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VISUAL GLOBAL MOTION PROCESSING IN ADULTS WITH DYSLEXIA: AN

EVALUATION OF DIFFERENT THEORETICAL EXPLANATIONS

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Abstract

Research has shown an association between functioning of the visual magnocellular system and dyslexia. While many studies have provided evidence supporting the magnocellular deficit, some studies have failed to replicate these findings. The main aim of the current study was to examine different theoretical explanations of reduced motion sensitivity in dyslexia. These included: (1) a sensory deficit caused by a structural abnormality in the magnocellular system affecting the processing of sparse motion signals (Talcott et al., 1998), (2) a deficit in temporal integration (Raymond & Sorensen, 1998), (3) a deficit at extrastriate visual areas only (e.g., Hill & Raymond, 2002), and (4) a deficit in noise exclusion (Sperling, Lu, Manis, & Seidenberg, 2005, 2006b). Three global motion experiments were conducted to investigate motion extraction, motion integration, and simultaneous motion processing. A local motion control task was also administered. Participants were two groups of high functioning adults with and without dyslexia.

The dyslexia group were significantly less sensitive than the skilled reader group on each of the global motion processing tasks, but not on the local motion processing task. Manipulations of dot density, the number of animation frames presented in the random dot kinematogram (RDK), and signal dot lifetime affected motion sensitivity in the dyslexia and skilled reader groups similarly. A combination of high dot density and presentation of an increased number of animation frames in the global motion stimulus increased sensitivity for both reader groups. These results suggest that the global motion deficit found in dyslexia can partially be explained by sensory and perceptual motion processing deficits mediated by visual area V5.

Manipulating the salience of signal and noise dots in the RDK showed that motion sensitivity was reduced when noise elements were of greater salience than

signal elements. These findings partially support the noise exclusion hypothesis. Consistent with the between group global motion sensitivity differences found, significant linear correlations were found between all reading measures and motion sensitivity.

The second aim of the study was to determine the proportion of individuals in the dyslexia group with a motion deficit, and to assess whether the cognitive profile of dyslexia groups with and without a motion deficit differed. Three classification techniques were evaluated. Across the different experiments logistic regression analyses classified 40-48% of the dyslexia group and 4-16% of the skilled reader group with a consistent global motion deficit. Comparatively, deviance analyses classified 29-38% of the dyslexia group with a deficit, while the 16th percentile estimates classified about 5-21% of the dyslexia group with a deficit. When individual experiments were evaluated the deviance and logistic regression analyses also classified about 4% of the skilled readers with a motion deficit. When individuals were classified with a global motion deficit only if criteria were satisfied for a deficit in Experiments 1 and 3, one individual in the dyslexia group (7%) was classified with a global motion deficit based on 16th percentile estimates. This increased to four individuals (30%) when either deviance analyses or logistic regression were used. Logistic regression technique also identified one skilled reader with a consistent global motion deficit.

When the profile of the dyslexia group classified with a motion deficit based on deviance analyses was compared to the dyslexia group without a motion deficit, there were no significant differences in reading skills found between the two groups. However, the verbal short-term memory and the visual-motor-spatial integration abilities of the dyslexia group with a motion deficit were poorer than that of the

dyslexia group without a motion deficit. The motion deficit subgroup also reported greater difficulties with sequencing.

The current results have significant implications for informing current theory concerning the aetiology of dyslexia. Future research should further investigate the specific neural and perceptual processes that contribute to reduced sensitivity to global motion in dyslexia. In addition, explanations why only a proportion of individuals with dyslexia have a motion processing deficit should be considered. Further assessment of the profile of dyslexia groups with and without motion deficits may inform educational and health professionals of the most effective assessment and remediation strategies for individual presentations of dyslexia.

Declaration

I declare that this work has not previously been submitted for a degree of diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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Gry Lilleskaret

November 2008

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CHAPTER 1: Dyslexia

1.1 Introduction

Developmental dyslexia is a disorder that extends across the lifespan, affecting between 5 and 15% of the population in English speaking countries (Shaywitz, 1998; Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992). The most salient feature of the disorder is impaired reading (Frith, 1997). However, as reading is a complex process that involves auditory, visual and language processes, poor functioning in any one of these areas may produce reading difficulties. Over the last thirty years a number of theoretical approaches have been put forward to explain the processing mechanisms associated with dyslexia. These range from explanations based on neural impairments of the language system, producing a core deficit in phonological processing (e.g., L. Bradley & Bryant, 1983; Bruck, 1990; Snowling, 2000), to explanations of neural impairments in the visual system (e.g., Eden & Zeffiro, 1998; Livingstone, Rosen, Drislane, & Galaburda, 1991; Stein, 2003). These explanations propose a casual link between abnormal brain processing, poor cognitive word decoding and poor reading, and are consistent with a neurobiological-cognitive-behavioural framework. Within this framework the chain of causal links from brain to mind to behaviour is set within the context of environmental and cultural influences (Frith, 1997).

One visual explanation of dyslexia that has received considerable attention over the past 30 years is the magnocellular, or M deficit hypothesis. This hypothesis postulates that there is specific damage to the magnocellular system in dyslexia, affecting the processing of rapidly changing sensory stimuli (Habib, 2000; Lovegrove, 1996; Stein & Walsh, 1997). The magnocellular deficit may produce a language processing deficit, which in turn explains reading difficulties (Talcott et al., 1998).

While many studies have found that dyslexia groups have a specific deficit affecting the processing of visual information in the M system (Lovegrove, Martin, & Slaghuis, 1986; Slaghuis & Ryan, 1999; Talcott, Hansen, Assoku, & Stein, 2000), some studies have reported findings inconsistent with a selective M system deficit (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Kronbichler, Hutzler, & Wimmer, 2002). These inconsistent findings have produced considerable controversy concerning the role of the magnocellular system in dyslexia (Ramus et al., 2003; Skottun, 2000). However, some of the inconsistent findings may be explained by reports that only a proportion of individuals with dyslexia also have an M system deficit (Borsting et al., 1996; Johnston et al., 2008; Pellicano & Gibson, 2008; Ramus, 2004; Slaghuis & Lovegrove, 1985; Slaghuis & Ryan, 1999), and by some of the stimulus parameters used to assess M sensitivity (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Hill & Raymond, 2002).

The current research project investigated one aspect of neural processing in the M system; global motion processing. The main aim was to evaluate different theoretical explanations for the motion deficit in dyslexia. The magnocellular deficit hypothesis proposes that a low level dysfunction in the M pathway extends into higher cortical areas affecting processing throughout the M system (Stein & Walsh, 1997). However, as progressively more complex processing occurs at higher levels in the M system, some research has suggested the global motion deficit arises from abnormalities at extrastriate cortical levels in the parietal cortex (Amitay et al., 2002; Hill & Raymond, 2002), affecting only complex motion processing (Raymond & Sorensen, 1998). A third line of research has explained the reduced motion sensitivity of dyslexia groups in terms of a noise-exclusion deficit (Sperling et al., 2005, 2006b). As part of the current research a number of measures of motion processing were

administered that manipulated specific parameters expected to discriminate between the different sensory and perceptual explanations of dyslexia.

The second main aim of the current research was to examine the associations between sensitivity to motion and the sub-skills of reading. In addition, the profile of dyslexia groups classified with and without persistent motion deficits based on 16th percentile estimates, deviance analyses and logistic regression was examined. The effectiveness of the three classification techniques in identifying individuals with a stable and consistent motion deficit were investigated, as the validity of the techniques has not yet been established. The current research is an area of critical importance aimed to enhance our understanding of why otherwise intelligent individuals fail to develop adequate reading skills.

1.2 Defining Dyslexia

Within the research literature the terminology used to refer to individuals with reading difficulties varies. Some of the terms used are dyslexia, poor readers, impaired readers, reading disabled and reading disordered. In this review the term dyslexia will be used. Dyslexia is a specific learning disability that is neurobiological in origin (Lyon, Shaywitz, & Shaywitz, 2003). It is commonly defined as "*an unexpected difficulty in reading, occurring in children and adults who otherwise possess the intelligence, motivation, and schooling considered necessary for accurate and fluent reading*" (Shaywitz, 1998, pp. 307). As reflected in the definition of dyslexia, poor reading in itself does not imply a dyslexia diagnosis. While dyslexia can be familial and heritable (Pennington, 1994), environmental factors also play a role in the development of reading difficulties (Manis, Seidenberg, Doi, McBride-Chang, & Peterson, 1996). This makes it important to distinguish poor reading due to

low IQ or educational background from unexpected difficulties in reading (e.g., Stein, 2001; Talcott et al., 1998).

Achievement-ability discrepancy criteria, which require a substantial discrepancy between reading achievement and intellectual ability, have commonly been used in English speaking countries to diagnose dyslexia. It is still adhered to by the American Psychiatric Association in the text revision of the "Diagnostic and Statistical Manual of Mental Disorders-Forth Edition" (2000), which is the diagnostic guideline used by many health professionals. However, this approach has been widely criticised (Gustafson & Samuelsson, 1999; M. S. Meyer, 2000; Siegel, 1989; Stanovich & Siegel, 1994), with one major limitation being that that individuals with lower IQ scores, and hence no significant ability-achievement discrepancy, may be denied remediation services. More recent definitions of dyslexia have tended to minimise the relevance of achievement-ability discrepancies (Fletcher, Coulter, Reschly, & Vaughn, 2004; Stuebing et al., 2002; Wadsworth, Olson, Pennington, & DeFries, 2000), and consistent with the definition provided by S.E. Shaywitz (1998), there is growing evidence that low reading achievement along with IQ within normal limits is the best strategy for diagnosing dyslexia. Such a definition typically involves a standardised IQ score above 90, and a reading ability score below the 15th percentile (Snowling, 2000). However, as reading skills are presented on a continuum in the population, the definitional cut-off points used to establish individuals with and without dyslexia are arbitrary at best (Shaywitz et al., 1992).

In terms of reading research it is still important to obtain estimated IQ scores. This is to ensure that differences in performance on the experimental tasks cannot be explained by differing cognitive abilities between the dyslexia and control groups, as general ability, and in particular non-verbal ability, has been found to significantly

impact psychophysical task performance (Conlon, Sanders, & Zapart, 2004; Deary, 1993).

As highlighted by the definition of dyslexia, impaired reading is the main behavioural characteristic of the disorder. However, dyslexia may be better viewed as a syndrome (Miles, 1970, 1983; Stein, 2001), as the problems commonly extend to poor motor coordination, left-right confusion, and poor sequencing abilities in both the temporal and spatial domains. These associated features of dyslexia will be discussed in more detail in section 1.4. However, first the definition of reading ability will be discussed.

