the angular disparity of rotations was present only for controls and not for dyslexics. Therefore, only controls showed a typical pattern of rotation, as the angular disparity increases the rotation-related negativity (RRN), see Figure.2.10.

Conversely, considering the variable laterality with the Bonferroni correction, controls showed significance for P3 versus Pz, $p = 0.000$ ($t(16) = -6.427$, $p = 0.000$) and for Pz versus P4, $p = 0.000$ ($t(16) = 5.391$, $p = 0.000$), while P4 versus P3, $p = 0.486$ ($t(16) = 1.465$, $p = 0.486$) was not significant. Without the Bonferroni correction, no different results were found.

Dyslexics showed significant main effects only for the variable laterality, $F(2, 24) = 4.729$, $p = 0.019$; no interaction was found to be significant. Further, with the Bonferroni correction, dyslexics showed significance only for P3 versus Pz, $p = 0.036$ ($t(12) = -2.959$, $p = 0.036$), and Pz versus P4, $p = 0.084$ ($t(12) = -2.501$, $p = 0.084$) while P4 versus P3, $p =$

1 ($t(12) = 0.666, p = 1$) was highly nonsignificant (see Figure.2.6). Without the Bonferroni correction, Pz versus P4, $p = 0.028$ ($t(12) = 2.501, p = 0.028$) was significant, but the condition P4 versus P3, remained nonsignificant.

Dyslexics and controls showed greater amplitudes for central parietal electrode (Pz) in comparison to the left and right parietal electrode (P3 and P4). Both groups did not differ in the activity related to the 'Left' and 'Right' Hemispheres, no hemispheric differences were observed (see table 1 and Figure.2.5). Overall, dyslexics showed reduced activity because they have more problems responding to mental rotation tasks in comparison to controls (see Figure.2.10).

ERP Results 2

On the basis of visual scanning for the dyslexic participants, a change between the baseline activity was observed in the time window of 800–1000 ms (see Figure.2.10). Therefore, a repeated measures ANOVA was performed for the amplitudes of the time frame of 800 - 1000 ms for both groups for *Laterality* (P3, Pz and, P4) and *Rotation* (30^0 and 330^0 – Level 1, 90^0 and 270^0 – Level 2, 150^0 and 210^0 – Level 3). *Group* and *Rotation* main effects were not found to be significant. Only the variable *Laterality*, $F(2, 56) = 31.014, p = 0.000$ (see Figure.2.8) was significant and an interaction between variables *Rotation X Group*, (see Figure.2.9) showed a tendency towards significance, $F(2, 56) = 35.333, p = 0.066$ (see table 2 for mean reaction times and SD values).

Two factorial within-subject ANOVAs in each group were performed. Controls showed significant main effects of the variable laterality, $F(2, 32) = 28.030, p = .000$. With the Bonferroni correction, significant differences were found between P3 versus Pz, $p = 0.000$

($t(16) = -4.883, p = 0.000$), and Pz versus P4, $p = 0.000$ ($t(16) = 8.930, p = 0.000$), and P3 versus P4, $p = 0.344$ ($t(16) = -1.688, p = 0.344$) was not significant. Without the Bonferroni correction, no different results were found. Control participants did not show any significance for the variable rotation because they had finished rotation in the time window 400–700 ms.

Dyslexics showed significant main effects of the variables *laterality*, $F(2, 24) = 8.942, p = 0.001$, and *Rotation*, $F(2, 24) = 4.657, p = 0.020$, and no interaction was found to be significant. With the Bonferroni correction, significant differences were found between P3 versus Pz, $p = 0.017$ ($t(12) = -3.367, p = 0.017$), Pz versus P4, $p = 0.002$ ($t(12) = 4.697, p = 0.002$), while P3 versus P4, $p = 1$ ($t(12) = -0.358, p = 1$) was not found to be significant. Without the Bonferroni, no different results were found. With the Bonferroni correction, dyslexics showed a significant difference only for Level 2 and Level 3, $p = 0.053$ ($t(12) = -2.752, p = 0.053$), while Level 1 versus Level 2, and Level 3 and Level 1 were insignificant. Without the Bonferroni correction, dyslexics showed significant difference between Level 2 and Level 3, $p = 0.018$ ($t(12) = -2.752, p = 0.018$), Level 3 and Level 1, $p = 0.079$ ($t(12) = 1.920, p = 0.079$) showed a tendency towards significance, Level 1 versus Level 2 was again nonsignificant. Dyslexics did not show a typical pattern of RRN, but some differences were observed between the levels of rotation. Level 3 showed the maximum amplitude in comparison to Level 2 and Level 1 (see table 2 and Figure.2.5). Dyslexics were not able to perform at Level 3 and, therefore, the activity did not change and remained more positive. Level 1 showed less positive amplitude compared to Level 3 and it could be that dyslexics performed some rotation at Level 1 and, because of the easier rotation condition, they were able to rotate the letters (see table 2). For the time window 800–1000 ms, dyslexics and controls replicated the findings for the variable laterality mentioned in the results section's ERP analysis 1 (400–700 ms).

Mean Amplitude						
Laterality				Rotation		
	P3	Pz	P4	Level1	Level2	Level3
Dyslexics	6.616	9.477	6.279	7.33	6.524	8.591
Controls	5.371	8.169	4.460	6.546	5.780	5.674
Mean Standard Deviation						
	P3	Pz	P4	Level1	Level2	Level3
Dyslexics	3.505	6.075	5.606	5.635	4.705	4.905
Controls	3.344	4.078	4.021	4.345	3.723	4.050

Table 2. Mean reaction times and standard deviations (SD) (800 ms - 1000 ms).

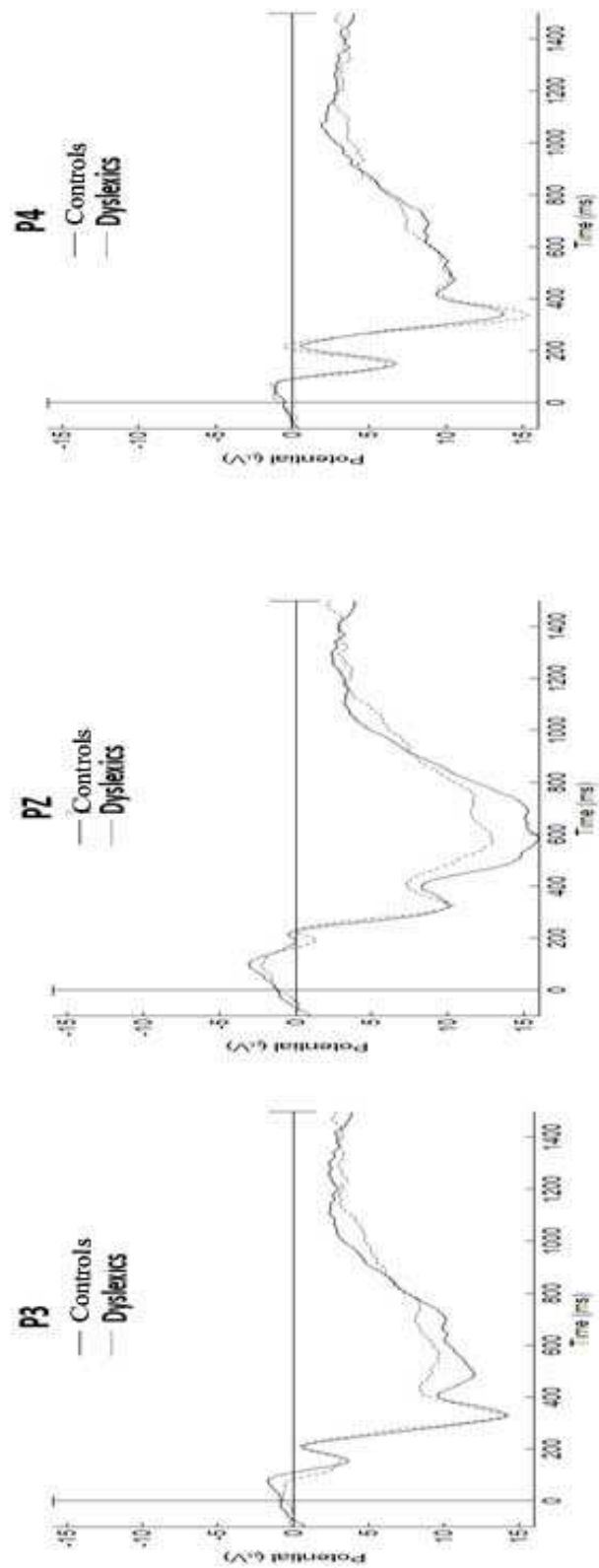


Figure.2.5. ERPs for Rotation for the electrodes P3, PZ and P4 (left – Controls and right – Dyslexics).

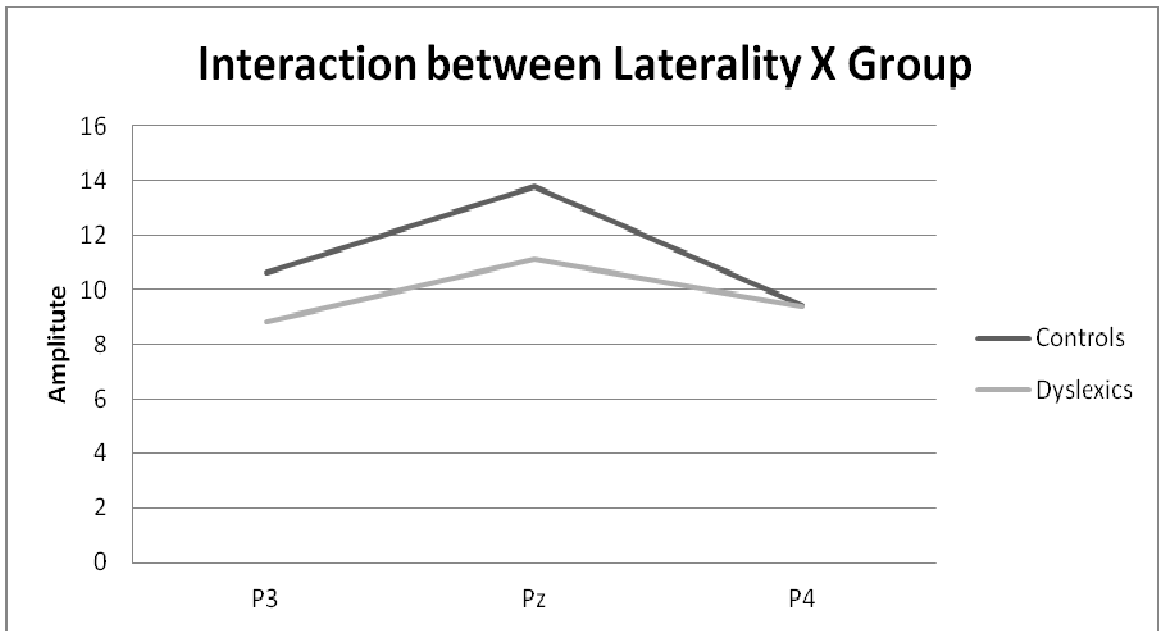


Figure.2.6. Interaction between Laterality X Group (400-700ms).

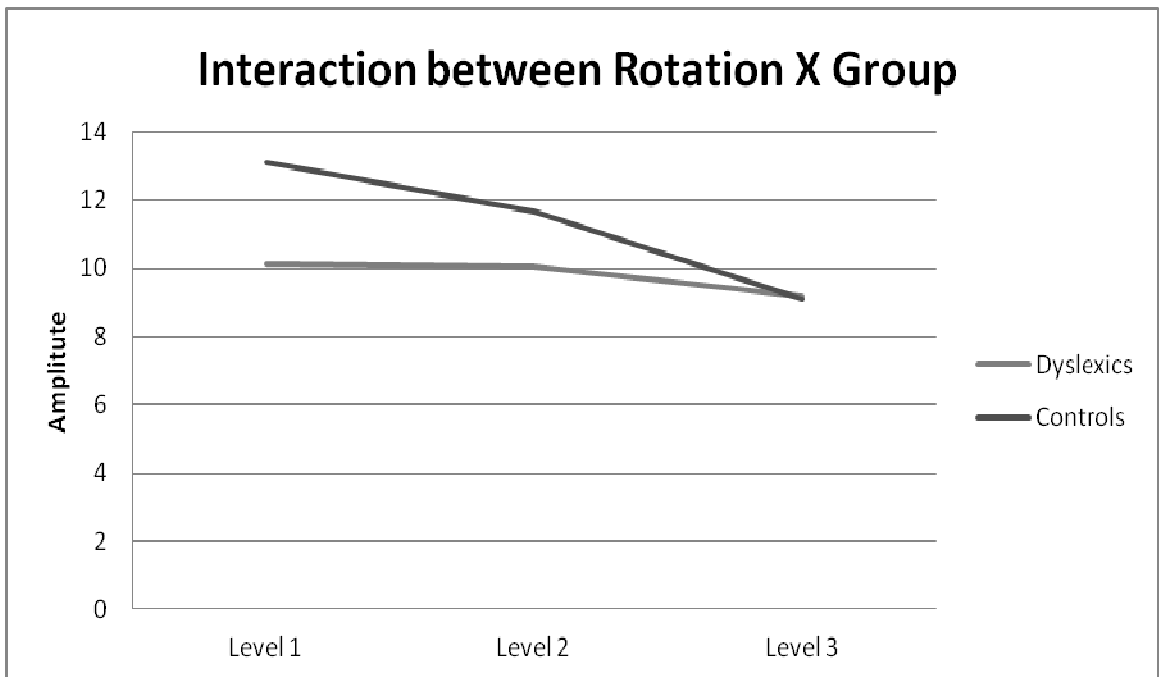


Figure.2.7. Interaction between Rotation X Group (400-700ms).

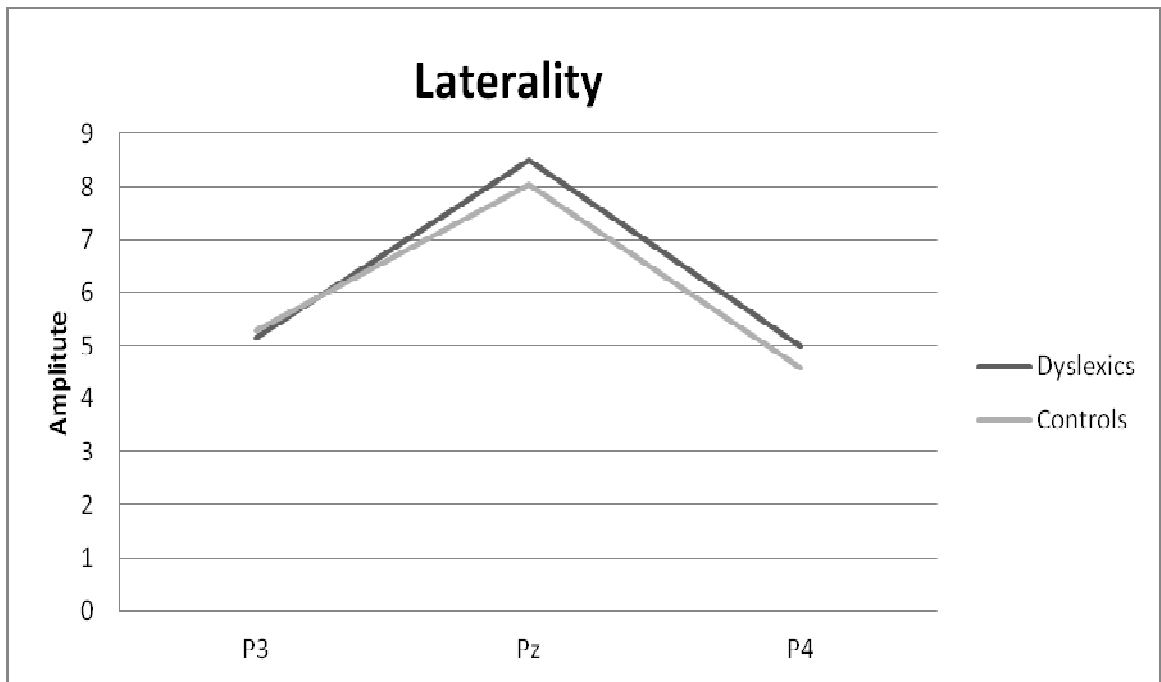


Figure.2.8. Plot for the variable Laterality (800-1000ms).