Reading skills have been measured in different ways within the research literature, and by definition consist of two distinct processes. These are word decoding and reading comprehension. Reading comprehension is assessed by reading of a text passage followed by questions about the text, while word decoding is commonly assessed by orally reading single words. While reading comprehension is the main goal of reading, it has been suggested single word reading may be a better measure of reading ability, as it measures more basic cognitive processes (Siegel, 1993). Word decoding skills are also fundamental to the comprehension of written text (Gough & Tunmer, 1986), with all other processes depending upon it (Snowling & Hulme, 2005). Hence, the current discussion was limited to word decoding.

Word decoding consists of phonological and orthographic components, with poor phonological skills being a core difficulty in dyslexia (Bruck, 1990, 1992; Frith, 1997; P. J. Hatcher, Hulme, & Ellis, 1994; Snowling, 1987, 2000; Stanovich & Siegel, 1994).

1.3 Two Types of Word Decoding Skills

1.3.1 Phonological Skills

Phonology is defined as the ability to access the underlying sound structure of words (Shaywitz, 1998). In relation to reading, phonological skills refers to the ability to break spoken words up into their composite sounds, and to transfer the visual representation of the words into their corresponding speech sounds (Castles & Coltheart, 1993). This process depends heavily upon learning how word sounds are represented visually by letters (Stein, 2003).

Phonological skills can be used to read words that adhere to print to sound conversion rules. An example is the reading of the word "hat", which can be accurately decoded by sounding out /h/ /a/ /t/. Past research has identified a number of different components of phonological processing, with three aspects being specifically pertinent to dyslexia. These are phonological awareness, verbal or phonological short-term memory and lexical retrieval (Ramus, 2004; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003; Wagner & Torgesen, 1987). A recent paper referred to these three dimensions as "the dyslexic triad" (Ramus & Szenkovits, 2008), linking phonological awareness to the conscious access, attention to, and manipulation of phonological representations and their sub-units. Verbal short-term memory is described in terms of the temporary storage of phonological representations, either by briefly copying the representations into phonological buffers or by actively processing them in the phonological loop (between input and output sub-lexical representations). Finally, lexical retrieval is critical for the recall of lexical phonological representations from long-term memory. One recent suggestion is that the phonological representations, or memory 'codes' of the 44 phonemes in the English language are actually intact in dyslexia, but that the short-term memory processes

used for retrieval of these phonemes are impaired (Ramus & Szenkovits). This produces a capacity limitation that prevents access to the phonological representations, with the deficit being most visible on tasks that are particularly demanding in terms of phonological access. If this argument is accurate, then verbal short-term memory would be the underlying core problem in dyslexia. This explanation is partly consistent with the 'anchoring deficit hypothesis' (Ahissar, 2007; Ahissar, Lubin, Putter-Katz, & Banai, 2006; Ahissar & Oganian, 2008). This hypothesis proposes that dyslexia is caused by the dynamics that link perception with perceptual memory through the implicit formation of stimulus-specific anchors. The perceptual anchor that guides the interpretation of subsequent stimuli is impaired in dyslexia, hence negatively influencing the ability to retain and explicitly retrieve recently presented stimuli.

Phonological skills are assessed in a number of ways. A discussion of all of these is far beyond the scope of this project. However, some of the methods used to assess the dimensions of the "dyslexic triad" are nonword decoding, phonological discrimination and phonological memory. Each will be briefly discussed. Phonological awareness is commonly assessed with nonword reading tasks. Nonwords are 'not real words'. They are made up of letter strings that can be accurately decoded following print to sound conversion rules. An example is the nonword "deprotenation'. These words have no meaning in English, but can be sounded out by segmenting the letter strings (dep/ro/ten/ation). Past research has consistently reported the nonword reading of dyslexia groups to be significantly poorer than that of skilled readers (Castles & Coltheart, 1993; Slaghuis & Ryan, 1999; Talcott et al., 1998; Witton et al., 1998). Phonological awareness has also been assessed using measures of phonological discrimination like a spoonerism task. These

tasks require participants to verbally transpose the first letters of two orally presented words (e.g., Michael Jackson becoming Jikal Mackson). As with nonword reading, individuals with dyslexia perform poorly on this task, both in terms of accuracy and in terms of response time (Conlon, Sanders, & Wright, 2009; J. Hatcher, Snowling, & Griffiths, 2002; Paulesu et al., 1996). Phonological or verbal short-term memory is often assessed through the repetition of orally presented digits or through the repetition of a series of nonwords, both with increasing length, with dyslexia groups being less accurate than control groups on these types of tasks (Brosnan et al., 2002; Ramus & Szenkovits, 2008; Snowling, 2000; Vellutino et al., 1996). Finally, lexical retrieval is generally measured using rapid naming tasks where participants are asked to name a grid of familiar objects as quickly as possible. This task also measures speed of phonological processing or phonological access, and has been associated with reading fluency (Snowling, 2000), with dyslexia groups performing more slowly than skilled readers on this task (Pennington, Orden, Smith, Green, & Haith, 1990; Snowling, vanWagtendank, & Stafford, 1998; Swan & Goswami, 1997).

1.3.2 Orthographic Skills

Orthographic skills refer to an awareness of the visual structure of the words in a language (Siegel, 1989). Orthography involves processing the visual form of words, such as the shape of the letters and the order of letters in words (Ellis, 1993). Orthographic skills are used to read irregular words that do not adhere to the print to sound conversion rules. These words are sometimes referred to as exception words. An example is the word 'yacht'. As there is no direct match between the graphemes and phonemes in the word, accurate decoding depends on the recognition of the global structure of the word (Castles & Coltheart, 1993).

Orthographic coding ability is often assessed using exception word reading. However, to be able to decode the orthographic features of a word an individual must have previously been exposed to, or learned, that word. Therefore, unless environmental factors such as text exposure have been controlled, a participants' exception word reading score may be confounded (Manis et al., 1996; Olson, Forsberg, Wise, & Rack, 1994a; Stanovich, Siegel, & Gottardo, 1997). While dyslexia groups show impaired orthographic skills when compared to control groups (Conlon et al., 2009; Cornelissen & Hansen, 1998; Talcott, Witton et al., 2000a), the independence of orthographic coding from phonology and semantics have been questioned (Seidenberg & McClelland, 1989; Vellutino, Scanlon, & Tanxman, 1994). This is because some exception words can be partly decoded following regular phoneme to grapheme conversion rules (Olson, Forsberg, Wise, & Rack, 1994b). However, orthographic coding may be particularly important for word decoding in English speaking countries, as English, with its many irregularities, has been found to have one of the hardest orthographies to master (Snowling & Hulme, 2005). Consistent with this, some research has found that in children poor orthographic skills may be a better predictor of overall reading ability than poor phonological skills (Talcott, Witton et al., 2000a).

1.4 Adult Classification of Dyslexia

Research has shown dyslexia persists into adulthood both for individuals classified with dyslexia in childhood (Shaywitz et al., 2003), and for individuals who report a significant history of undiagnosed reading difficulties (Lefly & Pennington, 2000). It has been suggested that in adult populations dyslexia is best classified by poor phonological decoding and poor reading fluency (Birch & Chase, 2004; Bruck,

1990, 1992, 1993; Lefly & Pennington, 1991; Wilson & Lesaux, 2001), along with poor verbal short term memory (Brosnan et al., 2002; Ramus & Szenkovits, 2008; Snowling, 2000). Poor orthographic processing has also been found in adult dyslexia groups (Conlon et al., 2009; Johnston et al., 2008; Lilleskaret, 2001).

Two groups of adults with dyslexia have been described. These are persistently poor readers and accuracy improved (or partly compensated) readers. Both groups have been found to demonstrate the behavioural difficulties of dyslexia outlined above. However, while the persistently poor reader group has poor word identification skills, the accuracy improved group has been found to demonstrate word identification skills in the low average, or even above average range (Shaywitz et al., 2003). This improvement in word decoding in some adults with dyslexia has been attributed to systematic reading remediation and high exposure to text (Bruck, 1992; Fink, 1998). Interestingly, the accuracy improved group has been found to be more likely to succeed academically, and are also more likely to enter university than the persistently poor reader group (Brunswick, McCrory, Price, Frith, & Frith, 1999; Paulesu et al., 2001). Linked to these findings it has been suggested that research using adults with dyslexia should obtain participants from higher educational settings, as this group's difficulties are more likely to stem from neurological processing deficits rather than from a lack of opportunity or exposure to text (Clay, 1987; Fink, 1998).

1.5 Associated Features of Dyslexia

Research has established some individuals with dyslexia display additional behavioural features, seemingly unrelated to reading. Some of these include poor balance and motor control (Fawcett & Nicolson, 1992; Nicolson et al., 1999), poor

development of automaticity (Fawcett & Nicolson, 1992; Nicolson & Fawcett, 1990), difficulties with map reading (Stein & Walsh, 1997), and difficulties distinguishing left from right (Miles, 1993). Behavioural deficits of this type have also been found at a brain processing level, and theoretical or neural explanations of these varied difficulties among individuals with dyslexia have included cerebellar abnormalities (Eckert et al., 2003; Harasty et al., 2001; Leonard et al., 2000; Rae et al., 2002), and cell abnormalities in the temporoparietal cortex (Galaburda, 1994; Galaburda & Kemper, 1979; Galaburda, Sherman, Rosen, Aboitz, & Geschwind, 1985; Humphreys, Kaufmann, & Galaburda, 1990; Larsen, Hoien, Lundberg, & Odegaard, 1990). The associated features of dyslexia have been explained within the framework of the magnocellular deficit hypothesis, with the generalised dysfunction of cells in the M system extending into the cerebellum and the posterior parietal cortex (Stein & Walsh, 1997). Both the cerebellum (Stein, 1986; Stein & Glickstein, 1992), and the parietal cortex (Ungerleider & Mishkin, 1982), predominantly receive M input, with the cerebellum being regarded as 'the head ganglion of the M systems' (Stein, 2001). The cerebellum is the brains' 'autopilot', specialising in automatic motor control and timing, while the parietal cortex is important for visuospatial analysis (Ungerleider & Mishkin). The visual system is discussed in more detail in the next chapter. While the focus of the current research was on mechanisms underlying processing in the magnocellular system, the companion parvocellular system will also be discussed to aid in the understanding of the neurological processes underlying the motion processing deficit in dyslexia.