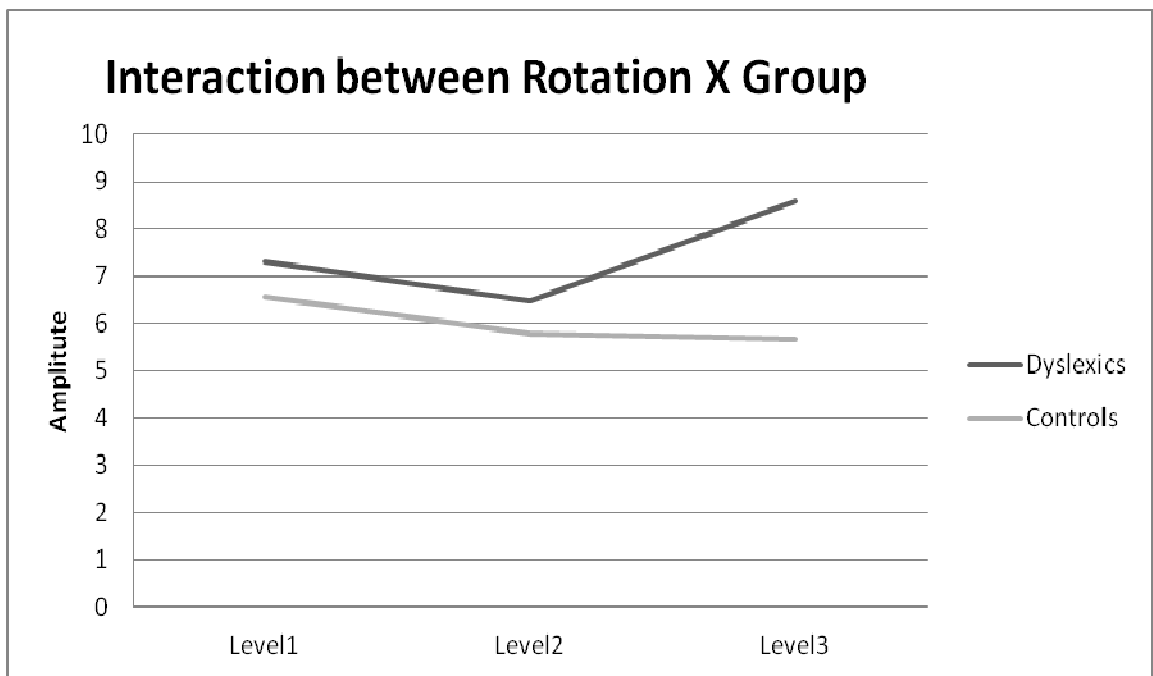


Figure.2.9. Interaction between Rotation X Group (800-1000ms).

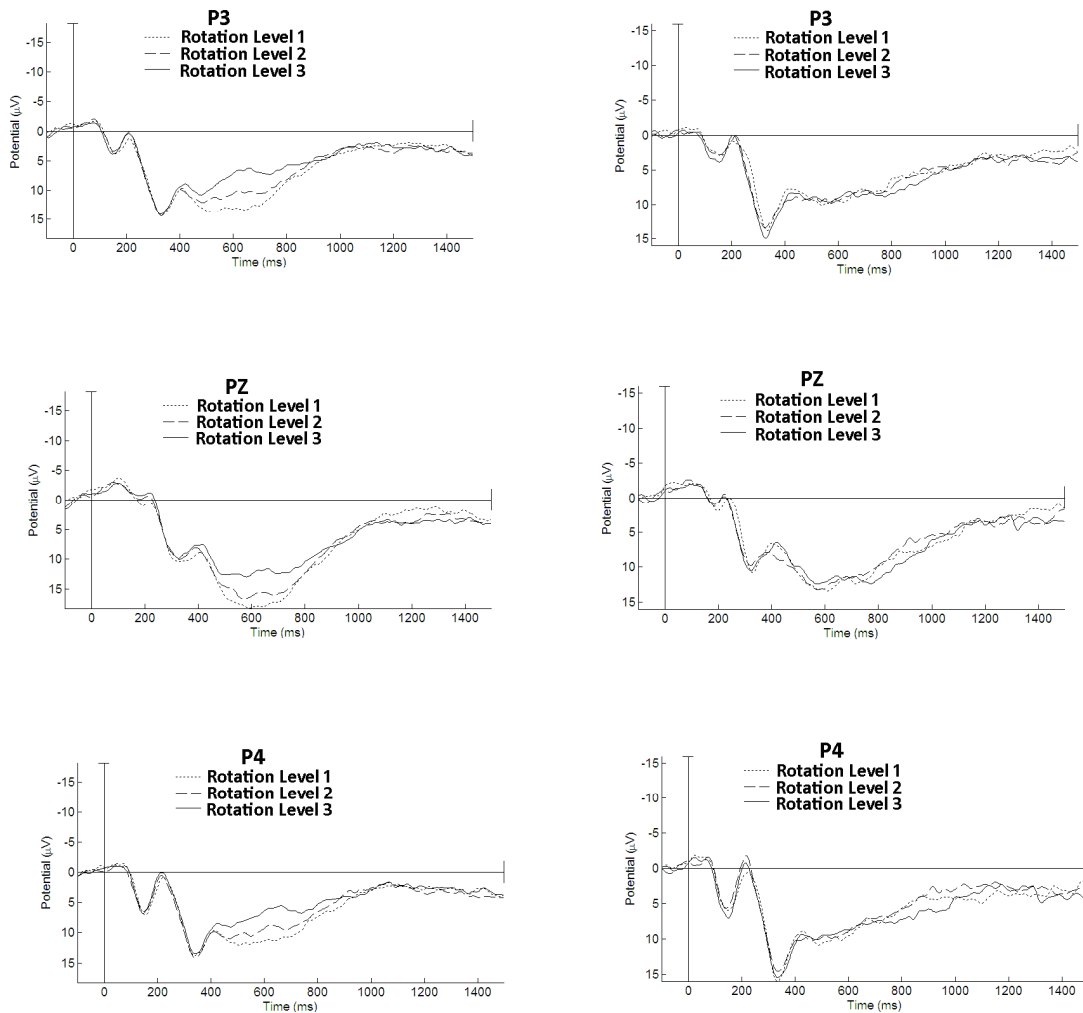


Figure. 2.10. Difference in Controls and Dyslexic children for the electrodes P3, Pz, and P4.

Discussion

Analysis without the Bonferroni corrections will be considered for the ERP analysis due to the fact that for ERP's, even a small difference is considered to be important. In this study, we analyzed the reaction times and ERP's of a mental rotation task. We examined the

difficulty associated with angular disparity of rotation from the upright position. Due to the inverse relation between increasing RT and angles of rotation, we hypothesized that the RRN would increase as the angular disparity increases. However, dyslexics and controls would reflect the same pattern on ERP's.

Behavioral findings

Dyslexics and normal reading children were compared in mental rotation tasks with letters. The letters and their mirrored images were presented in the center with the clockwise rotation ranging from 30^0 to 330^0 , with multiples of 60^0 each. Participants indicated with a different key press for normal or mirrored rotation (Cooper & Shepard, 1973a). Normal reading children were faster than dyslexics and visuo-spatial processing seems to be intact in dyslexics because identical effects were found on mental rotation tasks in both groups. Group differences were also observed and dyslexics have problems in responding to the letters which have non-symmetrical mirror images at the decision stage (Lachmann, 2002). These effects are not limited to the symmetrical letters "b" and "d" (Rusiak et al., 2007). The results replicated the findings of the FCD model by (Lachmann, 2002). An equal comparison between behavioural and ERP findings without Bonferroni analysis will be considered.

ERP Findings

Mental rotation is a delayed process, as more time is needed while making a decision on the stimuli presented with different angles of rotation. In the task, the rotated stimuli have to be matched with a natural version of the stimuli in the brain. The parietal cortex is

responsible for the spatial abilities of object and letter perception (Heilman, Watson & Valenstein, 1993; Heil, 2002). The effects of mental rotation on ERPs also take place at the later stage of information processing in the parietal electrodes, between the time window of 400 - 1000 ms (Heil, 2002). Controls showed prolonged positivity with a significant decrease in positivity (resulted in an increasing effect of negativity) as a function of increasing complexity associated with the stimuli in the time window of 400 – 700 ms (Wijers et al., 1989).

This finding replicates the previous finding of the mental rotation of non-corporeal objects and letters (Heil, 2002), the study shows the increasing effect of the mental rotation of stimulus resulted as a proportionate increase in RRN (decrease in positive waveform). Additionally, the observed RRN for letters is compatible with our behavioral data; the increase in RT's is a function of angle for rotations. Thus, our findings confirm the direct relation between RRN and the mental rotation process.

Dyslexics did not show any significant difference between the angles of rotation for the time window 400–700 ms, possibly because dyslexics had not yet finished the mental rotation and still did not know whether the stimulus was normal or mirrored. This could be a reason why dyslexics take more time in responding to letters, because they are trying to suppress the symmetries present within them. (Figure.2.10, and also see FCD Model, Lachmann, 2002), Possibly, late effects for dyslexics in the behavioral data is due to the delayed brain activity shown by ERPs because some late differences could be observed in the time window of 800–1000 ms. This could support one of our hypotheses that dyslexics respond to mental rotation tasks but require more time to finish the rotation process. The brain activity for dyslexics lasts for a longer duration due to the inability to suppress the symmetries between letters and their mirror images. Dyslexics start the mental rotation process at the same time as controls, but they need significantly more time to finish the

rotation process. Dyslexics treat letters not like symbols, but like objects, and as a result, have problems in suppressing the symmetries within a letter (Lachmann, 2002).

In the time window of 800–1000 ms, dyslexics showed a significant difference between Level 2 versus Level 3. Level 1 versus Level 3; showed a tendency towards significance, but Level 1 versus Level 2 was nonsignificant. The trend of RRN for the mental rotation task was absent for dyslexics, possibly because they showed floor effects and therefore no trend of RRN was found. Another possible explanation could be that they showed no RRN because they were more engaged in understanding the differences between normal and mirrored rotations. Some differences between the angles of rotation in the later time window (800-1000 ms) could also be explained as a confusion between normal and mirrored rotations.

Less positive activation in the ERP's show that the stimuli appear to be difficult for the participants and dyslexics showed overall less-positive activations (see Figure.2.5) because the task was more difficult for dyslexics than in controls. Adequate development of visual and phonological skill is required for differentiating between different orientations of letter perception and these skills are probably less developed in dyslexics.

Laterality differences in both groups showed similar patterns on ERP's. Dyslexics and controls both showed significantly greater parietal central (Pz) activations in comparison to the left or right parietal electrodes (P3 and P4). In many studies, the RRN was found in the central electrodes (Heil et al., 1998; Heil & Rolke, 2002; Milivojevic et al., 2003; Nunez-Pena & Aznar-Casanova, 2009; Ho, Chou, Huang, Lin, Shih, Han, ...& Liu, 2012) because the central hemisphere receives activation from both the left and right hemispheres. Larger mean amplitudes of rotation related negativity were found in the central hemisphere, signifying that the central electrode was salient for mental rotation. We also want to

conclude that, inconsistency between the behavioral and ERPs were found in the present study. The inconsistency may suggest that dyslexics may have different brain localization than controls. Dyslexics do not perform mental rotation in the brain area where P3, Pz and P4 electrodes were localized in comparison to controls.

Conclusions and implications

Dyslexics have difficulties in performing mental rotation in comparison to controls, as shown by more negative amplitudes (see Figure.2.5). Expected RRN was only present for controls and not for dyslexics. The cerebellum (the part of the brain responsible for motor movements) could play an important role in automatization of specific reading processes (Cerebellar Theory, Fawcett et al., 1996) and parts of the cerebellum are responsible for mental rotation as well. The results also suggested that dyslexics were using a different strategy for performing mental rotation and that there could be a difference between medial (left) and lateral (right) rotations (Horst, Jongma, Janssen, Lier, & Steenbergen, 2012). Further experiments should be performed to compare the differences between the left and right rotations. Good performance on the block design test is indicative of appropriate functioning of the parietal and frontal lobes; therefore, a verbally instructed block test could be used to train dyslexics on letter construction tests using different angles of rotation.

CHAPTER 3

Symmetry Generalization and Reading

Introduction

In Chapter 1, a mental rotation task was performed with letters having no visual or phonological similarities even after rotation. In this chapter, dyslexics and controls were tested on letters having visual and phonological similarities such as *b* versus *d*, *p* versus *q*. In other words, dyslexics and age matched controls were tested on symmetrical letters (*b-d*) and letters having similarities when rotated (*d-p*) on a letter identification task.

In the year 1896, a 14-year-old boy named ‘Percy’, despite being of normal academic performance, suffered from difficulty in learning to read and spell. No brain injuries, which could have been the source of his reading problems, were reported. At that time, Morgan (1896) postulated that a congenital defect could be a cause of this difficulty. He further explained that, this problem could be caused by a congenital defect in storing visual impression of words. James Hinshelwood (1900, 1917) also agreed with Morgan’s views; he gave a detailed description of the problem and considered it as a reading disability, characterized as “congenital word blindness”.

In 1925, Samuel T. Orton described this reading difficulty as strephosymbolia, or “twisted symbols”. He believed that strephosymbolia was a perceptual disorder where visual information is processed in a different way, such that “what is seen cannot be seen”. For example, this could be “seeing” the letter *b* as *d*, or *was* as *saw*. He also suggested that such difficulties were produced by a developmental delay in the establishment of hemispheric dominance and that the reversal errors reflected a cardinal symptom of the faulty development of cerebral dominance and inter-hemispheric communications. This developmental delay disrupts the development of the child’s ability to inhibit the mirror image and the counterparts of letters and even words. This assumed to lead to the optical

reversibility in visual perception of letter orientation and sequencing errors while oral reading and writing. Reversal errors are one of the most frequent problems related to developmental dyslexia. Individuals with dyslexia are very often confused when faced with letters which are identical in shape but different due to different spatial rotation/orientation (e.g. *b-d, p-q, b-q, d-p*) (Fisher, Liberman, & Shankweiler, 1978; Miles, 1993; Brendler & Lachmann 2001; Terepocki, Kruk, & Willows, 2002; Lachmann & Geyer, 2003; Badian, 2005). This problem is common for beginning readers and may disappear with a few years of reading experience. Orton (1925, 1928, 1929) identified three subtypes of reversal errors made in dyslexia:

(1) **Static reversals:** A visual difficulty in differentiating horizontally or vertically symmetrical letters, forming the combinations with symmetry or rotation (*b* versus *d*, *p* versus *q*, *b* versus *q*, and *p* versus *d*).

(2) **Kinetic reversals:** A tendency to confuse words which can be read both forwards and backwards, such as *was*, which can also be read as *saw*.

(3) The capability to process mirrored reading and writing.

The major gap in Orton's theory was that he never placed an emphasis on visual skills, as both visual as well as phonological skills are required in order to process a complex process like reading (Lachmann, 2002). Liberman et al., (1971); Vellutino (1977); Fisher et al., (1978) defined the importance of phonological processing in the area. Phonological segmentation, rhymes and other phenomena that require the processing of language have been shown to be more salient for the explanation of failures in reading development (Miles & Miles, 1999). As a result, most of the cognitive explanations of reading disability are based on the assumption of phonological deficits within the language processing system (Snowling, 2001). Reversal errors cannot be defined within the mono causal model (phoneme) of reading disability. Liberman et al., (1971); Fisher et al., (1978) have

emphasized the phonological aspect as a significant reason for reading disability. Phonological deficit theories of dyslexia are unable to fully explain the contradictory findings in the literature by only focusing on the phonological aspects of reading problems. Since many causal factors may affect reading, in this thesis we have examined multi-causal models for other important factors which may affect developmental dyslexia.