CHAPTER 2: Structure and Function of the Visual System

2.1 Introduction

Physiological research on macaque monkeys and psychophysical research on humans has identified two semi-independent pathways (magno and parvo), in the visual system (Livingstone & Hubel, 1987; Rao, Zhou, Zhuo, Fan, & Chen, 2003). There is also a third pathway, the 'koniocellular' (K), pathway (Hendry & Reid, 2000), which is less studied and appears to respond selectively to stimuli that modulate the *S*-cones (Irvin, Casagrande, & Norton, 1993; P. R. Martin, White, Goodchild, Wilder, & Sefton, 1997). However, this pathway was not relevant to the current discussion, and will not be discussed further. The systems of interest to the current research project were the magnocellular (M or dorsal) and parvocellular (P or ventral) pathways (Merigan & Maunsell, 1993; Tootell, Dale, Sereno, & Malach, 1996). While the magnocellular pathway technically projects into the dorsal stream, as discussed later in this chapter, in this thesis the magnocellular pathway will be referred to as an overall system, including the pre and post cortical components of the visual M system.

2.2 Magnocellular and Parvocellular Pathways

The M system, sometimes referred to as the 'where system', is mainly responsible for processing coarse visual information related to object location, such as spatial relationships, and movement, (Girkin & Miller, 2001; Zeki, 1993). The P system, sometimes referred to as the 'what system', is mainly responsible for processing fine and detailed information related to object recognition, such as form, and object discrimination (Maunsell & Newsome, 1987; Ungerleider & Mishkin, 1982).

Consistent with the notion of two separate processing systems, M and P cells are anatomically and physiologically distinct (Leventhal, Rodiek, & Dreher, 1981; Livingstone & Hubel, 1988). This distinction is important in terms of the visual information they process. M cells are much larger than P cells (Kalat, 2001), and they are more vulnerable to damage during the rapid development of the foetal brain (Braddick, Atkinson, & Wattam-Bell, 2003; Vincent et al., 2000). They are also more vulnerable to degeneration with aging (Fischer & Hartnegg, 2002). Further, as the receptive fields of M cells are also large, they gather light from a larger area, leaving them more sensitive to coarse visual features, such as low spatial frequencies (Legge, 1978; Tolhurst, 1975b). The smaller receptive fields of P cells have been found to produce greater sensitivity to fine visual detail, such as high spatial frequencies (Lovegrove, Bowling, Badcock, & Blackwood, 1980; Mason, Cornelissen, Fowler, & Stein, 1993). Spatial frequency is measured in cycles per degree of visual angle at specific distances from the retina. It is commonly assessed by the width of the bars in a sinusoidal wave pattern. A sinusoid consists of stripes of dark and light bars, with one light and one dark bar constituting one cycle. The number of cycles covering 1 degree of visual angle at a viewing distance of 57 cm determines the spatial frequency of the pattern. A low spatial frequency, for example 1 c/deg, produces a small number of cycles within an area of visual angle at the retina, with higher spatial frequencies, for example 10 c/deg, producing a greater number of cycles projected on the retina within the same visual area (Simos, 2002). Figure 1 shows three spatial frequencies at progressively higher spatial frequencies (from left to right).
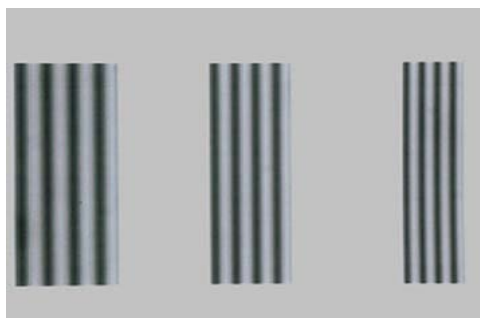
Figure 1. Sinusoid gratings presented at progressively higher spatial frequencies (Simos, 2002).

Research has shown that M cells show little responsiveness to spatial frequencies above 2 c/deg, while P cells show little responsiveness to spatial frequencies below 1.5 c/deg (Lennie, 1980). However, these estimates are not exact, and it has been suggested the spatial frequency at which sensitivity switches from M to P cells is somewhere between 0.2 and 3.5 c/deg (Tolhurst, 1975a). Further, M cells are more heavily myelinated than P cells, and consequently they have faster conduction velocities, firing at stimulus onset and offset. This makes M cells sensitive to high temporal frequencies (or movement), and they respond optimally to changes in the environment (Schwartz, 1999). Comparatively, P cells demonstrate little sensitivity to change or movement, and they respond best to stationary stimuli or low temporal frequencies (Merigan & Eskin, 1986; Merigan, Katz, & Maunsell, 1991). This means P cells process stimuli with a gradual, not abrupt onset. Temporal frequency refers to speed, or rate of change of the temporal qualities of a stimulus. It is measured in hertz (Hz) or cycles per second (Simos, 2002), and the higher the temporal frequency the faster the rate of change. Within the temporal domain it is generally agreed that low, medium and high temporal frequencies are measured by 1.0, 2.3 and 10 cycles per second respectively (Merigan & Eskin, 1986), with

temporal frequencies between 2.0 and 5.0 cycles per second representing a transitional phase between the M and P systems (Burbeck & Kelly, 1981). While different combinations of spatial and temporal frequencies have been used to differentially measure sensitivity in the M and P systems, physiological studies have shown that M cells respond selectively to a combination of low spatial and high temporal frequencies, while P cells respond optimally to a combination of high spatial and low temporal frequency information (Merigan & Eskin, 1986; Merigan, Katz et al., 1991; Merigan & Maunsell, 1993). This means a combination of spatial and temporal frequencies provides the highest degree of separation between the two systems.

M and P cells also differ in terms of their sensitivity to contrast. M cells have been found to have high contrast sensitivity, responding to luminance contrast (or brightness), as low as 2%. This means M cells respond better under low light conditions. In contrast, P cells have low contrast sensitivity, and rarely respond to luminance contrasts below 10% (Merigan & Maunsell, 1993). The two systems also respond differently to colour. M cells are largely 'colour blind' and are believed to be achromatic, as they respond poorly to colour alterations when the luminance of the colour is balanced (Merigan & Maunsell). However, P cells are highly sensitive to colour and colour change, regardless of colour luminance (Derrington & Lennie, 1984). The functional characteristics of the M and P systems are summarised in Table 1.

Table 1

Functional Properties of the M and P Systems (adapted from Lovegrove, 1993)

M pathway	P pathway
Sensitive to a combination of low spatial frequency (e.g., 0.5 c/deg), and high temporal frequency (e.g., 10Hz)	Sensitive to a combination of high spatial frequency (e.g., 10 c/deg), and low temporal frequency (e.g., 0.5Hz)
High contrast sensitivity	Low contrast sensitivity
Achromatic or 'colour blind'	Chromatic; Sensitive to colour
Fast transmission/response times; responding at stimulus onset and offset	Slow transmission times; responding throughout stimulus presentation

In addition to processing different types of visual stimuli, different neural locations within the M and P systems also process information about different visual qualities (Goldstein, 2002). The finding that specific neural locations are specialised to process specific types of stimuli is of relevance to the current research project, and the following sections will provide a review of the anatomical connections of the M and P systems, with particular emphasis being placed on the type of processing taking place in retinocortical and extrastriate areas.

The current project adhered to a hierarchical or feedforward model of visual processing. This model follows the steps proposed by Marr (1982), and is based on a cascade of filters that start from local analysis and progressively builds up to global 3D representations of a visual scene. The model is feedforward in that the selectivity of neurons at higher cortical areas are constructed by the ordered arrangement of feedforward inputs from lower visual areas (Van Essen & Maunsell, 1983). While there are other models, including extensive feedforward and feedback connections from higher visual areas (see Bullier, 2001 for a more extensive review), the hierarchical model is the most traditional and most frequently used model of visual processing reported in the research literature. Based on this model sensory sensitivity to global motion relies on the quality of information fed to V5 from lower retinocortical levels, as well as the efficiency of cooperative mechanisms within the

dorsal visual pathway. Retinocortical and dorsal system functioning is discussed below.

2.2.1 Retinocortical Functioning

The M and P pathways originate in the ganglion layers of the retina (Leventhal et al., 1981; Livingstone & Hubel, 1988). From the retina both pathways project via the optic nerve, optic chiasm, and optic tract to separate layers of the lateral geniculate nucleus (LGN) (Zeki, 1993). The LGN is a pre-cortical structure located in the thalamus. It consists of six distinct layers, two of which are magnocellular and four of which are parvocellular. The M layers (bottom two layers) receive input from the M ganglion cells, while the P layers (top four layers) receive input from the P ganglion cells (Merigan & Maunsell, 1993; Simos, 2002).

The M and P streams project further from the LGN, via the optic radiation, into Visual Area 1 (Merigan, Byrne, & Maunsell, 1991). Within the research literature this area is sometimes referred to as primary visual cortex, area 17, the striate cortex, or the calcarine cortex, but the term V1 will be used in this review. V1 is the lowest level in the visual cortex and it is located in the occipital lobe (Merigan & Maunsell, 1993). The two pathways up to V1 are illustrated in Figure 2.
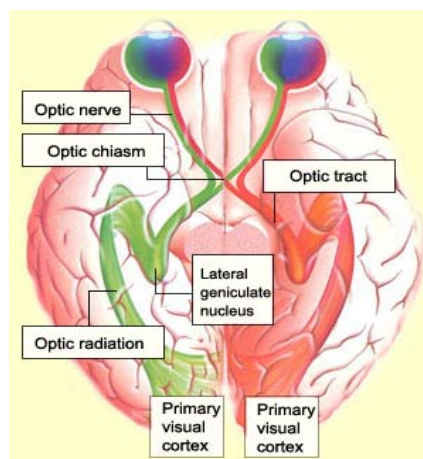
Figure 2: Visual streams from the retina to V1 (primary visual cortex). From Dubuc (2006).

V1 consists of six main layers, and the separation between the M and P pathways are still maintained at this level. Layer 4Ca receives mainly input from the M layers of the LGN, while layers 4Cβ and 4A receive mostly P input from the LGN (Simos, 2002). V1 is believed to represent the entire visual field projected onto the retina (Gattass et al., 2005), and it contains all the sub-modalities of vision, such as colour, motion, orientation, and depth (Simos). The role of V1 is to segregate incoming information, and to re-distribute different forms of information to specialised visual areas in the extrastriate cortex for further processing (Zeki, 1993).

At the level of V1, M and P cells can only detect local (or single) motion and form signals (Klein, 2000). Hence, while M cells at this structure can detect the direction of motion of a single stimulus (i.e., a single dot) they cannot detect the motion attributes of a stimulus when individual signals must be integrated to form a global whole (Vaney, He, Taylor, & Levick, 2001). Similarly, while P cells at V1 can detect the presence of a single stimulus, such as the orientation of a line, they cannot detect a shape that is constructed from a number of different components (DeWeerd, Desimone, & Ungerleider, 1996; Zeki, 1983). For example, while specific local

features of a face may be extracted, the overall face cannot be detected at this level. Global processing (the putting together or summating a number of signals which produces a percept of overall movement or a specific pattern), takes place in extrastriate areas beyond V1 (Newsome & Pare, 1988).

The anatomical segregation of the M and P pathways becomes less clear after V1. While accumulated evidence supports the existence of two functionally separate systems (ventral and dorsal) also in extrastriate regions (Simos, 2002), there is some evidence of intermixing of M and P input beyond V1 (Sincich & Horton, 2004; Zeki, 1993). A broad overview of the projection routes of the dorsal ('where') and ventral ('what') systems is shown in Figure 3.
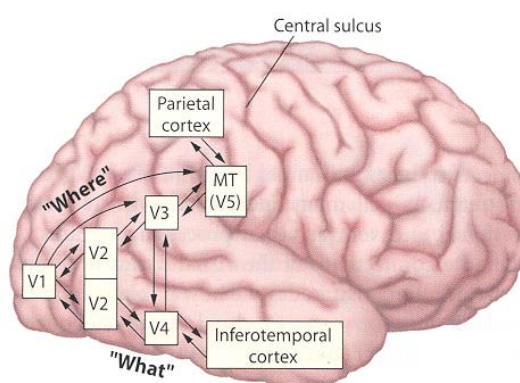
Figure 3. Broad overview of the projection routes of the ventral (P) and dorsal (M) systems (Gazzinga, Ivry, & Mangun, 1998).

2.2.2 The Dorsal Stream

From V1 input from the M system projects predominantly to the extrastriate dorsal stream (Garrett, 2003). Information travels from V1 through areas V2 and V3, into the middle temporal (MT) visual area (DeYoe & Van Essen, 1998; Merigan & Maunsell, 1993; Milner & Goodale, 1995) and the superior temporal (MST) cortex, before terminating in the area just behind the somatosensory cortex in the posterior

parietal cortex (PPC) (Merigan & Maunsell). The main location of interest for the current research project was the middle temporal visual area, referred to as MT in monkeys and visual cortical area V5 in humans. The term V5 will be used in this review. V5 is located in the posterior parietal cortex (PPC) in the dorsal bank of the superior temporal sulcus (Simos, 2002).

Visual detection is a hierarchical process in which the initial extraction of local motion is followed by a 'pooling' of these signals at a later global motion processing stage (Albright, 1984). V5 is the first location in the visual system where local motion signals are integrated to produce a global motion percept (Baker, Hess, & Zihl, 1991; Castelo-Branco et al., 2002; Newsome & Pare, 1988). Global motion processing involves a number of complex perceptual processes, and it is one method of distinguishing the functional properties of V5 from the lower levels in the visual system (Goldstein, 2002). Cells at V5 are arranged in columns according to the specific direction they prefer (Albright, Desimone, & Gross, 1984), and these columns code for a particular direction of motion in a restricted region of the visual field (Maunsell & Van Essen, 1983). Within the columns the local motion signals are integrated, summated, or segmented. This occurs because of the large receptive fields of cell groups in this visual area. These processes allow neurons at V5 to detect the motion attribute, for example speed or the direction of the stimulus motion (Braddick & Qian, 2001; Newsome & Pare, 1988; Simos, 2002).

While input into V5 is predominantly magnocellular, projected from the M layers of V1 (Maunsell & Van Essen, 1983), there is also evidence of some P input into this area. For example, area V5 receives input from lamina 4b of area V1, which receives input from both the M and P systems (Sawatari & Callaway, 1996). Nevertheless, lesions to the M layers of the LGN in primate brains have been found to

result in consistently reduced responses at V5, while no such effects have been found

at V5 when the P layers of the LGN have been impaired (Maunsell, Nealey, &

DePriest, 1990). Due to its specialised role in motion processing V5 is sometimes

referred to as the visual motion-processing centre of the brain (Zeki, 1993). There is

strong evidence that if V5 is damaged, global motion processing is severely degraded

(Britten, Shadlen, Newsome, & Movshon, 1992; Zihl, Von Cramon, Mai, & Schmid,

1991). Lesions to V5, though neural accidents such as strokes, have also been found

to severely impact humans' ability to discriminate motion from dynamic noise (Baker

et al., 1991; Hess, Baker, & Zihl, 1989; Zeki, 1991), with visual tasks tapping the

sensitivity of the M stream up to and including V1 being only slightly impaired in

these same individuals (Baker et al; Hess, Baker, & Zihl).

From V5 the M and dorsal system project into the posterior parietal cortex (PPC).

As the PPC is dominated by input from these pathways (Ungerleider & Mishkin,

1982), it can be viewed as a subset of the V5/MST area. Important functions at this

level include visuospatial analysis (Ungerleider & Mishkin, 1982) and the detection of

visual motion (Zihl, Von Cramon, & Mai, 1983; Zihl et al., 1991). The parietal lobe is

also involved in directing automatic attention (Posner & Raichle, 1997) and in

controlling sequential attention (Vidyasagar, 1999), eye-movements (R. A. Andersen,

1989), and peripheral vision (Ungerleider & Mishkin, 1982). Neuropsychological

studies have demonstrated that individuals with lesions to the PPC show severe

impairments in sensorimotor behaviour (Bremmer, Schlack, Duhamel, Graf, & Fink,

2001), and reading (Brunn & Farah, 1991).

2.2.3 The Ventral Stream

From V1, input from the P system projects predominantly to the extrastriate ventral pathway (Simos, 2002). Within this pathway visual area V4 has received the most attention in the literature. V4 occupies a zone of the neocortex that extends from the anterior bank of the lunate sulcus to the posterior bank of the superior temporal sulcus (Simos). Similar to V5 in the dorsal stream, V4 is the first location in the ventral stream where global information processing occurs (i.e., segmentation and integration of local signals). However, unlike V5, V4 does not respond to global motion (Schiller, 1996), and *f*MRI studies have shown that the two areas are activated by different types of tasks (Braddick, O'Brien, Wattam-Bell, Atkinson, & Turner, 2000).

V4 is thought to be the major intermediate level of the form (pattern) vision pathway from V1 to the inferior temporal cortex (Heywood, Gadotti, & Cowey, 1992; Merigan, 1996), and it is involved in the processing of fine visual details, (Merigan & Maunsell, 1993; Simos). Its most prominent role is that of processing global form (O'Brien, Spencer, Atkinson, Braddick, & Wattam-Bell, 2002) and complex visual patterns (DeWeerd et al., 1996; Gallant, Braun, & Van Essen, 1993; Gallant, Connor, Rakshit, Lewis, & Van Essen, 1996). V4 is also involved in processing perceived colour and colour constancy (Garrett, 2003; McKeefry & Zeki, 1997; Simos, 2002; Zeki, 1993).

From area V4, the ventral pathway projects into the inferior temporal cortex (DeYoe & Van Essen, 1998), located at the lower boundary of the temporal lobe (Garrett, 2003). This is an area essential for processes involving object recognition and discrimination (Maunsell & Newsome, 1987). While research has shown that V4 and V5 are parts of distinct functional brain systems, it has been estimated that the

ventral pathway receives approximately equal input from M and P sources (Stein, 2003). Area V4 receives input from the M and P systems directly through V1, and indirectly through V2, with V5 also projecting into the inferior temporal cortex (Zeki, 1993). For this reason P sensitivity was not assessed in the current study, with the focus being on motion processing in the M system.

An overview of the psychophysical measures of local and global motion processing administered as part of the current research will be provided in the next chapter of this thesis. This will be followed by a discussion on the effect of stimulus parameters on global motion sensitivity. While many tasks have been used to assess motion processing within the research literature, a review of all of these tasks was considered outside the scope of this project. However, some additional tasks will be introduced and described in Chapter 4, as part of reviewing the evidence for a motion processing deficit in dyslexia.

CHAPTER 3: Psychophysical Measures of Motion Processing

3.1 Introduction

A number of psychophysical tasks have been developed to measure motion processing in the M system. Two types of tasks that are frequently used are measures of local and global motion sensitivity. Local motion processing assesses an individual's ability to detect a single stimulus attribute, for example the direction of movement of a single stimulus. This type of task measures sensitivity at pre cortical levels in the visual system (Klein, 2000). Global motion processing tasks assess the visual system's ability to extract motion signals that contain a specific attribute from distractor or noise elements. These signals are then integrated to produce a global percept of movement. This complex neural process measure motion sensitivity at a cortical visual level, V5 (Newsome & Pare, 1988). While the focus of the current research project was on global motion processing, a local motion control task was also administered. All of the tasks administered were apparent motion tasks. This chapter will briefly describe apparent motion, outline each of the tasks administered and discuss how the use of different stimulus parameters can increase or decrease an individual's sensitivity to global motion.

3.2 Apparent Motion

In apparent motion tasks the perception of movement occurs as a result of the presentation of a series of computer generated 'stills' or animation frames (Snowden & Braddick, 1989b). While the frames are stationary, when they are viewed in rapid succession apparent movement is produced (Hill & Raymond, 2002). Figure 4 illustrates the generation of apparent motion in a two frame stimulus. In the first frame, the dot is presented at the top left corner of the screen, and in the second frame

it is presented towards the middle of the screen. If dot (1) is removed and replaced by dot (2) it looks to the human eye as if the dot has moved from the first to the second location, producing a percept of apparent motion. The greater the distance between the presentations of the two dots, the faster is the apparent speed of the stimulus. A percept of apparent motion can be generated using either single dot stimuli, as shown in Figure 4, or with more complex visual arrays, as shown in Figure 5. Apparent motion can be produced both at a local and at a global processing level. Each will be described in the following sections.

Figure 4. The generation of apparent motion in a two frame stimulus.

3.3 Local Motion Tasks

The task used to assess local motion sensitivity was a minimum dot displacement task adapted from Wood (2002). This is an apparent motion task where the signal dots undergo a constant displacement in a uniform direction, and although the apparent motion stimuli jump rather than move smoothly, the processing of the stimuli is believed to be mediated by an early motion system (J. M. Wood & Bullimore, 1995). The task was chosen because the format was compatible with the global motion measures administered (i.e., random dot kinematograms, described further in section 3.4). The local motion task is described in more detail below.