Letter reversal in the framework of Functional Coordination Deficit (Lachmann, 2002)

Reading is a complex cognitive technique which can only be explained by a multi causal model since reading is the coordination of visual functions, verbal (language) functions such as phonology, semantic and syntactic coding and decoding, guiding functions such as memory, attention and motor skills, and orthographic (word form) analyses. If any one of these many functions is faulty or lacks coordination with the others, then reading is not intact. Reading is seen as a primarily linguistic skill. According to the disability literature, reversals are assumed to be caused by a failure in binding together the visual and phonological information representation in memory.

Reading problems in dyslexics result from failure to assign a phonemic sound to the correct visual representation (Corballis & Beale, 1993; Lachmann, 2002; Lachmann & Geyer, 2003). Dyslexics are commonly confused by letters which have the same shapes but are represented with different rotations (e.g. *b* versus *d*, *p* versus *q*; Fisher et al., 1978; Miles, 1993; Willows & Terepocki, 1993; Brendler & Lachmann, 2001; Terepocki et al., 2002; Lachmann & Geyer, 2003; Badian, 2005).

According to the FCD model (Lachmann, 2002), reversal errors are explained as resulting from a failure in suppressing symmetry generalization in reading. Symmetry generalization is understood as an evolutionary bias in the developing infant towards an integrative, holistic representation of the visual world (Rusiak et al., 2007). Reversal errors are not

difficulties resulting from spatial processing of language symbols or objects; they are a problem resulting from an ambiguous graphemic-phonemic representation. This problem occurs when different letters have similar orientations when rotated or are mirror images, like *p* and *d*, *b* and *d*. This is one of the cases where symmetry generalization produces a problem. Failure to suppress such information during reading will produce wage relations between visual and phonological information. This disturbs the functional coordination of the phonemic and graphemic codes and causes challenges in learning to read (Lachmann, 2002).

Aim of the study

Reversal errors are very commonly associated with dyslexia, including: (1) reversing letters while reading and writing as in seeing *b* instead of *d*, termed *static reversal*, and (2) confusions with palindrome words (reversible words), such as seeing or writing *was* instead of *saw*, which is termed a *kinetic reversal*. Therefore, to test the responses of reading-disabled individuals on static reversals, we used the letters *b*, *d*, *p*, and *q* in different combinations and predicted that dyslexic individuals would show significant difficulty in differentiating letters which were horizontally or vertically similar (e.g. *b* and *d*) or similar because of rotation (e.g. *b* and *q*). We used different letter combinations including both types of similarities. For example, tasks included “for *bd* – press right arrow key and *pq* – press left arrow key” (symmetrical versus symmetrical) and “for *bq* – press right arrow key and *dp* – press left arrow key” (rotation versus rotation). These conditions would tend to be easier for dyslexics because they are making use of only one strategy at a time, either symmetry or rotation. However, when the letters were paired using both symmetrical and rotation similarities within the same condition, then the reading impaired would show difficulties in responding because they needed to differentiate between the letters using two strategies simultaneously, and this would make the task difficult and more

challenging for dyslexics compared to controls. We were interested to test the reversal error paradigm using Indian children diagnosed with dyslexia and age-matched controls. These children were non-native English speakers and English was the medium of education in the schools.

Method

Diagnostics

Identification of normally progressing readers and dyslexic readers was based on multiple measures, including a teacher's report in the form of a problem checklist, performance on reading tests assessing reading accuracy, speed, and nature of errors in Hindi (L1) as well as English (L2). Progressing readers were identified by the teachers of grades 3rd and 4th on the basis of academic performance and reading and writing skills as well as the teacher's report on the problem checklist (Tripathi & Kar, 2008). The experiment was carried out in three schools in Allahabad City, located in the northern Indian zone. The children identified by the teachers were further subjected to a formal assessment, including tests of such reading skills as word and non-word reading, reading and listening comprehension and a test of intellectual functions. Children, whose scores were greater than 80% on the reading tests of word and non-word reading and reading comprehension, and who had average or above average intellectual functions, were considered to be normally progressing readers. Dyslexic readers were also initially screened by the class teachers of the 3rd and 4th grades across three schools using the problem checklist (Tripathi & Kar, 2008) and were subjected to the same reading assessment battery used to identify normally progressing readers. Children who were found to be average or above average (defined as on or above the 50th percentile on CPM) on intellectual functions and those with adequate listening comprehension, but who scored two standard deviations below the mean performance of normally progressing readers on reading tasks, particularly word and non-

word reading, were considered to be dyslexic readers. From these, only 14 students classified as having dyslexia participated in the study. The combined accuracy scores from each separate reading test of normally progressing readers and dyslexic readers were found to be normally distributed. Among all the reading measures, word and non-word reading tests were found to be more accurate in classifying normally progressing readers and dyslexic readers (for details, see Appendix I).

Participants

Altogether, 27 Indian children (mean age: 9.8 years), 14 dyslexic children (four females) and 13 controls (five females) participated in the study. All participants were reported to have normal vision or corrected to normal vision. The study was conducted in English-speaking schools in Allahabad, Uttar Pradesh, India. The English language had been the medium of education for all participants since kindergarten (KG). Written consent was obtained by the school authorities in order to conduct the study. The study was approved by the University of Allahabad's Human Participation in Scientific Research Ethical Committee.

Material and Procedure

The experiment was performed in schools in a dimly lit room with minimal environmental noise. Stimuli were presented using Direct RT experimental software approved by the American Psychological Association. The experiment was performed on a 15'' laptop computer positioned approximately 50 cm from the participant, resulting in a visual angle of 2.9 degrees, without head fixation. The study was conducted in two sessions, using four different response categories, consisting of combinations of letters. The participants' responses on a visual choice reaction task were recorded. Four lowercase letters, *b-d* and *p-*

q, were used in the study with two different contrast conditions, low and high. Each letter was presented in black on a white background. On each trial, one of the four letters was presented at the center of the screen, followed by the visual fixation cue. All participants were instructed to respond by pressing the appropriate left or right arrow keys for the various letter combinations (e.g. *bd* (left) versus *pq* (right) and *bq* (left) versus *dp* (right)). Response categories and response keys were counterbalanced over the participants. The contrast was used as an additional variable for the experiment, and each letter was presented using two different contrast conditions: (1) high contrast (48%) and (2) low contrast (4%). For every participant, appointments were made for two consecutive days, and, on average, participants took 40 minutes to complete one experimental session (see Figure 3.1).

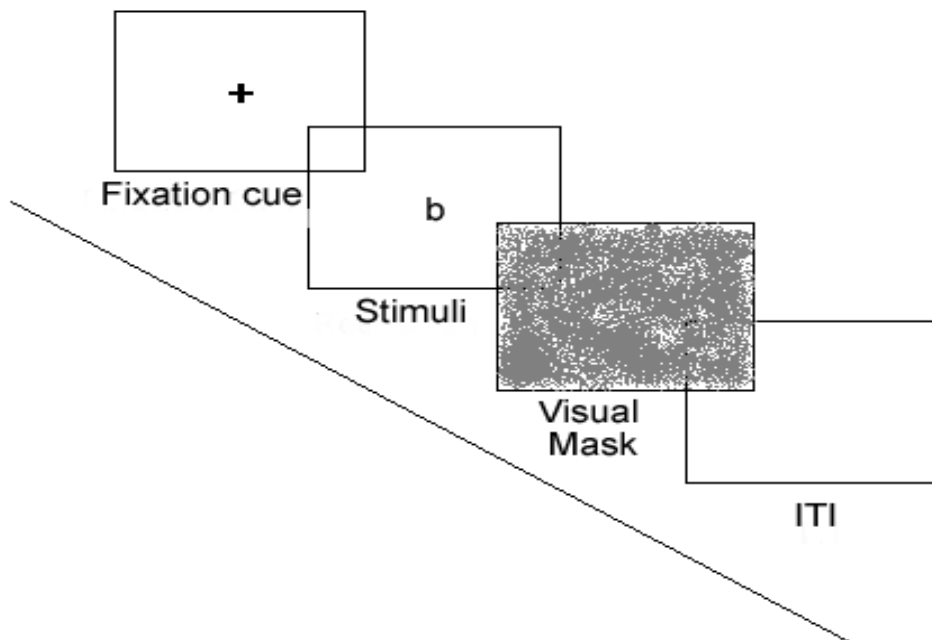


Figure 3.1. The procedure for stimulus presentation.

Reaction times								
	Low Contrast				High Contrast			
	bd	pq	bq	pd	bd	pq	bq	pd
Dyslexics	1583.84	1651.30	2229.836	2363.551	1399.053	1463.155	2144.417	2173.319
Controls	990.261	980.930	1612.083	1611.141	903.1449	954.3614	1417.60	1387.980
Standard deviation (SD)								
	bd	pq	bq	pd	bd	pq	bq	pd
Dyslexics	467.810	533.563	581.1	589.25	456.523	537.759	583.250	654.680
Controls	251.526	214.634	637.987	559.866	223.029	260.993	492.661	410.445

Table 3. Mean reaction times for dyslexics and controls across conditions.

Results

A repeated measure Analysis of Variance (ANOVA) was performed on the correct reaction times of dependent variables including (outlier criteria being Rt 's more than 145 ms and less than 8000 ms):

- Response Category (*bd*, *pq*, *bq*, *pd*), and
- Contrast(low and high contrast) as the within-subject variable, and
- Group (dyslexics and controls) as between-subject variables.

The main effects of Response category, $F(3, 75) = 47.006$, $p = 0.000$, Contrast, $F(1, 25) = 43.190$, $p = 0.000$, and Group, $F(1, 25) = 16.008$, $p = 0.000$ were found to be significant. Dyslexics (mean RT = 1877, SD = 114.74) were slower in comparison to controls (mean RT = 1232, SD = 93.6). Interestingly, a triple interaction between Response Category x Contrast x Group showed a tendency towards significance, $F(3, 75) = 2.533$, $p = 0.063$.

Two factorial within-subject ANOVA's in each group were performed. Controls, $F(1, 12) = 22.265$, $p = 0.000$, and dyslexics, $F(1, 13) = 22.165$, $p = 0.000$, and both showed a significant difference for the variable Contrast. Controls, $F(3, 36) = 26.256$, $p = 0.000$, and

dyslexics, $F(3, 39) = 23.622$, $p = 0.000$, also showed a significant difference for the variable Response Category. On the other hand, controls showed a significant double interaction of Contrast x Response Category, $F(3, 36) = 4.588$, $p = 0.008$, which was not true for dyslexics. Furthermore, adjustment for multiple comparisons was done using the Bonferroni correction to perform pair wise comparisons for the variables Contrast and Response Category. Overall, participants were slower in responding to the low contrast condition (mean RT = 1640, SD = 539.01) in comparison to the high contrast condition (mean RT = 1492, SD = 514.89). A significant difference was found between high and low Contrast for controls, $p = 0.000$ (low contrast mean RT = 1298.60, SD = 392.12, high contrast mean RT = 1165.74, SD = 319.35), and for dyslexics, $p = 0.000$ (low contrast mean RT = 1957.13, SD = 462.91, high contrast mean RT = 1794.98, SD = 480.40); see Figure 3.2. Both groups showed insignificant differences for the conditions *bd* versus *pq* and *bq* versus *dp*, all $p = 1$ (see Table 3 for mean RTs and SD). Further, controls (see Figure 3.3) and dyslexics (see Figure 3.4) showed a significant difference between *bd* versus *bq* (dyslexics, $p = 0.000$, controls, $p = 0.001$), *bd* versus *dp* (dyslexics, $p = 0.000$, controls, $p = 0.000$), *pq* versus *bq* (dyslexics, $p = 0.001$, controls, $p = 0.000$) and *pq* versus *dp* (dyslexics, $p = 0.000$, controls, $p = 0.000$).

As mentioned above, a triple interaction indicated a tendency (Response Category x Contrast x Group). The data were also analyzed to check these effects. Controls and dyslexics both showed insignificant differences for the condition (1) *pq* (high and low contrast condition), $p = 1$ (see Figure 3.4 and 3.3). Dyslexics and controls both showed significant differences for (2) *bd* (high and low contrast), $p = 0.003$ (controls) and $p = 0.002$ (dyslexics), (3) *pd* (high and low contrast), $p = 0.004$ (controls) and $p = 0.009$

(dyslexics), and controls also showed significant difference in (4) *bq* (high and low contrast), $p = 0.007$, while dyslexics did not, $p = 1$.

On average, dyslexics and controls both displayed an error rate of less than 5% while responding to the letters. Analysis of variance was also performed on error rates for both the groups on the above mentioned independent variables. This variable contrast was significant, $F(1,25) = 4.329$, $p = 0.048$, but no other variable nor any interaction was found to be significant.

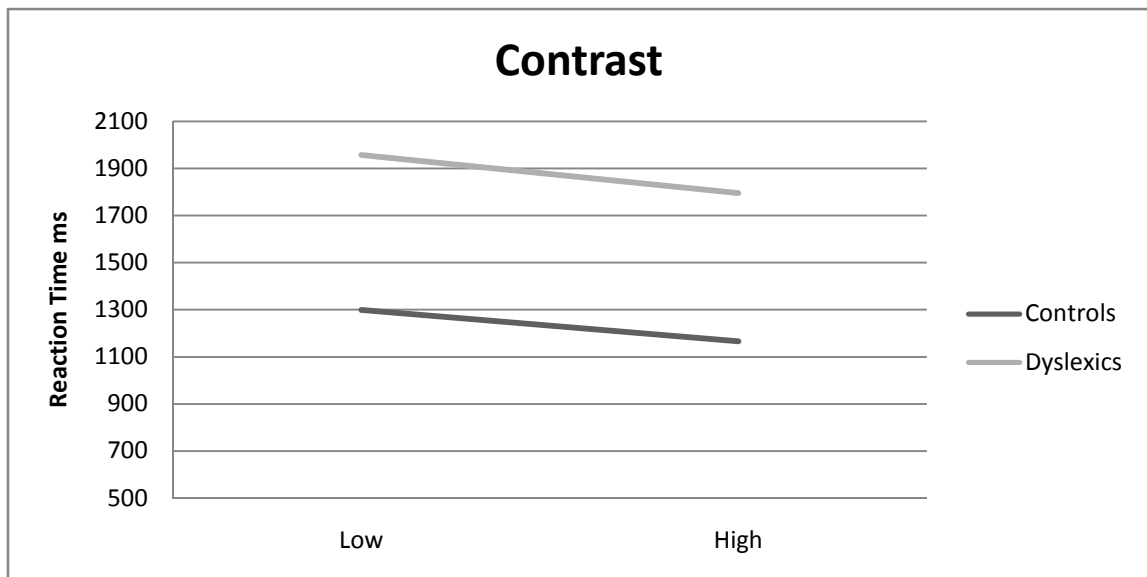


Figure 3.2. Correct reaction times for dyslexics and controls for the contrast condition (low and high).