3.3.1 Minimum Dot Displacement

The minimum displacement task, or D_{min}, consists of two borderless stimulus panels where one panel is superimposed over the other. Both panels contain white (stationary) dots presented on a black background. In each trial the background panel remains stationary, while the superimposed panel is displaced in one of four directions (left, right, up or down), producing a percept of apparent motion. The task is illustrated in Figure 5.
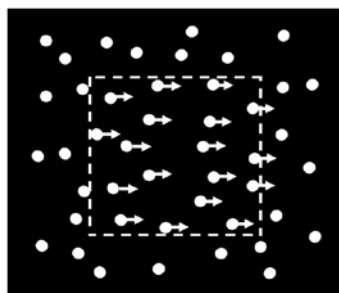
Figure 5. Example of a minimum displacement stimulus where the centre square moves towards the right

Sensitivity is calculated by the minimum displacement (or amount of movement) needed by an individual to detect that movement has taken place (i.e., displacement threshold) within an image (J. M. Wood & Bullimore, 1995). As the dots within the superimposed image are perfectly correlated and move as a whole or as a single image, only local or low level motion processes are activated.

3.4 Global Motion Tasks

Global motion processing differs from local motion processing because it involves the extraction and integration of local motion signals into a global whole. In a global motion task a proportion of the pixel elements or dots move coherently. The

direction of motion is perfectly correlated over successive screen refreshes (Talcott, Hansen et al., 2000), producing an apparent motion stimulus.

Two types of global motion task were administered as part of the current research; a coherent motion task and a motion transparency task. Each of these tasks are well established measures of global motion processing (Britten et al., 1992), and both are presented as random dot kinematograms (RDKs). RDKs are computer generated arrays of randomly spaced dots moving in different directions. Past research has found these types of tasks to be effective in discriminating between the performance of dyslexia and control groups (Stein, 2001), with *f*MRI studies demonstrating that both tasks preferentially activate area V5 in the M stream (Castelo-Branco et al., 2002; Tootell et al., 1996).

3.4.1 Coherent Global Motion

Functional MRI studies have established that coherent motion preferentially activates area V5 in humans (Tootell et al., 1996; Tootell et al., 1995; Zeki et al., 1991). Physiological investigations have demonstrated the same effect in monkeys (Britten et al., 1992; Newsome & Pare, 1988). In a coherent motion task an RDK is presented where a percentage of the dots are 'signal' dots that share a common characteristic, for example direction of motion. Correlated motion signals of this type are often presented in the horizontal plane moving either leftward or rightward. The remaining dots in the display are 'noise' dots, which move in random directions in the stimulus array at the same speed as the signal dots. The percentage of signal dots required to correctly detect the direction of stimulus motion determines global motion sensitivity. A typical coherent motion stimulus is illustrated in Figure 6. In panel (a) the motion signals are all random so no direction of global motion can be extracted,

and in panel (b) a percentage of the signal dots contain the motion signal with arrows pointing to the left.

(a)   *(b)*
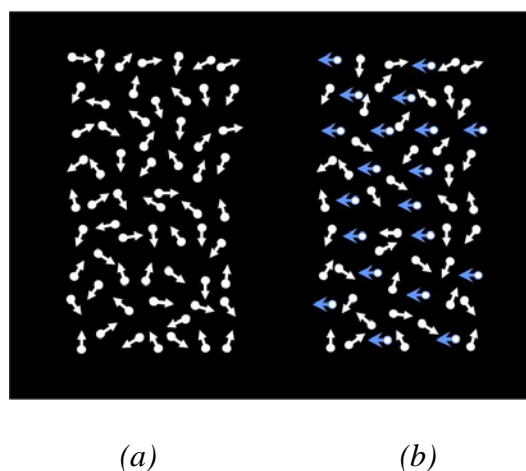
Figure 6. Example of a coherent motion stimulus. Panel (a) shows noise dots moving randomly. Panel (b) shows signal dots (moving to the left) surrounded by noise dots.

To detect the direction of global motion in a coherent motion task, two processes must occur. First, cells at V5 must perform a signal-to-noise analysis extracting the motion signal from the noise and second, these signals must be integrated across space and time to form a global motion percept (Braddick, 1993; Snowden & Braddick, 1989b). While cells at V1 are important in the extraction of the motion signals, these cells can only represent a single motion direction at a given location in space, meaning they cannot detect the global motion percept (M. Edwards & Greenwood, 2005). The processes and stimulus parameters involved in extracting and integrating global motion will be discussed in more detail in section 3.4.

3.4.2 Motion Transparency

The extent that V5 can process multiple coherent motion signals concurrently is measured psychophysically using motion transparency tasks. In this type of task an

RDK is presented with stimuli containing dots moving in two or more directions of correlated motion presented simultaneously within the same spatial location (Curran, Hibbard, & Johnston, 2007). When two directions of motion are presented simultaneously, with half moving horizontally (for example to the left) and half moving vertically (for example upward) two sheets of dots appear to "slip across one another", forming the transparent stimulus. To control for the motion opponency effect (the suppression of V5 neurons when motion in non-preferred directions is presented together with motion in preferred directions), as discussed further in section 3.4, the transparent sheets of dots are presented in separate depth planes (D. C. Bradley, Qian, & Andersen, 1995). This depth constraint provides a way of confining the filtering mechanism to a particular surface (Born & Bradley, 2005). An example of a motion transparency task is presented in Figure 7.
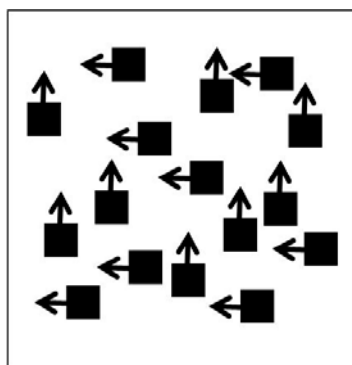
Figure 7. Example of a motion transparency stimulus where the directions of motion are up and left.

As seen from Figure 7, no noise dots are present in the display. The stimulus contains stimuli moving in two orthogonal directions with half the stimuli presented moving in each of these directions. This is a frequently used transparent motion

presentation. The neural processes involved in motion transparency detection differ from those involved in coherent motion detection. In a coherent motion task the unidirectional signal has to be extracted from the surrounding noise elements, and then integrated into an overall motion percept. Transparent processing however, involves the segmentation and grouping of two concurrent signals. Because two or more objects move over the same region of space, transparent motion can be perceived in two ways. First, the visual system can process the motion components simultaneously (M. Edwards & Greenwood, 2005). This means that representations of both motion signals are available to the perceptual system at the same time (Braddick, Wishart, & Curran, 2002). For this to occur the stimulus duration must be 250msec or less (Mulligan, 1992). If the duration exceeds 250msec participants can process the motion stimuli in a sequential, rather than simultaneous manner (i.e., first detecting one direction of motion then searching for a second), producing the second technique for detecting motion in transparent stimuli. Studies on the macaque monkey have demonstrated that the processing of transparent motion cannot occur at lower cortical levels, with neural activation not emerging until area V5/MT (Castelo-Branco et al., 2002; Snowden, Treue, Erickson, & Andersen, 1991; Stoner & Albright, 1992).

Research has been conducted into how the visual system in normal observers processes transparent motion. One study that used a temporal two alternative forced choice paradigm (2AFC) investigated how many motion signals a well functioning human visual system could perceive simultaneously (M. Edwards & Greenwood, 2005). In that study participants were required to determine which of two intervals presented contained the largest number of motion directions, with a maximum of five directions simultaneously presented. All of the dots were signal dots, and the signal intensity for each direction of motion was reduced as the number of directions

increased. For example, if there was one motion direction the signal intensity was 100%, while in an interval that contained five motion directions the signal intensity for each direction of motion was reduced to 20%. Before administering the task it was ensured participants were able to accurately detect one direction of motion at a signal intensity of 20%. Signal directions were randomised, and there was at least a separation of 45 degrees between each direction of motion. The results showed that participants could reliably process two directions of motion simultaneously. This is consistent with another study that used a 2AFC task, also reporting the motion transparency limit to be two planes (Mulligan, 1992). When the stimulus duration is longer than 250msec a greater number of directions can be detected. However, in this instance sequential, and not simultaneous, processing occurs. For example, observers can detect three signal directions when the stimulus duration is 2 seconds (G. J. Andersen, 1989). Other studies have reported that greater accuracy is obtained when orthogonal, rather than oblique signals are presented, with the motion streams being perceived independently if separated by more than 20 degrees (Braddick et al., 2002).

In terms of neural activity, cells at V5 are highly tuned to signal intensity. Past research has shown that the response of the cells increases in a linear manner with increased signal intensity, or the number of signal dots in the RDK (Britten, Shadlen, Newsome, & Movshon, 1993; M. Edwards & Badcock, 1998). One study that investigated the effect of signal intensity on coherent motion and motion transparency sensitivity found that while about 15% of the dots in a coherent motion task had to be signal dots for normal observers to be able to accurately identify the direction of motion, this number increased to about 42% for each signal direction for the transparency task (M. Edwards & Greenwood, 2005). Based on these findings it was concluded that the perceptual and attentional processing cost associated with the

processing of motion transparency is higher than that required for the processing of coherent motion. The three-fold increase in signal intensity implies that the neural activity needed to perceive transparent signals far exceeds that required to perceive a unidirectional signal.

3.5 The Effect of Stimulus Parameters on Global Motion Sensitivity

When producing global motion tasks the stimulus parameters used determine the sensitivity found. Seemingly small changes in the stimulus parameters can produce changes in sensitivity in normal observers, and affect the utility of global motion tasks in discriminating between the sensitivity of dyslexia and control groups (Stein, 2003).

Two of the parameters critical to consider when producing global motion tasks are the number of animation frames presented in the RDK (i.e., the number of 'stills' that make up the stimulus), and the lifetime of the signal dots (i.e., the dots that contain the directional signal). Dot lifetime refers to the number of frames that the signal dot moves across with an uninterrupted trajectory (Festa & Welch, 1997). At the end of the lifetime of a signal dot, the signal is transferred to another randomly selected dot within the stimulus field. Noise dots randomly change direction with each screen refresh. The minimum dot lifetime in a coherent motion task must be two animation frames for the percept of movement to be seen (as illustrated in Figure 7), and both the number of frames presented and the dot lifetime are determinants of the perceptual difficulty of the task. As the number of frames presented increases, and as the signal dot lifetime increases, sensitivity is increased. This occurs because of the greater capacity of the visual system to sample signal dots, producing greater neural stimulation (Festa & Welch). While the lifetime of the signal dots can be increased

past two animation frames, it should be limited to three or four frames to ensure that the direction of motion cannot be determined by tracking the trajectory of a single signal dot (Scase, Braddick, & Raymond, 1996).

As the number of animation frames presented in a single RDK increases, sensitivity to global motion also increases. This is referred to as sequential or temporal recruitment (McKee & Welch, 1985). Increasing the number of animation frames presented from 2 to 10 in a stimulus, while restricting dot lifetime to 2 animation frames produces a consistent increase in sensitivity in normal observers (Raymond & Isaak, 1998). Temporal recruitment occurs because the perceptual mechanisms of the visual system have more opportunities to detect and integrate the local motion signals across time (Raymond & Isaak), allowing for greater cooperation between motion analysers (Snowden & Braddick, 1989b).