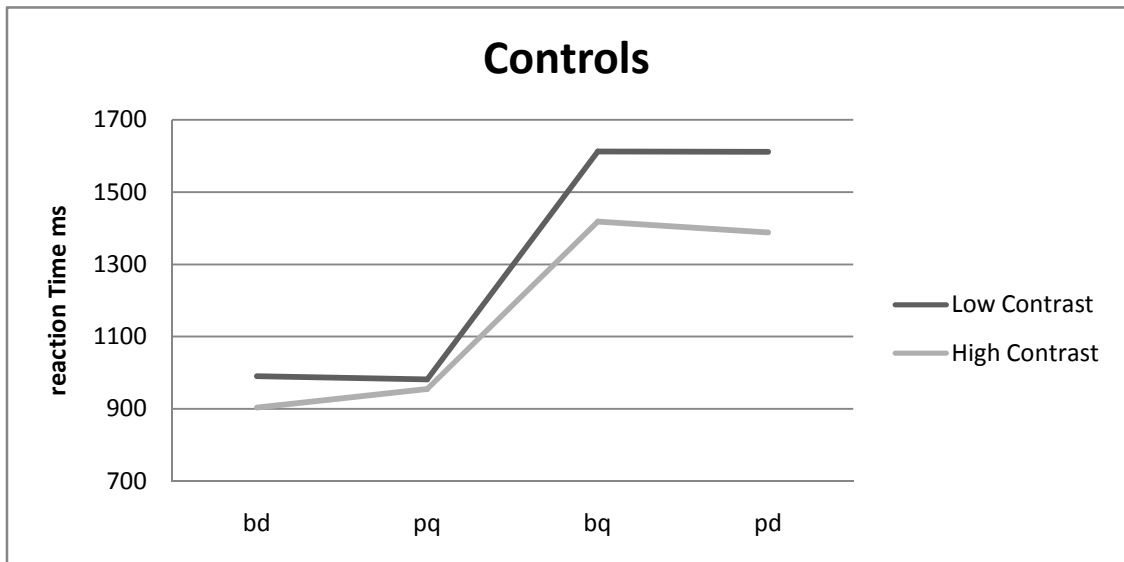


Figure 3.3. Correct reaction times of controls for the response categories.

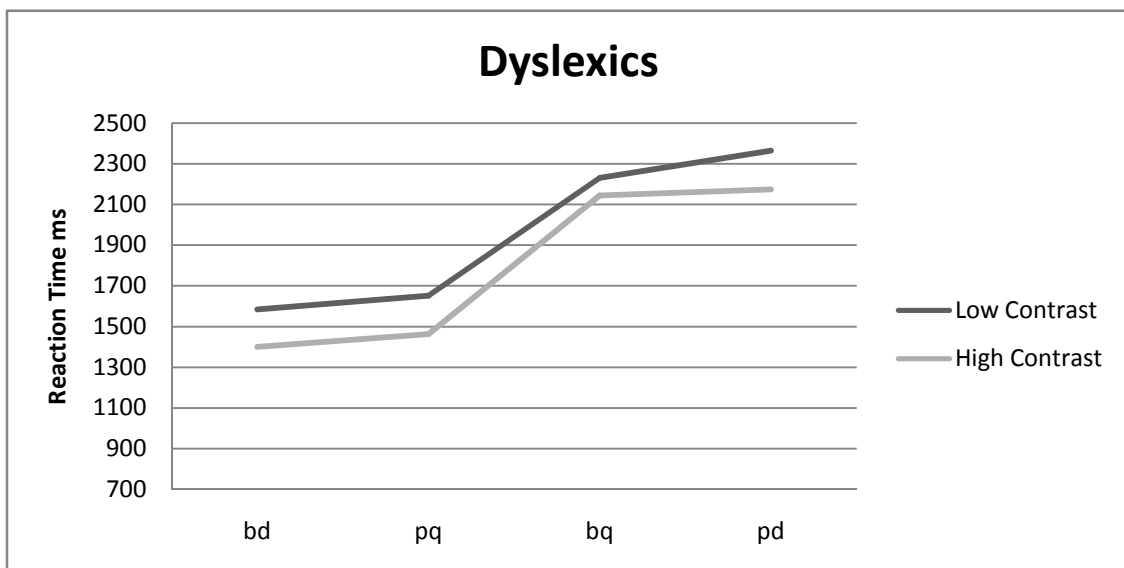


Figure 3.4. Correct reaction times of dyslexics for the response categories.

Discussion

The present study aimed to establish the difference between age-matched dyslexics and controls on a letter identification task. As mentioned above, the task was a choice reaction task where two different types of response buttons were assigned to two types of response categories for a total of four letters, two of them having one common response key. The

response category was designed on the basis of (1) reversible similarity (vertical or horizontal symmetry) and (2) rotation (similarity on the basis of orientation). Dyslexic participants were slower in comparison to controls, responding to the letter identification with response patterns similar to those of the control group. Dyslexics showed significant differences between low contrast and high contrast conditions, and they were faster on high contrast tasks. Dyslexics also showed a similar pattern of responses to controls in these conditions. Dyslexics were slower on contrast conditions compared to controls, but the pattern of responses was similar for both groups (see Figure 3.2). This could be explained in the framework of the magnocellular theory of dyslexia (Stein, 2001). Lovegrove et al., (1980) found that the contrast sensitivity of dyslexics is impaired when compared with controls (Mason, Cornelissen, Fowler, & Stein, 1993). Dyslexics have more difficulty identifying things in a low contrast condition due to the impairment in the M pathway (Stein & Walsh, 1997; Stein & Talcott, 1999).

Dyslexics and controls also showed similar responses in the condition response categories (see Figures 3.3 and 3.4). When response categories were similar on the basis of horizontal or vertical symmetry or in rotation, then the effects were insignificant. When symmetry and rotation were both present within the two response categories, the effects were found to be significant irrespective of the letter. In other words, symmetry versus symmetry or rotation versus rotation was found to be insignificant, and symmetry versus rotation and rotation versus symmetry were significant.

Dyslexics and controls were faster in the condition of symmetry versus symmetry and rotation versus rotation. Since they had to use one strategy at a time, they might possibly be using a visual strategy to respond to the task associated with symmetry. Dyslexics and controls both showed significantly faster responses for the condition symmetry versus symmetry compared to rotation versus rotation; the reversible letters or letters which have

similar mirror images being assigned common response keys facilitated performance. This may explain why the response time was lower for symmetry versus symmetry than rotation versus rotation. Rotation versus rotation was difficult, because the letter combinations were not reversible, but rather rotated (180°). In this condition, dyslexics and controls were required to scan every character, match the letters with the template stored in their brain, and create a response. Here, the visual similarity was no longer helpful; they had to store the information of the visual structure of the letter and its association to the response keys. They treated letters as symbols and not as objects (Chomsky, 1959; see also Klix, 1985; Byrne, 1995; Deacon, 2000; Friederici & Lachmann, 2002; Lachmann, 2002). Responses to identical letters are assumed to be a symptom of deficits in the coordination of visual and phonological decoding (dyslexia). The failure to suppress visually identical information in the representation of visual symbols such as letters may produce faulty relationships between visual and phonological information. This could in turn disturb the functional coordination of processing of a letter between grapheme and phoneme conversion, which could be one of the major reasons why dyslexic participants showed delayed responses (FCD model by Lachmann, 2002).

For symmetry versus symmetry, the task was automated wherein the information about visual structure had to be stored with the respective response keys (left button for up and right button for down). In the rotation versus rotation condition, both types of the visual structure of letters were present in a single response category (left for up and down and right for up and down). The results were consistent with the findings of Orton (1925) that dyslexic individuals display a significant difficulty in differentiating letters which are horizontally or vertically symmetrical to each other or rotated. They are also consistent with the findings of Brendler & Lachmann, (2001) that controls and dyslexics had greater

difficulties in differentiating between the orientations of the letter. These findings are interpreted as an indication of problems in the learning mechanisms.

The response category symmetry showed a significant difference in rotation, and again the above-mentioned explanation applies; responses were faster for the reversible letters, or symmetries, in comparison to rotated (Pornstein & Krinsky, 1985; Wenderoth, 1995; Herbert & Humphrey, 1996). The behavioral relevance of the orientation of the symmetries may be the result of frequently synchronized activations which depend upon the behavioral relevance of the memory unit (anagram) represented by the neural cell assembly, which is activated by the symmetrical version of the object (Hebb, 1949; Lachmann, 2002). Here, we could claim that because of symmetries present in the letters (reversed or rotated), phonological deficits cannot be the only cause of such problems, but that these problems are related to an inadequate suppression of generalized symmetry information. These suppression processes could be addressed by a training process.

Conclusion

Delayed responses to the contrast condition seen in people with dyslexia could be explained as a problem associated with the M-pathway. The neurons in the M-pathway for dyslexics are not linearly aligned, and the number of neuronal connects are also less than those of controls. This could be a reason why dyslexics showed delayed responses to the contrast condition. Further, delayed responses of dyslexics in the response categories involving similarity on the basis of symmetry were found to be more difficult compared to rotation, which could be interpreted as an indication of problems in the learning mechanism itself. One of the primary reasons why dyslexics showed delayed responses was faulty relationships between visual representations of the letter stored and associated

phonology, which interferes with the normal processing of letter representation. Thus, delayed responses could be due to this faulty connection.

CHAPTER 4

Reading Structure from Motion

Introduction

In the previous chapter, we tested dyslexics and age-matched controls on a letter identification task using identical letters with various combinations of visual and phonological similarities. This chapter led us to investigate the perception of dyslexics of meaningful words in motion. This chapter proposes that dyslexics have difficulty identifying the lexical information in motion due to the problem in their Magnocellular pathway (M pathway) of vision. Human vision performs a grouping of elements based on figure-ground segregation. The region, which has defined shape and boundaries, viewed as the figure, and the region that lies behind the defined shape, which is continuous in nature, processed as background. Many visual cues contribute to figure-ground segregation:

- Symmetry
- Area
- Convexity
- Common fate
- Proximity
- Similarity
- Flicker synchrony

For example, a lower region in an ambiguous figure-ground display is more likely to be perceived as figure than the upper regions (Vecera, Vogel, & Woodman, 2002). The figure and ground perception involve two different types of image analysis. Extracting edges and assigning them to regions of interest as figures or objects is important for effective segmentation. Figural assignment also depends on perceived differences in qualities such as luminance, color, motion, and texture between two regions. This implies that figure-

ground segregation critically depends on surface representations in addition to edge-based processing. Weisstein and colleagues (Weisstein, Maguire, & Brannan, 1992) have emphasized the role of spatial and temporal frequencies in figure-ground segregation (Klymenko & Weisstein 1986; Wong & Weisstein, 1987; Klymenko, Weisstein, Topolski, & Hsieh, 1989; Weisstein et al., 1992). They found that regions filled with high spatial frequencies tend to be perceived as figures, whereas regions filled with relatively low spatial frequencies tend to be perceived as ground.

According to Weisstein et al., (1992) it is assumed that there are two distinct types of feature analyzers, those which prefer lower spatial and higher temporal frequencies, and those which prefer higher spatial and lower temporal frequencies. The division, which prefers lower spatial and higher temporal frequencies represents the ground, or locations in the image that appear to be farther, and will be called M for the magnocellular pathway. The other class will be named P, for parvocellular pathway, and represents figures or surfaces in the image plane that appears to be closer. The experience of figure and ground segregation is due to the correlated activity of these two channels. These representations are continuous, and there are additional computations made by the human visual system in order to obtain the binary classifications of figure and ground.

M-cells are more sensitive to motion, depth, low spatial and high temporal frequencies and low-contrast information (Cavanagh, Tyler, & Favreau, 1984; Livingstone & Hubel, 1987). P-cells are comparatively more responsive to color, form, high spatial and low temporal frequency, finer detail and high contrast information (Schiller & Logothetis, 1990). Red backgrounds relative to green and blue backgrounds increase the response latency of the human M pathway (Breitmeyer & Williams, 1990). All these functional distinctions

establish a connection for perceiving visual information between ground (M-pathway), and figure perception (P-pathway; Weisstein et al., 1992).

One of the most interesting things about the human visual system is the perception of color. Color vision begins at the point where light is absorbed in the retinal photo cone receptors, whose primary aim is to transduce this electromagnetic energy into electrical voltages. A complicated system of cells converts this voltage into action potential, and the information is transmitted to the lateral geniculate nucleus (LGN). The LGN is a unique structure in the visual system, as it has been psychophysically identified that several fundamental computations related to color, form and motion occur in the LGN. This processing is carried to the cortical areas of the brain. Color vision emerges through the combined activity of neurons at different levels.

Motion perception serves several important functions. It provides the visual system with information concerning the relative velocity, or speed and direction, of objects in the visual environment. Even animals equipped with poor visual acuity can detect form through motion, because any movement in the environment could signal the presence of a predator or prey. At the level of the LGN, the processing of color, form and motion starts and, at this level, it is not possible to separate the coding of visual attributes, such as processing of form and motion as opposed to that of color. According to Weisstein (Weisstein et al., 1992) and colleagues, hypothesised that, the M-activity is suppressed due to the presence of red color or the subsequent assignment to the regions filled with red as the ground. The M-pathway is connected to the perception of motion, and when a region is filled with red color the M-pathway activity is generally suppressed and the activity of the P-cells comes into prominence. This results in the identification of the form much more quickly and

easily as compared to the absence of the effect of the color red. Based on this hypothesis, we have explored the phenomenon of structure-from-motion in the presence of color.

Magnocellular Deficit and Reading

People who suffer from dyslexia have difficulty detecting things in motion in comparison to controls. To make a direct comparison, behavioral studies are needed. Many studies focus on macaque monkeys with specific lesions to the M and P cellular visual pathways. These monkeys have a neuroanatomically similar structure to humans, simplifying the comparisons of anatomical and electrophysiological data from these species to the human vision system. In both species, two types of ganglion cells access the visual information transmitted from the retina. These are:

1. **Magnocellular (M) cells** are more sensitive to motion, depth, low spatial and high temporal frequency (ground), and low-contrast information (Cavanagh et al., 1984; Livingstone & Hubel, 1987).
2. **Parvocellular (P) cells** are comparatively more responsive to color, form, high spatial and low temporal frequency (figure), finer detail and high contrast information (Schiller & Logothetis, 1990).

These two cells are located in the layers of the lateral geniculate nucleus (LGN) of the brain region named as the thalamus. The information obtained from M and P cells is further distributed. In the year 1991, Livingstone and his colleagues compared M and P cells in the layers of the LGN from dyslexic individuals and controls. No differences were found in P cells for controls and dyslexic children. However, when comparisons were made of M cells, they found that, in dyslexic individuals, the M cells were found in smaller

amounts and the size of the cells were relatively small compared to controls. This finding further highlighted how the anatomical abnormality of M cells in the dyslexic brain can also cause problems such as motion blindness (Schiller & Logothetis, 1990). The above findings suggest that a magnocellular deficit can explain reduced motion sensitivity and reading problems in people suffering from dyslexia.

Magnocellular Theory of Dyslexia (Stein, 2001)

In general, as a process, reading is complicated and requires good orthographic skills for the recognition of the visual form of words so that meaning can be understood. In addition to this, reading requires developed and automated phonological as well as visual skills to differentiate between familiar and unfamiliar words after acquiring the language skills required for reading. In the human brain, many asymmetries are also present, which may vary with the nature of the task as either the left or the right hemisphere may offer an advantage. For reading, the controls will have the advantage of the left hemisphere over the right (Demonet, Wise & Frackowiack, 1993). Tempo-parietal language areas at the tempo-parietal junction are responsible for language processing, but the dyslexic's brain is without any left-side advantages (Galaburda, LeMay, Kemper, & Geschwind, 1978). About temporal processing of events, guided from visual action, the M pathway is also responsible for the temporal processing and timing of visual events while reading. Dyslexic readers have delays in processing the reading task, and an M cell deficit could be a reason for their delayed response. M layers of the LGN are underdeveloped in dyslexics, having fewer cells in a smaller diameter (Stein, 2001). Due to this, dyslexics may experience reduced motion sensitivity, and the binocular fixations could be unsteady as well, which could lead to the poor visual localization of letters in the space (Eden, VanMeter, Rumsey, Maisog, Woods, & Zeffiro, 1996).

One of the important functions of the M system is to help in controlling eye movements. As mentioned above, it is argued that dyslexic individual has an impaired M system which might result in destabilizing binocular fixation and poor binocular control (Stein & Walsh, 2007). This could mean that for dyslexics letters appear to cause visual confusions (*b* is seen as *d*) and could also give a moving effect. Dyslexic individual has unstable vision, which makes them more likely to make visual errors while reading. Our M cell system helps us to fixate at one position with both eyes, and the higher the sensitivity of M cells, the higher the fixation. The binocular static fixation also ensures that the letters appear properly while reading. Dyslexic readers tend to make relatively fewer errors when they have to process the visual information with one eye. The reason could be understood as monocular occlusion, where one eye is protecting the visual information to prevent the moving around effect that occurs with both eyes in binocular occlusion. Thus, reading with one eye can also reduce the quantity of visual errors made by dyslexics, and this continuous practice over a few months can permanently improve their fixation (Stein & Fowler, 1985). Furthermore, binocular vision creates instability by presenting competitive versions at the locations of the letters. Therefore, reading with one eye blindfolded improves reading ability (Fowler & Stein, 1979; Cornelissen, Bradley, Fowler, & Stein, 1992; Stein et al., 2000). In addition, Breitmeyer (1993) suggested that the M activity during each saccade (eye movement) is also important to erase the previous fixation. Humans having a weak M cell system may fail to do this, leaving the previous visual fixation still active, possibly leading to a superimposed effect of the current and the previous fixation. Children also easily confuse a letter with the neighboring letters. The minimum distance possible should be covered which still leaves a space for reading saccades, as children tend to confuse letters more often when letters are separated by 6-7 millimeter (mm). The M cells are also more salient for dyslexics individuals because this

system reaches the thalamus 7-10 ms sooner than the P cells (Maunsell & Gibson, 1992; Kranich & Lupfer, 2014). With the help of M cells, the visual motion sensitivity of a child helps to find the correct order of letters in a word. If a child has a low M cell sensitivity, it results in reduced visual motion sensitivity, reduces speed and increases the number of errors while making a judgment on the correct order of letters in a word, especially when seeing briefly presented neighboring letter anagrams (e.g., *rain* versus *rian*; Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998; Stein, 2001).

Overall, the M system is the hub of visuo-motor capabilities which resides in the posterior parietal cortex. The superior colliculus and cerebellum receive delayed signals. This means that for dyslexics, M cells receive less input from the muscles controlling the eyes (utricular control), delayed responses are experienced and less stabilize fixation is produced, especially when the eyes are converged at 30 cm while reading. This could be a plausible reason why the vision lines of dyslexics cross over each other, and the same phenomenon could be experienced with the letters. That is why dyslexics often reverse the order of letter attributes, confuse *b*'s with *d*'s and reverse the order of the letter presented. Hence, the magnocellular system has a greater impact while reading. This is why dyslexics often complain that letters seem to be dancing or blurring.

On the other hand, the cerebellum has a very important role in the ganglion cell family (M cells); because it is also responsible for the binocular fixations, it also contributes to controlling the motor moments of the eye to fixate at one point. Dyslexics also have an issue with the connection between the cerebellum and ganglion cells, which often leads to the problem of automatic shifting of the eye gaze into space.

The other aspect of magnocellular pathway is that, it plays a vital role in low contrast information and high temporal and low spatial frequency, which is responsible for figure

perception (Livingstone et al., 1991; Stein & Walsh, 1997; Stein & Talcott, 1999). Dyslexics also experience challenges, identifying things with reduced contrast (Lovegrove et al., 1980) and in differentiating between figure and ground. Dyslexics are also impaired when distinguishing between letter sounds and tonal modulation in speech while reading because they are insensitive to perceiving high frequency and amplitude modulation (prosody). This insensitivity can also explain the problem related to phonology.

Aim of the study

The anatomical differences between dyslexic and normal brains can only be differentiated before the information reaches the primary visual cortex (area V1 in the occipital lobe); beyond this point, no differentiations can be made because here the information is combined and processed. Information from the magnocellular pathway provides key input to the visual areas of the Medial Temporal Cortex (MT), sometime also called V5, responsible for analyzing movement of objects and their location in space (Milner & Goodale, 1995). The M and P cells contribute to the early processing of form, color and motion, which contributes to the separation of figure and ground. The processing of these cells is not unique and there is considerable overlap between them. Considerable research has gone into the understanding of perception based on structure-from-motion. However, little of it has explored the perception of motion from the standpoint of figure-ground separation. Dyslexics often complain that letters seem to be blurred or dancing, and this is because of the instability of their visual system (Eden et al., 1994). This study aims to explore how when dyslexics see the lexical information in motion, despite being impaired in the task, they can still correctly respond to motion. We have also introduced the red background relative to a green background to examine whether color information increases the response latency of the human M system. We will also explore whether dyslexic individuals will perform better with the task or if they will find the task more complicated

due to the M deficit. For controls, diffuse red light will suppress the activity of the transient M activity (De Monasterio, 1978; Wiesel & Hubel, 1966).

Method

Stimuli

For details of the diagnostic process used in this experiment, see Chapter 3, Method section, and refer to Appendix 1. An image consisting of a red or green background made up of broken stationary black lines to create noise at 13.13 deg x 14.04 deg was shown at the center of the screen. The luminance of the red and green colors was physically matched (33.9 cd/m² and 33.6 cd/m²). Words were made up of broken stationary black lines and perfectly camouflaged with the background noise (broken lines). The experiment contained 60 different four-letter words, both nouns and verbs (Appendix II). They constituted 3.8 deg x 8.06 deg visual angles, and were only discernible when they moved from left to right or vice versa. The distance between the monitor and the observer was approx 50cm (see Figure 4.1).

Procedure

Altogether, 28 Indian children (mean age: 9.32 years), 14 dyslexic children (four females) and 14 controls (six females) participated in the study. Details of the process of identifying dyslexics and controls in India are discussed in Appendix 1, and Figure 4.4 contains details about the intercept plot for the controls and dyslexics who participated in the current study using red and green backgrounds. All participants in the current experiment were reported as having normal or corrected to normal vision. The study was conducted in English speaking schools in Allahabad, Uttar Pradesh, India. The English language had been the medium of education for all participants since kindergarten (KG). Written consent was

guaranteed by the school authorities in order to conduct the study. The University of Allahabad's Human Participation in Scientific Research Ethical Committee approved the study. The stimuli were in the form of movies where four-letter English words moved from left to right or right to left. These stimuli were presented using Direct RT stimulus presentation software. The software recorded the type of stimulus presented, presentation time, response time, and accuracy. The experiment was carried in a dimly lit room on a 15" laptop with a refresh rate of 60 Hz. The maximum stimulus (movie) presentation time was 35000 ms. The experiment consisted of 60 trials. For each participant, half of the trials were presented in red and the other half on green backgrounds, and background color and words were counterbalanced across the participants. The words were initially still for 2000 ms before they began moving. The task was to press the left arrow key as soon as the moving word was identified. When the key was pressed, a blank screen appeared with a text box and the participant typed the identified word. With children (dyslexics and controls), the experimenter typed the words in the text box as named and spelled by the participant. A self-driven key was pressed to begin the next trial (see Figure 4.1). Each participant received four practice trials before the main session began, including two words with each color. These words were not used in the main experiment session. The trials were randomized. Before the session, the experimenter briefed the participants and gave detailed instructions about the experiment. After the session, the participants were also debriefed about the experiment and their feedback was noted.

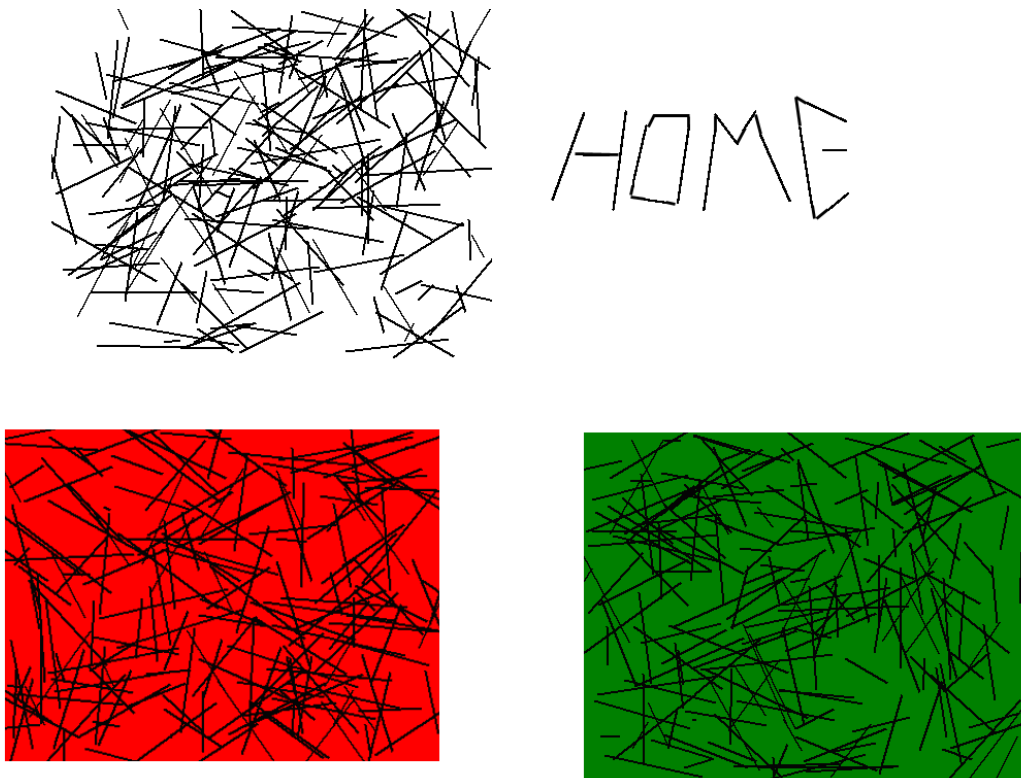


Figure 4.1. The background noise and the construction of words used in the experiment (list of words can be found in Appendix 2) on red and green backgrounds.

Results

Correct reaction time on the word recognition task between groups (dyslexics and controls) against red and green diffused backgrounds (color) was computed. A two-way factor analysis of variance (ANOVA) for word recognition against the red and green backgrounds was performed. The independent variable Color, $F(1,26) = 4.836$, $p = 0.037$, and Group, $F(1,26) = 40.878$, $p = 0.000$, showed significant effects. Interestingly, the interaction

between background Color and Group $F(1,26) = 3.920, p = 0.058$, was also found to be significant. Overall, dyslexics (mean RT = 3582 ms, SD = 95) were slower in comparison to controls (mean RT = 2491ms, SD = 39) in responding to the word recognition task. Dyslexics showed significant main effects of the variable Color, $F(1, 13) = 8.026, p = 0.014, (t(13) = 40.348, p = 0.014)$. No significant difference was found for Controls for red (mean RT = 2499ms, SD = 595) and green (mean RT = 2483ms, SD = 539) background $t(13) = .162, p = .873$. Adjustment for multiple comparisons was done using the Bonferroni correction to perform pair-wise comparisons of the variable Color for dyslexics. Significant differences were found in red and green background color, $p = 0.14$. Dyslexic participants were significantly slower (see Figure 4.2) responding to red (mean RT = 3728 ms, SD = 453) in comparison to the green background (mean RT = 3436 ms, SD = 319). An interaction between Color x Group was significant because both groups responded differently to the red and green background colors. Slower responses by dyslexics are discussed further in the discussion section of this chapter. The Intercept point for controls and dyslexics for red and green backgrounds (see Figure. 4.4).

Errors were also computed in order to understand the effect of the word recognition task on the two different background colors. The main group effect was found to be significant $F(1,26) = 14.156, p = 0.000$. No effects of color, nor the interaction between Color and Group, were found to be significant (see Figure 4.3).

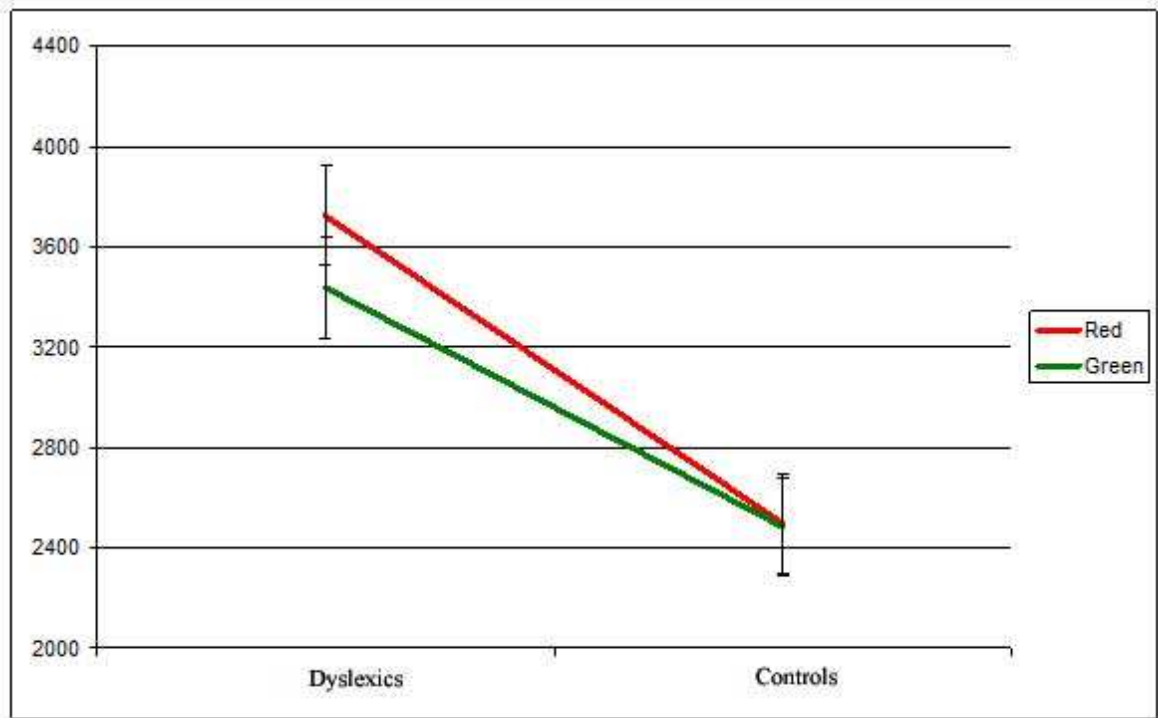


Figure 4.2. Corrected reaction times (Y axis) for dyslexics and controls (X axis) for red and green backgrounds.

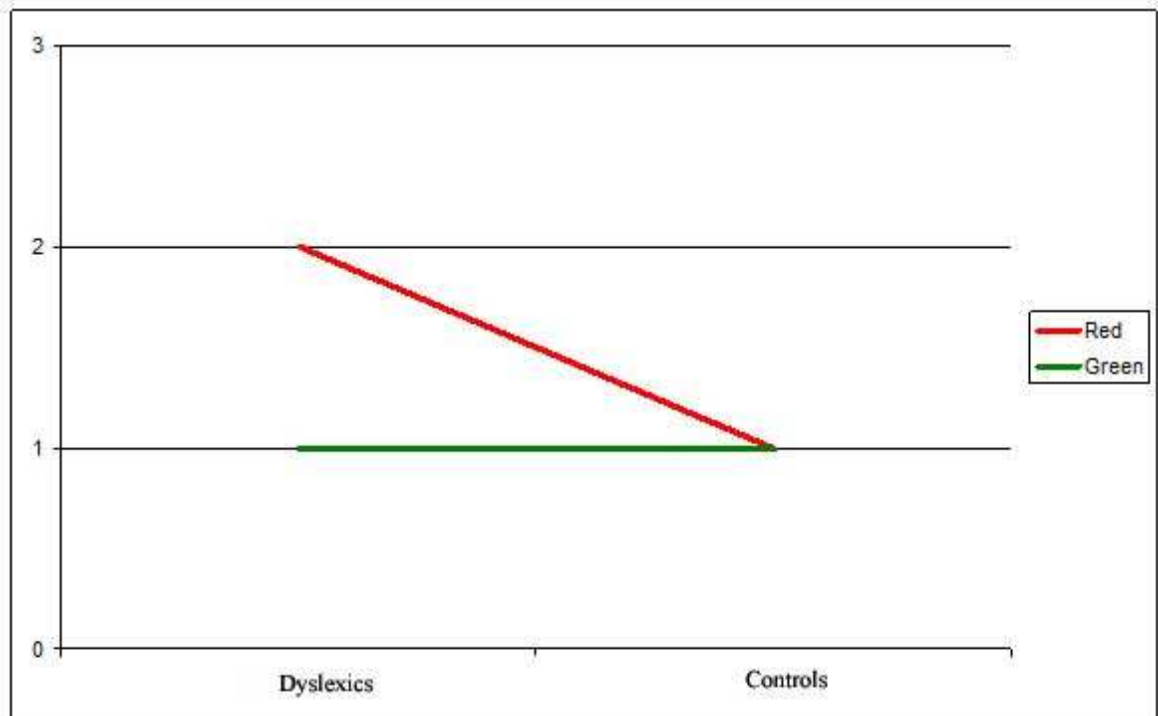


Figure 4.3. Error % (Y axis) of dyslexics and controls (X axis) for red and green backgrounds.