The duration of a single animation frame and the total duration that the stimulus is presented influence the visual system's ability to integrate the individual motion signals. Two studies that manipulated the frame duration of an apparent motion stimulus reported different integration characteristics (Snowden & Braddick, 1989a, 1989b). When the frame duration was 20msec maximum sensitivity was not reached even when 8 animation frames were presented (total stimulus duration of 160msec). However, when the frame durations were 50msec or 100msec, maximum sensitivity was reached with presentation of between 4 and 6 frames (total stimulus duration ranging between 200-600msec). These results show that when the length of time that the stimulus is displayed increases, whether it occurs because of a longer frame duration or from presentation of a greater number of animation frames, sensitivity to global motion is increased.

The influence of dot density has also been investigated. Dot density refers to the total number of dots presented within a stimulus display, and it is measured in dots/deg^2, defined as the number of elements per square degree of visual angle in the area subtended by the stimulus (Talcott, Hansen et al., 2000). When the dot density is low the number of motion signals available within the receptive field of each motion detector is low. However, as dot density increases the signal dots are closer together in space, producing greater stimulation of receptive fields within motion detectors (Talcott et al., 1998). Few studies have evaluated the influence of dot density in normal observers, with little influence of dot density found (Barlow & Tripathy, 1997; Talcott, Hansen et al., 2000). The same has been reported for transparent motion tasks, with changes in dot density from 0.1 to 40 dots/deg^2 having little effect on accuracy (Braddick et al., 2002; Dakin & Mareschal, 2000). Taken together these findings suggest that in normal observers dot density appears to have little influence on the ability to integrate motion signals in global motion RDKs.

The presence of noise elements in the RDK is another critical parameter to consider. To extract signal from noise in a coherent motion task the perceptual system is required to ignore the noise elements and focus exclusively on the signal. Signal is defined as motion vectors in the preferred direction of the cell, and noise is defined as vectors in all other (non-preferred) directions (M. Edwards & Nishida, 1999). The percentage of signal dots required to perceive global motion increases as the number of noise dots in the RDK increases (M. Edwards & Greenwood, 2005). This effect has been explained in terms of motion opponency, or suppression (Born & Bradley, 2005), which means that V5 neurons do not respond as strongly to motion in their preferred direction when motion in non-preferred directions (i.e., noise) are also present in the display (Snowden et al., 1991). Motion opponency takes place to assist

V5 neurons filter out noise from the processing stream, and to assist the system in accurate motion detection. Hence, increased noise in the RDK increases the perceptual difficulty of the task, as it becomes harder for the system to detect the signal elements used in the first stage of coherence detection. In this way one can think about the global motion threshold as a way to establish an individuals' critical signal to noise ratio, which is how much noise can be present in the display for the visual system to be able to extract the signal elements (M. Edwards, Badcock, & Nishida, 1996).

Finally, the salience of the motion signal has an impact on motion sensitivity (Sperling et al., 2006b). Salience directs attention primarily through bottom-up processes (i.e., rapid and automatic) in a well functioning system. If the stimulus is sufficiently salient, signals will pop out of a visual scene (Itti & Koch, 2001). The most important factor for the computation of salience is feature contrast with respect to the contextual surround, rather than absolute feature strength, like motion, or other detailed characteristics of the features (Itti & Koch).

As outlined in this chapter, manipulating the stimulus parameters used when measuring global motion sensitivity influences sensitivity in normal observers. Importantly, this may also influence outcomes found in research on a motion processing deficit in dyslexia. Chapter 4 reviews the evidence for an M system deficit in dyslexia, and a number of theoretical explanations for a motion deficit in dyslexia are reviewed.

CHAPTER 4: The Visual Magnocellular Deficit Hypothesis of Dyslexia

4.1 Introduction

The visual magnocellular deficit hypothesis proposes that the reading problem characteristic of dyslexia is the result of a deficit in the magnocellular system. Explanations of this deficit are currently a topic of intense debate within the research literature. A sensory processing deficit beginning at the LGN is the most frequently reported explanation (e.g., Lovegrove, Bowling et al., 1980; Lovegrove et al., 1982; Stein & Walsh, 1997; Talcott et al., 1998). According to this explanation the sensory deficit produces reduced sensitivity throughout the magnocellular system, increasing in magnitude at extrastriate visual levels (Stein, 2001; Talcott, Hansen et al., 2000). Due to failures to replicate, and results inconsistent with a sensory deficit of this type, other explanations have been presented. These include a selective vulnerability in the dorsal stream, affecting only the processing of complex motion stimuli (e.g., Hill & Raymond, 2002; Raymond & Sorensen, 1998; White, Frith et al., 2006), and an explanation suggesting that the motion deficit in dyslexia is caused by a generalised deficit in noise exclusion, where dyslexia groups have specific difficulties when extracting signal from noise (e.g., Sperling et al., 2005, 2006b). Supporting evidence for each of these explanations will be reviewed in the following sections.

4.2 Sensory Processing Deficit in the Magnocellular System

The explanation that has received the most attention within the research literature proposes that groups with dyslexia have a sensory processing deficit in the magnocellular, but not parvocellular pathway of the visual system (e.g., Demb, Boynton, & Heeger, 1998; Eden et al., 1996; Farmer & Klein, 1995; Livingstone et al., 1991; Lovegrove et al., 1986; Stein, 2001, 2003; Stein & Walsh, 1997; Talcott,

Hansen et al., 2000; Talcott et al., 1998; Talcott, Witton et al., 2000b; Witton et al., 1998). It is argued the development of the M system in individuals with dyslexia is impaired, with the deficit present throughout the whole M system (Stein, 2001). Anatomical, electrophysiological and behavioural evidence have been used to support this argument. Evidence of a deficit at the level of the LGN and V1 will be presented first, followed by an overview of the evidence for a deficit at extrastriate cortical areas.

4.2.1 Sensory Processing Deficit at LGN and V1

4.2.1.1 Anatomical Evidence

Evidence of a structural deficit in the magnocellular, but not parvocellular, layers of the LGN has been obtained from a single autopsy study (Livingstone et al., 1991). Post-mortem brain examinations were performed on five adult males with dyslexia and on five controls. The findings demonstrated that the structure of the P layers of individuals with and without dyslexia were the same. However, the M layers of the dyslexia group were disorganised and abnormally underdeveloped. The M cells were on average 27% smaller and had thinner axons. Based on these findings it was proposed the deficit found in the M layers of the LGN would produce slower conduction velocities, reduced speed of processing and reduced sensitivity to the temporal attributes of a stimulus in individuals with dyslexia. The results of the autopsy study were interpreted to provide strong support for a sensory deficit in the M, but not P, system of individuals with dyslexia.

4.2.1.2 Electrophysiological Evidence

A number of electrophysiological studies have measured visual evoked potentials (VEPs) to investigate the different response properties of the magnocellular and parvocellular systems in individuals with dyslexia. Presentation of stimuli of low contrast and high temporal frequency, which are known to activate the M system (Merigan & Eskin, 1986; Merigan, Katz et al., 1991), has resulted in findings of reduced VEP amplitudes in dyslexia, compared to control groups. However, presentation of stationary, or high contrast, stimuli with high spatial frequencies, which are known to activate the P system (Merigan & Maunsell, 1993), have produced similar VEP amplitudes for dyslexia and control groups (Kubova, Kuba, Peregrin, & Novakova, 1996; Livingstone et al., 1991; May, Lovegrove, Martin, & Nelson, 1991). Further evidence of reduced activity in the M system of dyslexia groups has been found by surrounding the stimuli with a uniform-field flickering background (Lehmkuhle, Garzia, Turner, Hash, & Baro, 1993), and when stimuli of different velocities have been presented (Schulte-Korne, Bartling, Deimel, & Remschmidt, 2004).

However, some studies have not found any differences in VEP amplitude between dyslexia and control groups (Johannes, Kussmaul, Munte, & Mangun, 1996; Victor, Conte, Burton, & Nass, 1993). One study reported findings consistent with a deficit in the P system of the dyslexia group, while reporting M processing to be intact (Farrag, Khedr, & Abel-Naser, 2002). A more recent study reported reduced VEP amplitudes only in a small proportion of the dyslexia group (Vaegan & Hollows, 2006). The inconsistency in results has been attributed to poor selection of stimulus parameters (Schulte-Korne et al., 2004), and to the use of inappropriate selection criteria for the dyslexia and control groups (Slaghuis, 2007). For example, Victor et

al., used a wide age range of subjects (ages ranging from 6 to 46 years), and they relied primarily on a previous history of unexpected reading failure, rather than directly measuring evidence of poor reading skills in participants.

4.2.1.3 Psychophysical Evidence

A range of psychophysical techniques have been used to measure the sensitivity of poor and skilled reader groups to stimuli that assess characteristics of the magnocellular and parvocellular pathways at the LGN and V1. Some of these include minimum motion, visible persistence or gap detection, Ternus apparent motion, flicker fusion, and frequency doubling, with the most commonly used technique measuring spatiotemporal contrast sensitivity.

Few studies have investigated the minimum motion threshold in dyslexia, with the results to date producing inconsistent results (see section 3.2 of the last chapter for a review of the minimum motion task). One study that used adult participants reported the D_{min} processing of the dyslexia group to be significantly impaired compared to that of the control group (Everatt, Bradshaw, & Hibbard, 1999). However, examination of individual performance within the dyslexia group showed a high degree of variability within the data set, with some individuals in the dyslexia group having higher sensitivity than the skilled reader group. The significant between groups effects found were consistent with the magnocellular deficit hypothesis. In a single study that measured D_{min} in children with dyslexia evidence of a significant between groups effect was not found (Dougherty et al., 1997). Little information was provided for the Dougherty et al., study, and hence the potential differences in stimulus parameters between this task and other studies could not be assessed.