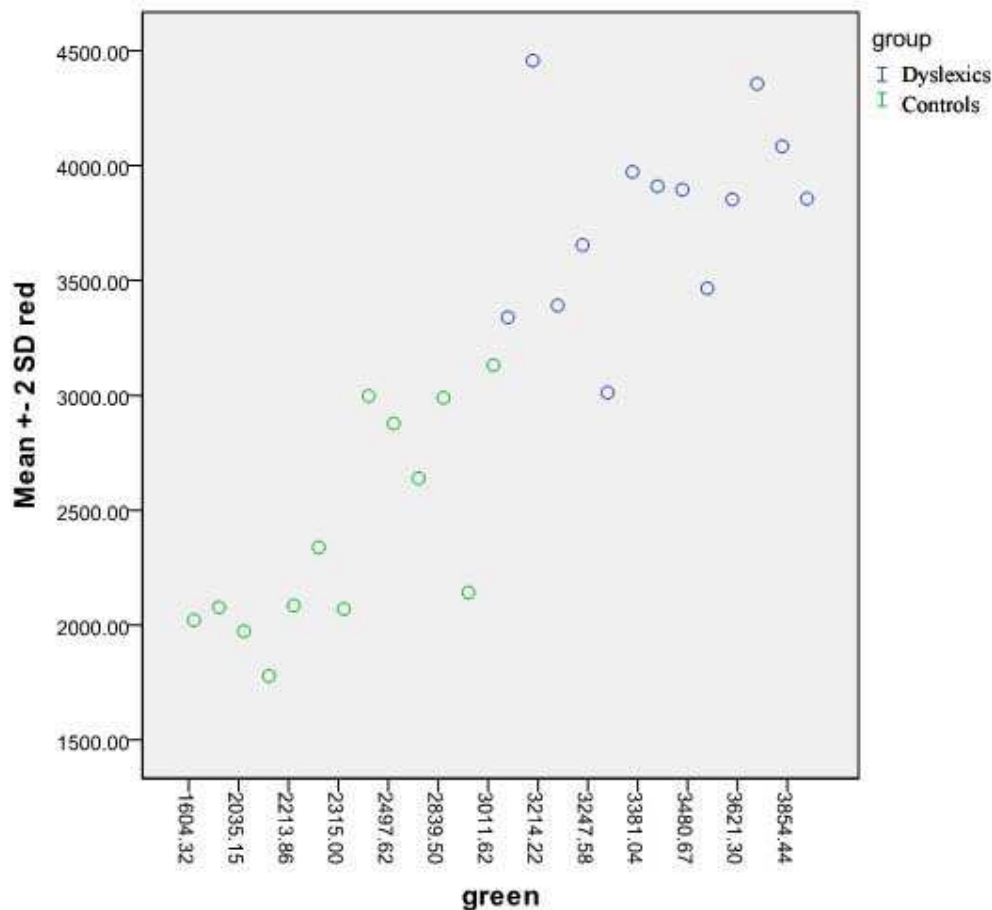


Figure 4.4. Intercept point for controls and dyslexics for red and green backgrounds.

Discussion

On the basis of the current literature, we had predicted that dyslexics would be impaired in the motion lexical task because of the problem associated with motion perception (Stein, 2001). Dyslexics took a significantly longer time in responding to the motion task compared to controls (Livingstone et al., 1991; Stein & Walsh, 1997; Stein & Talcott, 1999). M cells are more sensitive to motion, depth, low spatial and high temporal frequency (ground), and low-contrast information (Cavanagh et al., 1984; Livingstone & Hubel, 1987). The reason for the impairment of dyslexics in a motion lexical task is that the magnocellular layers of the LGN of the thalamus are disoriented, and the neurons are relatively smaller in a confined area when compared to controls (Livingstone et al., 1991;

Galaburda & Livingstone, 1993). This explains the reduced motion sensitivity of people suffering from dyslexia, reflected by the delayed response times.

The P cells of the LGN are responsible for color, form, high spatial and low temporal frequency (figure), finer detail and high contrast information (Schiller & Logothetis, 1990). In our study, we used two contrast-matched background colors, red and green. Controls did not show a significant difference in responding to these colors. Red is considered to be salient because of its long wavelength of approx 700 nanometers (nm), while green belongs to a relatively short wavelength of approx 500 nm. According to the Weisstein et al., (1992) model, impairing the functioning of the M-P Cells of the LGN allows the activity of the P-cells to be at an advantage. In our experiment, the M-pathway was found to be involved in the lexical motion task, and diffused red light did not increase the activity of the P pathway for controls. On the other hand, the lexical motion task was a less sensitive measure than the effects of background color on M-channel activity, which is why no significant effects were found for background colors for controls.

Dyslexics showed significantly long reaction times for red in comparison to green backgrounds. Dyslexics generally do not have any difficulty with the perception of colors, because color perception is a function of the P pathway, which is intact. Dyslexics have impairments for tasks associated with the M-pathway. Using the red background decreased the M activity for dyslexics, and thus the task of recognizing words in motion was made even more difficult. Therefore, the reaction times increased and dyslexics were slower in responding to the lexical motion word recognition task. Consequently, the response latencies were higher for red backgrounds compared to green. Responses to the red background were significantly longer because dyslexics found diffused red light to be interfering with the motion task. Therefore, higher activations of P cells were found in comparison to M cells, since dyslexics were more engaged in perceiving the differences

between background color than in the motion task. Diffused red light can make the responses more challenging for the reading impaired. Further, we also predicted that dyslexics would have significantly higher activations for P cells in comparison to M cells because of the color saliency effect. M cells will have reduced activity, because there are fewer neuronal connections in the area, and color saliency will have the advantage over motion detection.

Conclusion

Overall, dyslexics were impaired on word recognition, motion detection tasks because of problems associated with the M-pathway. The task was even more difficult due to the red diffused background, which also signifies the involvement of the P-pathway over the M-pathway. Dyslexics showed differences in performance between the two background colors, which could suggest the involvement of P pathway over the M pathway. Dyslexics have problems related to the M pathway, which may be why higher involvement of the P pathway is reflected in the reaction times. The results also show that, for figure-ground separation (word recognition on background colors), no significant differences were observed in controls for red and green background.

CHAPTER 5

Analytic Perception of Letters and Shapes: Evidence from Non-Reading Group

Introduction

In the present Chapter, we have compared illiterate individuals on letter and shapes congruent task. These people were unable to identify the letters. Thus a follow up study by van Leeuwen & Lachmann (2004) on congruency effects was performed. Reading is a secondary process; learning to read depends on functional coordination of two established skills: visual object perception and the ability to use spoken language. Whereas the former emerges at a much earlier stage than the second, both are well entrenched in human evolution. In learning to read, these skills are recruited, modified, coordinated, and finally automated, in order to enable skillful, fluent reading (Lachmann, 2002). As a result, letters are detected and processed automatically in a cross-modal fashion (Blomert, 2011). To establish such a cross-modal representation requires long training, possibly 3-4 years of practice. Suboptimal automatization of this functional coordination may lead to reading disability (Lachmann, 2002; Lachmann, Schumacher, & van Leeuwen, 2009; Blomert, 2011). As a result of reading practice, a differentiation in perceptual processing emerges (van Leeuwen & Lachmann, 2004; Burgund, Schlaggar, & Petersen, 2006; Burgund, Guo, & Aurbach, 2009). For instance, children whose reading skills are not yet fully automated process letters and similar geometric shapes in the same, holistic fashion: surrounding irrelevant visual information are uniformly assimilated with target letters and shapes (Lachmann & van Leeuwen, 2008). Adult skilled readers, while still processing the shapes holistically, treat letters analytically: surrounding irrelevant visual context is ignored (Lachmann & van Leeuwen, 2004; 2008) or even actively suppressed (van Leeuwen &

Lachmann, 2004) in the early stages of visual feature binding. The question could be asked: what perceptual skills do we lose when we acquire the differentiation in letter versus non-letter processing? (Serniclaes, Ventura, Morais, & Kolinsky, 2005; Deheane & Cohen, 2007; Lachmann & van Leeuwen, 2007; Blomert, 2011). There is evidence to suggest that normally reading children lose the ability to process letters holistically. For instance, with letters and dot-patterns in a non-lexical *same-different* task, dyslexic children equally benefit from symmetry in both dot patterns and letters, whereas their normal reading peers only perceived the symmetry in the dot patterns. As a result, normally reading children were *slower* for letters than dyslexics (Lachmann & van Leeuwen, 2007). On the other hand, skills seemingly lost while in transition to fluent reading may resurface later when reading is fully integrated into our system. The contrasting strategies for analytic processing for letters versus holistic processing for shapes in a classification task gave way to uniformly holistic processing, once the task required that (van Leeuwen & Lachmann, 2004). Thus, literate adults cannot be said to have lost the ability to process letters holistically. To properly investigate the question, what we lose when learning to read, we compared a group of adult skilled readers to a group who never learned to read, using the classification task in which the differentiation in processing between letters and non-letters was originally found (van Leeuwen & Lachmann, 2004). In this task, target letters and non-letters were surrounded by a task-irrelevant shape. Non-letters were classified faster if the target and its surrounding were formed congruent as compared to when they differed in shape, i.e. when both were incongruent. This is an example of the well-known congruence effect (Pomerantz & Pristach, 1989; Bavelier, Deruelle, & Proksch, 2000); and can be related to early and mid-level visual perception (van Leeuwen & Bakker, 1995; Boenke, Ohl, Nikolaev, Lachmann, & van Leeuwen, 2009). The congruence effect indicates holistic perceptual grouping. The

surrounding visual information is bound to the target, and is processed faster if both call for the same response. For letter targets, however, the opposite result was found: letters were categorized faster when surrounded by an incongruent non-target than when the non-target was congruent, e.g., a negative congruence effect.

	Response Category 1		Response Category 2	
Selection 1	A	□	L	△
Selection 2	A	○	C	△
Selection 3	A	□	H	△
Selection 4	L	○	C	□
Selection 5	L	□	H	□
Selection 6	C	□	H	○

Figure 5.1. Six selections of stimuli used in the experiment for individual participants.

The observed dissociation was considered a product of a special analytic strategy optimized during learning to read in order to guarantee a rapid grapheme-phoneme

mapping. Binding irrelevant visual information from the surrounding would disturb this fast mapping. The visual structure of the surrounding shape is therefore suppressed (Lachmann, 2002). Doing so is more difficult for congruent than for incongruent items, resulting in negative congruence effects (Briand, 1994; van Leeuwen & Bakker, 1995; Bavelier et al., 2000). Thus, we may conclude that in the early or intermediate stages of visual perception, skilled readers process letters using a unique analytic encoding strategy, whereas to processing shapes a holistic processing strategy is still applied. For adults who have never learned to read and are unfamiliar with the alphabet, we should not expect such dissociation. Since they are not able to differentiate letters from non-letters, they will process both letters and non-letter shapes with one and the same strategy (e.g., Dehaene, Pegado, Braga, Ventura, Nunes Filho, Jobert, ... & Cohen, 2010b). The question is: will that be a holistic or an analytic strategy? If the former, we may conclude that the analytic strategy is a secondary adaptation; if it is an analytic strategy, we should conclude that both analytic and holistic processing is intrinsic, primary strategies of the visual system.

Method

Participants

Fifty-eight adults participated in this experiment. The experimental group consisted of 32 Indian illiterates (18 females), aged between 20 and 31 years ($M = 28$ years, $SD = 3.71$), from a suburb Gadaiya Kalan (approximately 450 inhabitants) close to Jasra village, located 27.2 km west from the city of Allahabad (Uttar Pradesh). These participants have been living in this village since they were born. Because there was no school close by when they were children, none of them attended school. All participants are involved in farming and sell their products to external dealers coming to this village. There is no library in the village, nor is there any access to newspapers. These participants received

150 Rs. (equivalent to about 3 \$US) for completing the experiment. All these participants reported that they, while having normal vision and hearing are not able to read neither English nor Hindi, do not speak English, and are not familiar with Latin alphabets. Prior to the experiment their familiarity with the alphabet was determined by using a paper and pencil, letter identification test, which included 72 letters and non letter items, aligned in 6 rows. Each row contained 4 letters and 8 non-letters. Participants were instructed to mark four items in each row of which they think they were letters (see Figure 5.2). They were informed that payment does not depend on test performance. In case they were unable to decide (typical statement: “this all looks English to me”), they were instructed to guess. The total mean hit rate in the questionnaire was 11 (SD = 4). All participants included in the present study performed within chance level for at least two rows. The control group consisted of 26 Indian students (7 females), aged between 22 and 29 years (M = 26 years, SD = 1.97) from the University of Kaiserslautern, Germany. All of them were able to read fluently and to write in English. They received 5 Euros (equivalent of 7 \$US) for performing in this experiment.

Material

As in van Leeuwen & Lachmann (2004, Experiment 4), there were 24 unique stimuli. They consisted of targets: the four capital letters *A*, *H*, *L*, *C*; and the four geometrical shapes square, triangle, rectangle, circle, each of which was shown either in isolation or surrounded by a congruent or incongruent non-target geometrical shape (see Figure. 5.1). For instance, *A* in isolation, *A* surrounded by a triangle (congruent condition), *A* surrounded by a rectangle (incongruent condition). The stimuli were scaled to an imaginary 50 x 50 mm matrix, and the surrounding shapes to an imaginary 80 x 80 mm matrix. Stimuli were presented in black (.29 cd/m²) on a Laptop screen set to white (27.3

cd/m²) at about 50 cm distance, resulting in a visual angle of 3° without, and 4.5° with surrounding. There was no head fixation.

Procedure

Literate participants performed in a laboratory at the university. For the illiterate participants, a room was rented in a private house in the village which was prepared in such a way that conditions were as similar to the laboratory as circumstances allowed. Electricity was guaranteed by using a generator. The same laptop computer was used for both groups. Participants of both groups were seated comfortably in the dimly lit environment. The illiterate participants reported to have never used a computer before. Therefore, before instruction, illiterates were familiarized with the screen, and with pressing and releasing response keys in an extensive practice session. Prior to the experiment, all participants performed 12 warm up trials. Six different subsets of stimuli were presented to participants in a counterbalanced fashion (as in the original experiment, see Figure. 5.1). For each individual, the stimuli were restricted to two letters and two shapes. Letters and shapes were pair-wise similar, e.g. an *A* and a triangle. They were assigned in a counterbalanced manner to two different response categories: For instance, Category 1 was “*A* and Rectangle” versus Category 2: “Triangle and *L*.” Note that letters and shapes that are similar to each other, such as the *A* and the triangle, were always assigned to different response categories. In skilled readers this design was found to implicitly require a distinction between letters and shapes (van Leeuwen & Lachmann, 2004). Response Categories 1 and 2 were assigned in a counterbalanced manner to two response keys on the keyboard.