In gap detection and visible persistence studies the length of time the stimulus percept persists after the stimulus has been physically removed is assessed. Persistence is measured by presenting sine or square wave gratings which alternate with a blank interstimulus interval (ISI). Participants then report whether they see the blank interval between the gratings or not, with failure to report the interval meaning the visible persistence of the first stimulus was still present at onset of the second stimulus (Cestnick & Coltheart, 1999). Visible persistence is believed to reflect ongoing neural activity generated by the presented stimulus (Lovegrove, 1993), and in normal observers durations of visible persistence increase with increased spatial frequency (Bowling & Lovegrove, 1980; G. E. Meyer & Maguire, 1977). However, a number of studies have demonstrated that the visible persistence of dyslexia groups do not follow this pattern of performance. Dyslexia groups have more difficulties than skilled readers in detecting the blank ISI at low spatial frequencies, but not at high spatial frequencies (Au & Lovegrove, 2001; Badcock & Lovegrove, 1981; DiLollo, Hanson, & McIntyre, 1983; Lovegrove, Heddle, & Slaghuis, 1980; Slaghuis & Lovegrove, 1984, 1985; Slaghuis, Lovegrove, & Davidson, 1993). These findings have been explained in terms of a selective deficit in the M system in dyslexia (Lovegrove et al., 1986). This interpretation is consistent with research that has used uniform-field masking to reduce M system involvement in the task, reporting no differences in visible persistence between the poor and skilled reader groups (Slaghuis & Lovegrove, 1984). However, from a methodological perspective gap detection and visible persistence studies have been criticised, as the measurement of visible persistence is determined by a subjective judgement, potentially providing unreliable data (Georgeson & Georgeson, 1985).

One way this criticism has been addressed has been to use a Ternus apparent motion task to obtain a measure of visible persistence in dyslexia groups. The Ternus task allows for illusions of movement to be created by presenting three equidistant and horizontally arrayed elements. The squares are briefly presented (frame 1), then re-presented by having moved one imaginary equidistant square and flashed on the screen again (frame 2). A number of altering presentations of frame 1 and 2 are given. The task differs from the traditional visible persistence measures in that the Ternus display is multistable, and depending on the ISI the observer will see one of two mutually exclusive percepts. These are group motion (which occurs when the ISIs are long), and element motion (found when the ISIs are short). Consistent with research using the traditional measure of visible persistence, a number of studies have found the dyslexia group requires longer ISIs to detect group movement on the Ternus task when compared to skilled readers (Cestnick & Coltheart, 1999; Kim, Davis, Burnham, & Luksaneeyanawin, 2004; Slaghuis & Ryan, 1999; Slaghuis, Twell, & Kingston, 1996). One study that employed a modification of the Ternus task to control for the effect of inattention reported that while the performance of the dyslexia group improved with the modification, significantly longer ISIs were still required to perceive group movement by the dyslexia than the control group (Davis, Castles, McAnally, & Gray, 2001). While these results have been used as support for a sensory processing deficit in the magnocellular system of dyslexia groups, not all studies have found significant between group differences in performance based on the Ternus task (Jones, Branigan, & Kelly, 2008).

Measurement of sensitivity to contrast (contrast sensitivity function, CSF) has frequently been used to investigate the response properties of the magnocellular and parvocellular systems. Contrast sensitivity thresholds are calculated as the minimum

contrast required by an individual to detect the presence of a spatial pattern, or to detect the presence of movement or flicker in a stimulus. Hence in these types of studies stimulus detection, not identification, is required for successful task performance. Imaging studies have demonstrated that tasks that measure CSFs activate motion processing at the LGN and V1 (Crewther & Crewther, 1990; Movshon et al., 1987).

The initial findings regarding an M system deficit in dyslexia originated from studies that measured spatial and temporal CSF. The first CSF studies in dyslexia were conducted by Lovegrove and colleagues. In those studies the dyslexia groups were less sensitive than the control groups when presented with spatial frequencies of 2 and 4 c/deg, while their sensitivity was equal to, or higher than, the controls when presented with spatial frequencies of 12 or 16 c/deg (Lovegrove, Bowling et al., 1980; Lovegrove et al., 1982; F. Martin & Lovegrove, 1984). Additional studies assessed sensitivity when the stimuli were temporally modulated. Using temporal frequencies between 2 and 20 Hz, the dyslexia group was less sensitive than the controls to all of the temporal frequencies presented, with increasing between group differences found as the temporal frequency of the stimulus increased (Brannan & Williams, 1988; F. Martin & Lovegrove, 1987)**.** Dyslexia groups are also significantly less sensitive than controls on measures of spatial frequency doubling (Pammer & Wheatley, 2001) and flicker fusion (Brannan & Williams, 1988; Talcott et al., 1998). The critical flicker fusion frequency is the highest temporal frequency at which flicker can be perceived, while spatial frequency doubling consists of a flickering coarse grating presented at very low contrast so that it is detected only by M cells, producing an illusion that the stimulus consists of twice as many stripes as it does in reality (Stein, 2003).

In terms of research that has measured CSF, the findings from the original studies have been criticised based on evidence that both the M and P systems are responsive to some of the stimuli regarded as exclusively stimulating the M system. One example is the use of spatial frequencies of 2 and 4 c/deg (Skottun, 2000), as the spatial frequency at which sensitivity switches from M cells to P cells has been estimated to be somewhere between 0.2 and 3.5 c/deg (Tolhurst, 1975a). In addition physiological research has found that the use of low spatial or high temporal frequency on its own is not a sensitive measure of M system functioning. A number of studies have demonstrated that the M system is most responsive to stimuli with a *combination* of low spatial (e.g., 1 c/deg) and high temporal (e.g., 10 c/deg) frequency, with the P system being most responsive to the combination of high spatial and low temporal frequency (Merigan, Byrne et al., 1991; Merigan & Eskin, 1986; Merigan & Maunsell, 1993). When contrast sensitivity has been investigated in dyslexia and control groups by presenting stimuli that assess the sensitivity of the two systems more directly, the dyslexia group has been found to demonstrate reduced sensitivity to stimuli that activate the M, but not the P system (Felmingham & Jacobson, 1995; F. Martin & Lovegrove, 1987; Pellicano & Gibson, 2008; Slaghuis & Ryan, 1999) .

The results obtained from CSF research are not undisputed. Some studies that have used stimuli designed to maximally activate the M and P systems have failed to replicate findings of an M system deficit in the dyslexia group (Cornelissen et al., 1995; Hayduk, Bruck, & Cavanagh, 1996; Spinelli et al., 1997; Walther-Muller, 1995; Williams, Stuart, Castles, & McAnally, 2003). Based on these inconsistent results some researchers have suggested inattention, and not a magnocellular deficit, explain the contrast sensitivity losses seen in dyslexia groups (Stuart, McAnally, & Castles,

2001). This argument was based on reports that inattention, or attention deficit disorder, sometimes co-occur with dyslexia (Willcutt & Pennington, 2000). Stuart et al produced a computer simulation to mimic the response pattern of participants displaying low concentration on a measure of contrast sensitivity using a standard adaptive staircase procedure. Based on the simulation it was concluded that poor attentional vigilance when performing psychophysical tasks could explain the reduced sensitivity found in the dyslexia group. However, this finding is not consistent with reports that dyslexia groups are equally, or more sensitive than control groups in response to high spatial frequencies (Lovegrove, Bowling et al., 1980; Mason et al., 1993) and with reports that no differences exist in the vigilance of adults with and without dyslexia (Conlon et al., 2004). The inconsistent results of the CSF studies, as highlighted by Skottun (2000), has led to much controversy in the literature concerning both the presence of, and the explanation of, an M system deficit in dyslexia. The relevance of contrast sensitivity for the determination of M system functioning has also been discussed (e.g., Habib, 2000). There are however, several important issues concerning the measurement of contrast sensitivity.

The first of these issues, while not limited to CSF studies, is the issue of participant selection. A number of CSF studies that reported no significant difference in performance between their dyslexia and control groups (Cornelissen et al., 1995; Hayduk et al., 1996; Spinelli et al., 1997) included participants with a different profile of impaired reading skills than that of children used in previous studies where an M system deficit was originally reported (Lovegrove, Bowling et al., 1980; Slaghuis & Lovegrove, 1984). An important characteristic of the children used in the original studies was that they had significant phonological difficulties, with the individuals with the most severe phonological difficulties being the ones with reduced contrast

sensitivity. A similar reading profile was found in a study that investigated directional motion contrast sensitivity to drifting gratings in groups of children with and without dyslexia (Slaghuis & Ryan, 2006). While there was no difference in sensitivity between the two groups when the dyslexia group was taken as a whole, children with the most global reading problem (mixed phonological and orthographic difficulties) were the ones with a concurrent motion deficit. This difference in participant selection criteria may explain the non-significant findings obtained from a contrast sensitivity study where the dyslexia group consisted of individuals with poor orthographic skills only (Spinelli et al., 1997). The suggestion of a subgroup of individuals in the dyslexia group with a motion deficit is not new. The first reports of a dyslexia subgroup with a motion deficit were produced in 1985 (Slaghuis & Lovegrove, 1985), and they are consistent with more recent reports of reduced contrast sensitivity only in a proportion of the dyslexia group (e.g., Borsting et al., 1996; Ridder, Borsting, Cooper, McNeel, & Huang, 1997; Slaghuis & Ryan, 1999; Spinelli et al., 1997). Based on different measures of temporal contrast sensitivity current estimates suggest about 24% of children (Pellicano & Gibson, 2008), and 59% of adults with dyslexia (Johnston et al., 2008) have a motion processing deficit.

Second, different stimulus parameters and methodologies have been used when measuring contrast sensitivity. For example, in some studies CSF has been measured using stimuli of high luminance (Cornelissen et al., 1995), which stimulates mainly the P, and not the M system (Dobkins, Gunther, & Peterzell, 2000). Further, and more importantly, the methodology used when measuring CSF has been found to influence the research outcome. Recent findings have suggested that the reduced sensitivity of the dyslexia group could be explained by a difficulty in performing a two interval, two alternative forced choice (2AFC) task, because of an impairment

found when processing stimuli that are presented sequentially (Ben-Yehudah & Ahissar, 2004; Ben-Yehudah, Sackett, Malchi-Ginzberg, & Ahissar, 2001). In a 2AFC task a target stimulus is presented in one interval and is absent in the second. Participants must determine in which interval the stimulus was presented. When presented simultaneously both stimuli are present in different panels (i.e., different spatial locations) on the computer screen. If a temporal, or sequential, method is used one stimulus is presented followed by a variable interstimulus interval followed by the second stimulus panel. The argument of an impaired judgement of temporal order in dyslexia groups is consistent with a recent study that administered several different paradigms to assess temporal contrast sensitivity (Ben-Yehudah et al., 2001). The results showed both reduced and normal CSF thresholds within the same group of participants, with the performance of the dyslexia group not differing from the control group when the stimulus was presented in a simultaneous 2AFC paradigm. However, Ben-Yehudah et al., reported impaired functioning to both drifting and flickering gratings in the dyslexia group when the stimulus was presented sequentially (temporal 2AFC), which is the way the Lovegrove group and others (e.g., Borsting et al., 1996), have presented their CSF tasks. Based on their findings, Ben-Yehudah et al. suggested the reduced sensitivity of the dyslexia group in response to CSF stimuli might be due to their limited ability to retain-and-compare perceptual traces across brief intervals, meaning that this group may have perceptual memory difficulties. This is consistent with findings that dyslexia groups have poor verbal short-term memory (Amitay et al., 2002; Brosnan et al., 2002; Siegel, 1999).