Figure. 5.2. The fourth out of six rows used in the paper and pencil letter identification test.

Altogether, each individual performed on 720 trials: 4 targets x 3 conditions (isolated, congruent surrounding, incongruent surrounding), with 60 repeated measures (see Figure 5.3). Trials were randomized, having 12 breaks in between. For illiterates the experiment took up to one hour including the letter test, instruction and practice; for controls it took about 25 minutes.






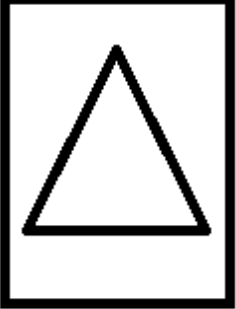
	Response Category 1	Response Category 2
Isolated		
Congruent		
Incongruent		

Figure 5.3. The stimuli used in Selections 1-3 (isolated, congruence and incongruence stimuli)

Results

Reaction times (mean RT) and error rates were analyzed after rejecting outliers, which were .5% for the criterion, mean RT < 145 ms, and .3 % for the individual criterion. RTs were analyzed for correct responses. Individual mean error rates and RT were not correlated ($r < .01$). For illiterates mean error rate was 3.3% and ranged from .4% to 15%, three participants had an error rate higher than 10%. Mean RT was 980 ms (SD = 455 ms). For literates, the mean error rate was 3.1 %, significantly below the 7.3% in the original study with German adults, $F(1, 49) = 10.1, p = 0.00$, and ranged from .1% to 10%, except for one participant error rates of all literates were below 10%. The error rate did not differ from that of illiterates. Mean RT was 454 ms (SD = 186), which did not differ from German adults in the original study (477 ms, SD = 126) but is significantly higher, $F(1, 56) = 111.2, p = 0.000$, than that in illiterates, whose RTs are more than double. Only two literate participants had average RTs over 600 ms and only one had larger RTs than the fastest participant of the illiterate group. Because there was no speed-accuracy trade-off in evidence, we report Analyses of Variance (ANOVA) for RT only, using Green-House Geisser correction for p levels; uncorrected degrees of freedom are reported. Since mean illiterates RTs were nearly entirely outside the range of those of normal adult readers (Lachmann & van Leeuwen, 2004; 2008; Jinchu, Lachmann & van Leeuwen, 2008; van Leeuwen & Lachmann, 2004), ANOVAs were run for each group separately. For the illiterate group, a two-factors repeated measures ANOVA with Congruence (isolated, congruent surrounding, incongruent surrounding) and Material (letter versus shape) as within-participant factors revealed a main effect for Congruence, $F(2, 62) = 5.86, p = 0.01$, but not for Material ($p = 1$). No interaction was in evidence ($p = 1$). Congruent items (995 ms, SD = 475) were slower than isolated ones (967 ms, SD = 458), $F(1, 31) = 5.67, p =$

0.00, and slower as incongruent ones (976 ms, SD = 429), $F(1, 31) = 4.8, p = 0.03$. Isolated and incongruent items did not differ ($p = 1$).

The same ANOVA was run with the data from literate participants. Main effects were found for Congruence, $F(2, 50) = 11.23, p = 0.00$, and Material, $F(1, 25) = 32.66, p = 0.02$. Isolated items (443 ms, SD = 186) were faster than congruent (458 ms, SD = 183) and incongruent items (461 ms, SD = 187), which did not differ. For Materials, letters (433 ms, SD = 177) were responded to faster than shapes (476 ms, SD = 191). An interaction was found between Material and Congruence, $F(2, 50) = 4.89, p = 0.00$, due to a negative congruence effect for letters and a positive congruence effect for shapes: Participants were faster with isolated letters (421 ms, SD = 178) than with incongruent letters, $F(1,25) = 7.99, p = 0.01$; Incongruent letters, in turn, were responded to faster than congruent ones (444 ms, SD= 175), $F(1,25) = 10.79, p = 0.01$. Also for shapes, a Congruence effect was observed, $F(2, 50) = 5.69, p = 0.00$. Participants responded faster to isolated (467 ms, SD = 191) than to incongruent shapes (487 ms, SD = 195), $F(2, 50) = 8.32, p = 0.01$ but not significantly faster than to congruent ones. Congruent shape (473 ms, SD = 186) were responded to faster than incongruent ones, $F(2, 50) = 6.04, p = 0.035$. Results for both groups are displayed in Figure 5.4.

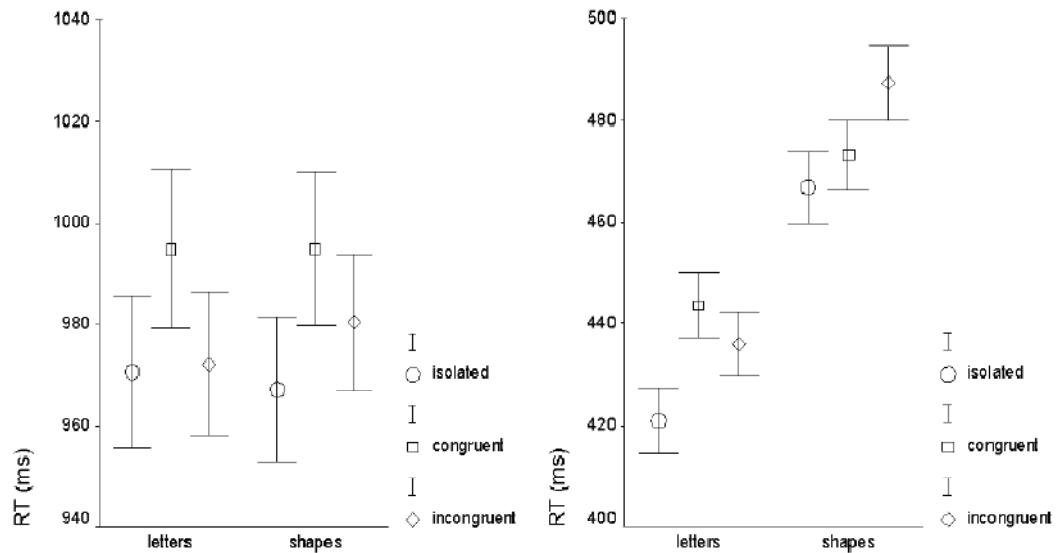


Figure 5.4. Average reaction times (RTs) with error bars (5% confidence interval) for the experimental conditions for illiterate participants (left) and for literate control participants.

Discussion and Conclusion

Amongst visual configurations, letters are special; practice and familiarity make that letters are processed much more efficiently than non-letter configurations of similar complexity (Burgund et al., 2006; Lachmann & van Leeuwen, 2007; van Leeuwen & Lachmann, 2004). In addition, letters have a specific functional relationship to phonemic representations, a relationship which is developed and automated while children learn to read (Frith, 1985). Recent studies have shown that this leads to enhanced differentiation and the responsiveness of the visual cortices to both orthographic and non-orthographic materials (Dehaene & Cohen, 2007; Dehaene, Nakamura, Jobert, Kuroki, Ogawa, &

Cohen, 2010a; Dehaene et al., 2010b; Cantlon, Pinel, Dehaene, & Pelphey, 2011). The differentiation gives a new role to establish perceptual skills (Dehaene & Cohen, 2007; Lachmann & van Leeuwen, 2007; Blomert, 2011) which, after modification, need to be coordinated in order to guarantee fast and accurate reading (Lachmann, 2002). To automate this functional coordination takes years of reading experience. The question is: what do we lose, once this automatization process is completed? In a sample of illiterate Indian participants, we found no difference in processing between letters and non-letter shapes. Both were processed with equal speed and accuracy, and both showed the same preference for items presented in isolation versus in surrounding, as well as the same effects of surroundings congruence. In both letters and non-letters, incongruent surroundings were preferred over congruent ones. Literates of the same ethnicity, in contrast, differentiated between letters and non-letters, just as groups of skilled readers of other ethnicities did (Lachmann & van Leeuwen, 2004; Jincho, Lachmann, & van Leeuwen, 2008). They also showed a letter superiority effect that, not surprisingly, is absent in illiterates: letters are processed faster than non-letters and produce opposite congruence effects: positive congruence effects for non-letters, *negative* congruence effects for letters.

The negative congruence effect in illiterates, i.e. their preference for incongruent surroundings, implies that an analytic perceptual strategy prevailed (see Figure. 5.4). Developmental studies might have led us to expect that before reading is automated, a holistic strategy to predominate. Lachmann & van Leeuwen (2008) compared adults with different groups of children: beginning normal readers from Grade 3 and 4, and age matched developmental dyslexics. Most of these children showed positive congruence effects for both letters and non-letters, indicating holistic preference. One reason could be that certain brain functions related to reading, especially auditory processing (Banai &

Ahissar, 2006) is still developing at this age (Courchesne, 1978; Cheor, Leppänen & Kraus, 2000; Shafer, Morr, Kreuzer, & Kurtzberg, 2000; Bruder, Leppänen, Bartling, Csepe, Demonet, & Schulte-Koerne, 2001; Cepomene, Shestakova, Balan, Alku, Yaguchi, & Naatanen, 2001; Parviainen, Helenius, Poskiparta, Niemi, & Salmelin, 2006; 2011). This may keep them from using an analytic letter processing strategy that would enable rapid grapheme to phoneme encoding. A subgroup of dyslexic children in Lachmann & van Leeuwen, (2008); (see also Lachmann, Steinbrink, Schumacher, & van Leeuwen, 2010), with particular difficulties in reading non-words, however, show particularly strong negative congruence effect for letters. This suggests that the analytic strategy, at least, is present at this stage in development. The results in dyslexics, therefore, are not inconsistent with those of illiterates: The negative congruence effects in illiterates means that analytic processing is not a reading specific, secondary differentiation in perceptual organization that accompanies the process of learning to read. Rather, it is a generic and the primary perceptual processing strategy, on a par with the holistic strategy. Skilled reading recruits this general perceptual strategy for letter recognition, and uses it in a coordinated fashion along with other functions, including phonological, cognitive, motor and attentional ones, in meeting the specific demands of reading. What is specific to skilled reading is not the automatization of a letter-specific perceptual strategy (Grainger, Tydgate, & Issele, 2010), but the automated coordination of the various functional components in their specific combination. In this process, letter processing becomes tied up with the analytic perceptual processing strategy. As a result, adult readers no longer show the ability to process simple, non-letter objects analytically. This result is in accordance with the pervasiveness of congruency effects in visual object perception (Erikson & Schultz, 1979; Pomerantz, Pristach, & Carson, 1989; Boenke et al, 2009). In *incongruent* conditions, observers fail to ignore irrelevant information, even if this would facilitate processing. This effect is usually

considered a result of *attentional* interference of the irrelevant flanking or surrounding information; this remains a puzzle if we consider that, in principle, focused attention could have been applied to the target (Miles & Proctor, 2010). The present study suggests that this is because analytic processing has preferentially become associated with reading. Despite this, having learned to read does not render entirely impossible the analytic processing of non-letter shapes. Evidence of analytic processing is not restricted to letters; negative congruence effects, although sparse, are found whenever active suppression of surrounding information is needed to distinguish a target (Briand, 1994; van Leeuwen & Bakker, 1995; Bavelier et al., 2000). The fact that these conditions are rare suggests that the differentiation that associates holistic processing with non-letters and analytic processing with letters is, by and large, effective.

CHAPTER 6

General Discussion

The preceding chapters combine different and common paradigms in the area of visual perception of letter and words. These experiments are aimed at understanding the deficit underlying developmental dyslexia, a very common reading disability observed in 5-10% of school-going children (Stein, 2001). This prevalence rate may differ from country to country, and even from region to region, because of the different orthographies and transparencies present in the languages. The other aim is to describe the differences between the dyslexic and the illiterate population. Despite rigorous training, reading disability can be reflected in delayed response time and high error rates when responding to letters. However, among those with no educational background, how do illiterate people process letters? These effects could be identical to dyslexia, or they may be average compared to the adequate reading population. Letters are unique because of the different grapheme representations and matched phonemes which cause them to be processed in a more important and efficient way than shapes or non-letters (van Leeuwen & Lachmann, 2004; Burgund et al., 2006; Lachmann & van Leeuwen, 2007; Chapter 5). Many studies have reported that dyslexics have problems in responding to letters rather than shapes, as reflected by delayed response times (Rusiak et al., 2007; Lachmann et al., 2009), while illiterate individuals process letters and shapes in the same way (see Chapter 5; Chapter 2 and Chapter 3), and no significant difference was found between letters and shapes. Results also indicated that analytic visual perception is dominant for the letter processing. Illiterate individuals use analytic perception as a common strategy for the processing of both letters and shapes (see Chapter 5). Therefore, analytic strategy is not a secondary development resulting from learning to read, but rather a primary medium of perceptual organization on a par with holistic perception, dominant for object perception. Dyslexics and controls both process letters using an analytic

and shapes using a holistic strategy, but illiterates were somewhere in-between, processing shapes and letters in the same manner. Dyslexics were further compared on a mental rotation task where it was reported that they had difficulties in responding to the mental rotation of letters (mirrored and normal, including clockwise and anti-clockwise rotations) because of the symmetries present in letters which create an uncertain relation in responding, regardless of whether the letter is normally or mirror rotated. Dyslexics and controls both showed a similar pattern of response on the mental rotation task; despite dyslexics being slower due to the visio-spatial processes dominant in mental rotation, these processes do not seem to be involved in dyslexia (Lachmann, 2002; Rusiak et al., 2007; Lachmann et al, 2009). The failure in suppressing symmetry generalization in grapheme-phoneme conversion is one of the important causes of dyslexia.

According to the Event Related Potentials, the effect of the mental rotation task, resulting in RRN was absent for dyslexics. Dyslexics showed some late effects in comparison to controls, and these could be interpreted as challenges at the decision stage where they are confused as to whether the letter is normal or mirrored. The cerebellum (the area of the brain responsible for motor movements) could play an important role in the automatization of specific reading processes, significantly suppressing the symmetries within a letter (Nicolson & Fawcett, 1994). Additionally, the results suggest that dyslexics were using a different strategy to perform mental rotation, in terms of the difference between medial (left - clockwise) and lateral (right- anticlockwise) rotations (Horst et al., 2012).

Dyslexics were also tested on a lexical motion detection task and the static reversal paradigm (*b* versus *d* – symmetry, *b* versus *q* – rotation) because they also have problems with letters which have similarity on the basis of symmetry and rotation. Furthermore, dyslexics also have problems identifying stimuli presented with different contrast, as well as detecting things in motion, particularly words. The reason could be the magnocellular cells

(M-cells; Stein, 2001) which are more sensitive to detecting motion, depth, low spatial and high temporal frequency (ground), and low-contrast information (Cavanagh et al., 1984; Livingstone & Hubel, 1987). Dyslexics were slower overall in responding to the above-mentioned tasks. Dyslexics also showed delayed responses for rotation compared with symmetries (see Chapter 3). These similarities present in the letters create an uncertain relationship between the visual and phonological information associated with letter perception. Dyslexic individuals have problems inhibiting the symmetries present in the letters, which, for satisfying reading, should be automatically processed. The inability to handle visual similarities within a letter can be reflected in the delayed response time taken in responding to the letter at the decision stage (FCD Model, Lachmann, 2002). Dyslexics also showed problems in responding to contrast conditions (low and high contrast), and the response latencies were significantly longer than for controls (see Chapter 3). Further, response latencies were also slower for dyslexics on the word in the motion detection task. M cell deficits could also explain the reduced motion sensitivity and problems associated with low contrast information in people suffering from dyslexia. Dyslexics have reduced motion sensitivity (Eden et al., 1996) and the binocular fixations are unsteady, which leads to poor visual localization of letters as objects in space. This is why dyslexics often complain that letters seem to be dancing or creating a fading or running effect. The M-pathway also keeps the temporal processing of events on track while reading, and the faulty processing of the pathway means that dyslexics are overall slower readers.

On the other hand, problems related to P-cells have not been reported for dyslexics because they do not have any deficits related to color perception. Using a diffused red background decreased the M activity for dyslexics and involved the P pathway more; thus, the task of recognizing words in motion was even more challenging. Higher response latencies were reported for dyslexics for red background conditions compared to green. In dyslexics, the

M-pathway is affected, and since using a red background decreases M activity and thereby increases the difficulty in identifying letters, this effect would generate poorer performance in red conditions compared to green. Hence, response times for a red background were greater than for those with a green background. Therefore, dyslexia cannot be attributed to a single cause, but is rather the result of multi-dimensional causes, which affect sufferers in a variety of ways.

Appendix I

Method

Participants

In total, 86 normal progressing readers and 20 dyslexic readers were identified, and later depending upon the availability and willingness of these participants a fewer number participated in the experiments. Out of these, only 27 children participated in the experiment mentioned in Chapter 3 and 28 participated in the experiment mentioned in Chapter 4. Children studying in coeducation schools with English as the medium of instruction participated in the study. Both, normally progressing readers and dyslexic readers were matched with respect to chronological age and educational level. None of the participants had a history of any neurological/psychiatric disorder.

As a usual practice in schools, in north India, children who participated in the study had been introduced to reading and writing skills simultaneously in both Hindi (L1) and English (L2) languages. Since, the first year of instruction at the kindergarten all the children had better oral proficiency in L1 and minimal oral proficiency in L2 before they started learning to read both the languages. Whereas, reading /writing skills for L1 and L2 start at the same time. All the children were tested for their oral proficiency in both the languages using an expressive speech task (naming, picture description, narrative, speech which includes making sentences with three given words) and they were found comparable with respect to vocabulary (appropriate to the age level) and object naming but fluency was better for L1 as compared to L2 on picture description task. Linguistic environment of all the participants was also examined by using a language background questionnaire administered with the parents of each participant (The Virtual Linguistic Lab (VLL) Child Multilingual Questionnaire, 2005). The information obtained on the questionnaire

indicated that more than 80% of the time L1 was the language of use at home. L2 as a spoken language was used only in school and mostly when talking to teachers. Exposure and use of L1 was more in the household and among peers for all the participants. All the participants were right handed and they were screened for visual acuity and auditory acuity using brief screening tests. All the participants had normal or corrected to normal vision. Written informed consent was obtained by the respective class teachers and parents for each participant during the identification procedure.

Identification of normally progressing readers and dyslexic readers

Identification of normally progressing readers and dyslexic readers was based on multiple measures, including a teacher's report (problem checklist), performance on reading tests (reading accuracy, speed, and nature of errors) in Hindi (L1) as well as English (L2) language (see Appendix A for description of general measures and reading assessment battery). Normally progressing readers were first identified by the class teachers of grade 1, 2, 3 and 4 across three schools in Allahabad city in northern India. On the basis of the academic performance, reading and writing skills teacher's reported to the checklist of problems (Tripathi & Kar, 2008) associated with these difficulties for every child studying in that grade . The children identified by the teachers were further subjected to a formal assessment, including tests of reading skills such as word and non-word reading, reading and listening comprehension, and a test of intellectual functions. Children who showed an accuracy of more than 80% on the reading tests of word and non-word reading, and reading comprehension as well as with average or above average intellectual functions were taken as normally progressing readers. Dyslexic readers were also initially screened by the class teachers of grade 1, 2, 3 and 4 across three schools using the problem checklist (Tripathi & Kar, 2008) and were then subjected to the same reading assessment battery used to identify normally progressing readers. Children who were found to be average or

above average (on or above the 50th percentile on CPM) on intellectual functions, those with adequate listening comprehension, but who scored two standard deviations below the mean performance of the normally progressing readers on reading tasks particularly word and non-word reading was considered as dyslexic readers. The data based on accuracy scores (scores of each reading test separately) of normally progressing readers and dyslexic readers taken together was found to be normally distributed. Among all the reading measures, word and nonword reading tests were found to be more accurate in classifying normally progressing readers and dyslexic readers.

In order to determine the tests with greater classification accuracy, ROC curves were plotted taking the scores of word and nonword reading, reading comprehension, and phoneme deletion of the normally progressing readers and dyslexic readers identified from the same schools, matched on educational level and tested on the same reading assessment battery. ROC curves were plotted for reading tests in Hindi and English language separately. ROC was used to measure classification performance (sensitivity and specificity) of all the measures. We used SPSS software to plot ROC curves. Each point on the ROC curve represents a sensitivity/specificity pair corresponding to a particular decision threshold. A test with perfect discrimination (no overlap in the two distributions) has a ROC curve that passes through the upper left corner (100% sensitivity, 100% specificity). Therefore, the closer the ROC plot is in the upper left corner, the higher the overall accuracy of the test (Zweig & Campbell, 1993). Among the reading tests, accuracy scores word and nonword reading in Hindi and English showed an overall classification accuracy of 85.4 % for word reading in Hindi, 89.3% of word reading in English, 91.6% for non-word reading in Hindi and 89.2% for non-word reading in English. The range of classification accuracy (85.4% to 91.6 %) for these four tests was the highest among all the other tests.

Thus, dyslexic readers were classified against normally progressing readers with reference to their performance on the tests of word and non-word reading. They were found to be in the range of 50th percentile (average) just above the 50th percentile (slightly above average) on the test of intellectual functions as per the Indian norms of CPM (Kar et al., 2004). Twenty-eight children were identified as dyslexic readers across grades 1-3, with 8 children from grade 1, 11 from grade 2 and 9 from grade 3. All the children identified as dyslexic readers scored 2SD below the mean for both Hindi and English word and nonword reading. All the children identified as normally progressing readers had an accuracy score of > 80% on tests of word and non-word reading in both Hindi and English language.

Description of general measures and reading assessment battery in Hindi and English

General Measures

A Problem Checklist (Tripathi & Kar, 2008) was administered to the teachers for an initial screening of children with reading difficulties. The checklist consists of items in four domains: language related problems, reading, writing, and behavior problems. This checklist provides the nature of learning related problems and ratings for the intensity of each problem perceived in terms of frequency of occurrence.

Colored Progressive Matrices (Raven, Raven, & Court, 1998) test was administered to examine the status of intellectual functions. The items of CPM are arranged to assess mental development up to the stage when the person is able to reason by analogy to adopt it as a consistent way of inference. Normally progressing readers were found to be in the range of 50th to 75th percentile whereas dyslexic readers were in the range of 50th percentile

and just above the 50th percentile with respect to intellectual functions on CPM referring to the Indian norms of CPM (Kar et al., 2004). None of the dyslexic readers were found to be intellectually deficient.

Working memory is known to be associated with the cognitive processes that underlie reading acquisition, particularly with respect to reading comprehension. The verbal n back task (Kar et al., 2004) was used as a measure of verbal working memory. The n Back Task is based on the theoretical premise that two variables can affect verbal working memory that is, word length and phonemic similarity. It consists of a 1 Back Task' and a 2 Back Task. The 1 back task consists of a list of phonemes. The list of phonemes is kept out of the participant's view. Each phoneme is presented at the rate of one phoneme per second. The participant is required to respond in terms of Yes or No for phonetically similar and dissimilar sounds respectively. The participant has to say 'yes' for each consecutively repeated sound and for the other sounds the response is 'no'. In the 2 Back Task each sound is presented and the participant has to decide whether or not it matched the sound that appeared two items back in the sequence and if so the participant has to respond in terms of 'yes' or 'no'. In this condition the participant must always maintain representations of the two most recent sounds in memory to compare with the current one. The n back task (verbal) obtains two scores. Hits and misses were recorded as two scores on this test. Normally progressing readers were found to have an adequate working memory when compared to the age norms, whereas slow progressing readers were adequate for the 1 back task, but showed difficulties when the working memory load was more in case of the 2 back task and performed at the level of 25th percentile on 2 back task.

Reading Assessment Battery

The reading assessment battery comprised of tests of letter identification, reading comprehension, listening comprehension, word reading, non-word reading, reading

irregular words only in English, spelling (writing words to dictation), and phoneme deletion. All the tests were developed in Hindi and English language and were made as much comparable as possible.

The verbal responses of the participants were recorded on a record sheet as well as using a voice recorder. A battery of six reading tests in Hindi and English was administered to children initially screened by the teachers as normally progressing readers. This battery of tests of reading skills in Hindi and English language was then administered to identify children with reading difficulties. The tests were designed such that the test items were graded in terms of the difficulty level. The grade appropriate curriculum was considered while selecting the passages for reading comprehension and dictation. Word reading and non-word reading tests in English were developed using the MRC psycholinguistic database taking the following criteria into consideration: age of acquisition, length of the words, and frequency/familiarity of the words. For the word reading test in the Hindi grade appropriate curriculum was considered and the textbooks were used to select the words which were then rated by five teachers on parameters of familiarity, frequency, and age of acquisition. Accuracy was the measure of performance for all the tests. Time taken in seconds to read the entire list of words was recorded using a stop watch for word reading and non-word reading tests. For tests such as listening and reading comprehension time taken to respond to each comprehension question was recorded using the digital voice recorder. Tests in Hindi and English language were developed on similar principles, for example non-word test included items developed from meaningful words in both the languages. Completely parallel versions were not possible as the two languages are different with respect to the basic graphemic unit. Moreover, as recognized by Geva and Seigal (2000) it is often not possible to design parallel tests in two

different languages that are matched on a variety of dimensions like word length, word frequency, syllabic length and structure. The description of each of the tests is as follows:

1. Letter Identification

This test was administered to examine graphemic/letter knowledge to ensure that the children, who were identified as normal and poor readers, did not have problems at letter identification level. The test consisted of 52 cards for English with a single printed alphabet in lower case and on another card in upper case. Similarly, 33 aksharas and 11 vowels in Hindi were presented. Random sequence of all the letters in Hindi and similarly for English were presented on a card one at a time and the participants were required to name the letter aloud. Participants were required to provide the letter name. The order of presentation of Hindi and English letters was counterbalanced with participants being presented with Hindi letters first and some others with English letters followed by Hindi letters. Performance on this test was measured in terms of number of correct identifications and average time taken to read each alphabet. Scores were calculated separately for Hindi and English. (Sample items: English: /B/, /e/, /T/, /h/; Hindi: /ग/,/ज/ (consonants); /उ/,/ ए/ (vowels)).

2. Word reading

Rationale

Words from one of the basic units of the written text. The level achieved in word reading can also predict the process of reading acquisition. Decoding in Hindi and English was measured by administering tests of reading frequent words taken from the MRC

Psycholinguistic database for English and from the text books of the grade to which the child belonged to Hindi.

Description

Thirty words were taken using the MRC Psycholinguistic database. The words were grouped into different grades according to their age of acquisition index. Selection of words was based on complexity in terms of number of letters, number of syllables, frequency, and familiarity. All the words were printed on an A4 size sheet. Words were equally spaced and printed in three columns. The participant was instructed to read each word aloud row wise and stop only when he/she has completely read out the list. The response of the child was recorded on a response sheet. The number of correctly read words comprised the score. Time taken to read the entire list of words was also recorded using a digital voice recorder which also records the time. Stop watch was also used and time from the onset of first word produced by the participant until the offset of the last word in the list was recorded. Errors like letter-by-letter reading, substitution, deletion, or addition of letters were also noted. (Sample items: English: ship, market, watch, flood; Hindi: कलम, सूरज, तालाब, फूलदान).

3. Non-word reading

Rationale

The Non-word reading test was designed and administered to assess decoding of letter strings. Non-word reading demands decoding at the sub-lexical level as for nonwords pronunciation has to be assembled. This test could efficiently test phonological processing, as one may not depend on sight or spoken vocabulary to read a nonword. Hindi being an alphasyllabary, may allow faster and more accurate decoding using a sublexical strategy.

Description

Thirty of three and four letter monosyllabic words in English and 30 of three and four letter words in Hindi were printed on A4 size paper in three columns. The participants were asked to read each word aloud row wise and stop only once they have completely read out the list of nonwords. Participants were told that they need to read words which are meaningless and may be unfamiliar to them, but they should read each word aloud as accurately as possible. All the words in the list were pseudo words and hence could be pronounced. Errors were also recorded and later classified as either phonological or lexical based errors (Defior, Martos, & Cary, 2002). Phonological errors involve producing another non-word, which is incorrect in some way as it involves a deletion, substitution, or inversion of a letter in the target non-word. Lexical errors involve producing a real word for a non-word. The words were controlled for neighborhood effect and only the non-words, which had fewer neighbors, were taken to ensure that the words are not decoded by analogy strategy rather only on the basis of phonological recoding. The list of non-words remained constant for all the grades. Accuracy as well as the time taken to read the word list was recorded. (Sample items: English: fasket, gapital, varpet; Hindi: रदी, तमल, जिताब).

4. Reading and Listening Comprehension

Rationale

Test of reading comprehension assessed the child's ability to read and comprehend sentences. Reading comprehension is a basic skill while one is learning to read. Test of listening comprehension was included to rule out problems with auditory comprehension.

Description

This test assessed the child's ability to read and understand the text. The test consisted of grade appropriate curriculum based passages of varying length for children across the three grade levels. The participants were required to read the passage aloud as accurately as possible. As soon as the participants finished reading the passage, five questions based on the passage were asked one by one and the answers given by the participants were noted down. The time duration between the offset of the question and onset of the response to each question was recorded and was later averaged across five questions which provided mean response time for reading comprehension. Errors made in reading, such as letter-by-letter reading and insertion/omission/substitution of letters or words were recorded.

5. Dictation

Dictation in Hindi as well as in English was developed and administered as writing to dictation task. 30 words in English and 30 words in Hindi with varying length (2 to 7 letter words in English and words with and without maatraas in Hindi) were taken for this task. These words were taken from the grade appropriate textbooks of Hindi and English. The participants were instructed to listen to each word spoken by the investigator and write down the spelling for the same. Number of correct responses comprised the score. Time was not a measure of performance on this task. (Sample items: English: bag, pet, kite, flower, bunch, country; Hindi: मटर, पुल, बागीचा, भाग्य).

6. Phoneme deletion

This test consisted of a list of 30 words in Hindi and thirty words in English. The investigator verbally presented words one at a time. The participants were required to delete a given sound in the word at the initial, middle, or final level and give the remaining words. After deletion, 80% of the words resulted in a meaningful word and 20% of the words in a pseudo word. There were five words for practice, followed by 30 test words.

For example, the participant was required to *delete the sound of /b/ in ball* and provide the remaining word for which the correct response is /all/. Phoneme deletion in Hindi involved only vowel-based deletions as consonants in Hindi have an inherent vowel and deletions based on consonants cannot be treated as true phonemic level manipulations. (Sample items: English: Shout, Stick, Snake; Hindi: /रात/, /किला/ /फूल/ participants were asked to reproduce the word after deleting the given underlined sound).

References

The Virtual Linguistic Lab (VLL) *Child Multilingual Questionnaire*. (2005). Cornell Language Acquisition Laboratory, Cornell University. <http://www.clal.cornell.edu/VCLA/index.html>

Appendix II

List of words used in the experiment

1	Boat	31	Team
2	Cake	32	Wind
3	Game	33	Milk
4	Land	34	Open
5	Lawn	35	Stem
6	Lake	36	Tape
7	Give	37	Year
8	Joke	38	Snow
9	Away	39	Song
10	Make	40	Sand
11	Hero	41	Nest
12	File	42	Move
13	High	43	Name
14	Leaf	44	Oral
15	Coin	45	Test
16	Book	46	Stay
17	City	47	Wash
18	Hope	48	Past
19	Farm	49	What
20	Idea	50	True
21	Cave	51	Page
22	Draw	52	Seat
23	Gold	53	Salt
24	Mark	54	Rose
25	Hold	55	Note
26	Cost	56	Race
27	Date	57	Melt
28	Flag	58	Zero
29	Bird	59	Shop
30	Play	60	Kite

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