Third, while the early research on M deficits in dyslexia focused on functioning at the level of the LGN and V1, the extent that a deficit in the M system at a pre-cortical level can be sensitively and consistently measured has been questioned.

Supporters of the sensory deficit explanation highlight that the M deficit at the level of the LGN is 'subtle', with a restricted range of measurement obtained when sensitivity thresholds are assessed at this visual level (Stein & Walsh, 1997). Further reductions in sensitivity have been predicted to occur at extrastriate visual levels because of a multiplicative effect of the sensory M system deficit (Stein, 2001). A current research focus in dyslexia has been M processing at extrastriate visual levels (V5) in the dorsal stream. More consistent evidence of an M deficit in dyslexia has been found in response to more complex motion processing tasks that stimulate the M pathway and motion detectors in extrastriate dorsal areas.

4.2.2 Sensory Processing Deficit in the Dorsal Visual Pathway

The extrastriate dorsal stream is generally considered to be part of the magnocellular system as it predominately receives input from the M pathway (Maunsell & Van Essen, 1983). As outlined in Chapter 2, area V5 in the dorsal stream specialises in motion processing (Baker et al., 1991; Merigan, Katz et al., 1991; Newsome & Pare, 1988), and for this reason it has become the focus for studies investigating M system functioning in the dorsal visual stream. Both electrophysiological and psychophysical techniques have been used to assess sensitivity in dyslexia groups in this visual area. The following sections will review the major findings in the literature, beginning with findings from anatomical and electrophysiological studies using *f*MRI and magnetoencephalography (MEG).

4.2.2.1 Anatomical Evidence

Further evidence of a structural difference in the magnocellular system of individuals with dyslexia, relative to controls, was obtained from a post-mortem

examination reporting abnormal symmetry in the posterior parietal cortex (Galaburda, Lemay, Kemper, & Geschwind, 1978) into which the M and dorsal streams project. In addition, a greater proportion of ectopias, or brain 'warts', have been found around the left temporoparietal language areas of individuals with dyslexia when compared to controls (Galaburda & Kemper, 1979). Ectopias are small outgrowths of cortical neurons that in the course of neural migration have missed their target in the cortex and escaped into the molecular layer through a breach in the outer lining membrane. They are associated with widespread disruption of normal brain connections (Stein, 2001).

4.2.2.2 Electrophysiological Evidence

There have been two influential studies that have used *f*MRI to assess the level of neural activity at V5 in dyslexia and control groups. One of these studies assessed the ability of dyslexia and control groups to discriminate between different speeds on a speed discrimination task (Demb, Boynton, & Heeger, 1998), while the other recorded neural activity when adults with and without dyslexia viewed a coherent motion stimulus (Eden et al., 1996).

On the speed discrimination task *f*MRI activity was recorded while five adults with dyslexia and five adult controls viewed two sequentially presented 0.4 c/deg gratings move at different speeds (Demb, Boynton, & Heeger, 1998). The baseline speed was 20.8 deg/sec. Compared to the control group the dyslexia group demonstrated reduced neural activity at V1 as well as in an area corresponding to V5. The corresponding assessment of psychophysical task performance showed that the dyslexia group required significantly larger speed differences than the control group to accurately discriminate between the two speeds. An important methodological

strength of the study was that both *f*MRI and psychophysical task performance were assessed concurrently; demonstrating both reduced neural activation and reduced psychophysical sensitivity in response to the task. Reduced neural activity at V5 was also found when adults (6 with dyslexia and 6 controls) were presented with a global motion stimulus (Eden et al., 1996). Neural activity at V1 did not differ for the dyslexia and control groups. No corresponding psychophysical evidence of reduced sensitivity in the dyslexia group was reported on the task.

Further studies have recorded whole-scalp MEGs (Vanni, Uusitalo, Kiesila, & Hari, 1997) or measured VEPs (Scheuerpflug et al., 2004) in response to global motion stimuli. Both studies failed to show reduced activity in the dyslexia groups relative to control participants. However, it is important to note that Vanni et al. used a stimulus speed of 2.5 deg/second, which may have produced insufficient stimulation to V5. Moreover, while VEP differences were not found on the measure of global motion processing used, reduced sensitivity was found on the same measure psychophysically (Scheuerpflug et al.), suggesting there were processing differences between the two groups.

4.2.2.3 Psychophysical Evidence

Evidence for a motion deficit in extrastriate regions in individuals with dyslexia has been obtained using speed discrimination and global motion tasks. For example, reduced sensitivity on a speed discrimination and a global motion task was obtained using a sample of 19 adults with, and 17 adults without, dyslexia (Wilmer, Richardson, Chen, & Stein, 2004). These effects remained significant after the variance attributed to intellectual ability were controlled. Importantly, no between

group differences in sensitivity were found for a corresponding measure of global form processing.

A commonly used measure to assess sensitivity at V5 in dyslexia is coherent (global) motion. Substantial evidence exists supporting an association between coherent motion sensitivity and dyslexia. The first psychophysical study to measure global motion sensitivity in groups of children and adults with dyslexia reported these groups had reduced sensitivity to coherent motion compared to age matched controls (Cornelissen et al., 1995). Substantial overlap in motion sensitivity thresholds in dyslexia and control groups, together with the finding that the dyslexia group was less sensitive on the coherent motion task, but not on a measure of contrast sensitivity, led to the suggestion that a subset of individuals with dyslexia may have a specific motion processing deficit at a parietal level, encompassing V5. Based on the same findings, but taking into account the high photopic luminance levels used in the CSF study, an alternative explanation was proposed (Stein & Walsh, 1997).

Stein and colleagues (e.g., Stein, 2001; Stein, Talcott, & Walsh, 2000; Stein & Walsh, 1997; Talcott, Hansen et al., 2000) explain the sensory processing deficit, found inconsistently when contrast sensitivity was measured, and more consistently using measures of global motion processing in the following way. At a low level in the magnocellular system the M deficit is subtle and the group effect size small, producing difficulties obtaining consistent between group effects on measures of contrast sensitivity. Increased sensitivity losses at extrastriate levels occur because of a 'multiplication' or 'cascade effect' caused by the anatomical connections of the M stream, with the slight impairment at the level of the LGN increasing in magnitude as increasingly poor quality inputs reach the higher levels in the hierarchical M pathway. These effects occur for two reasons. First, because of the deficit at LGN less motion

information reaches V5, which means that fewer neurons are activated at this level, making it more difficult for poor readers to detect the presence of global motion. Second, due to the reduced quality of the input from the LGN and V1 to area V5, cellular development in this area is also poor, manifesting itself in terms of poor structural integrity, with a smaller number of cells with reduced cell sizes (Stein & Walsh). As the ability to detect global motion depends on the successful integration of local motion signals both over space (i.e., dot density) and time (i.e., across frames) the fewer and more disorganised motion cells at V5 in individuals with dyslexia produce spatial and temporal undersampling of the incoming motion stimuli (Stein, 2003). One consequence of this undersampling may be poor temporal recruitment (Talcott, Hansen et al., 2000). Based on this explanation the sensory deficit by itself is regarded as sufficient to explain reduced sensitivity at the LGN, V5, along with reduced parietal (e.g., attention) and cerebellar (e.g., motor control and timing mechanisms) functioning, as these areas rely heavily on input from the M and dorsal streams.

Since 1995 numerous psychophysical studies have measured sensitivity to global motion in dyslexia groups, and studies that have used samples consisting of both children (Cornelissen & Hansen, 1998; Cornelissen et al., 1995; V. T. Edwards et al., 2004; Pellicano & Gibson, 2008; Raymond & Sorensen, 1998; Slaghuis & Ryan, 1999; Solan, Shelley-Tremblay, Hansen, & Larson, 2007; Talcott et al., 2003; Talcott et al., 2002; Wright & Conlon, In Press) and adults (Conlon et al., 2004; Cornelissen, Hansen, Gilchrist et al., 1998; Everatt et al., 1999; Hansen, Stein, Orde, Winter, & Talcott, 2001; Ridder, Borsting, & Banton, 2001; Roach & Hogben, 2007; Talcott, Hansen et al., 2000; Talcott et al., 1998; Wilmer et al., 2004; Witton et al., 1998) have found the dyslexia groups to have reduced coherent motion sensitivity

compared to controls. These findings have been strengthened by studies that have assessed both M and P processing in extrastriate areas. One study presented a coherent motion and a coherent form task to a group of adults with (n = 15) and without (n = 34) dyslexia (Hansen et al., 2001). The coherent form task is a parallel (spatial) task to the coherent motion task, and is designed to measure parvocellular sensitivity at V4. The results showed that while the dyslexia group was significantly less sensitive to the coherent motion stimulus there were no differences in sensitivity found for the reader groups on the form task. Additional evidence for a deficit at V5, but not at V4, came from a further study that assessed sensitivity to global form and global motion in adults with and without dyslexia (Wilmer et al., 2004). Using the same tasks as Hansen et al. they found reduced sensitivity in the dyslexia group in response to global motion, but not to global form.

However, not all studies have found reduced sensitivity to coherent motion in the dyslexia group (Amitay et al., 2002; Hill & Raymond, 2002; Hulslander et al., 2004; Kronbichler et al., 2002; White, Milne et al., 2006) and this has added to the debate concerning the presence of a visual M system deficit in dyslexia. However, consistent with findings of lower level visual sensitivity, poor global motion processing may only occur in a proportion of individuals with dyslexia (Stein, 2001), Some recent studies have reported the global motion deficit to affect from 16% (Heath, Bishop, Hogben, & Roach, 2006) to 78% (Solan et al., 2007) of individuals with dyslexia, depending on the classification method used, with deviance analyses producing estimates around 30% (Conlon et al., 2009; Reid, Szczerbinski, Iskierka-Kasperek, & Hansen, 2007). Of particular interest is a recent study that assessed both contrast sensitivity and global motion sensitivity in a group of children with and without dyslexia. Based on a deviance analyses approach (where individuals scoring

more than 1.65 standard deviations above the control group mean were classified with a deficit), it was estimated that 36% of the dyslexia group had a global motion processing deficit (Pellicano & Gibson, 2008). Comparatively, 24% of the same dyslexia group had a specific deficit on the measure of flicker sensitivity used. The finding of poorer sensitivity at higher, when compared to lower, processing areas in the M system is consistent with the magnocellular deficit hypothesis and the 'cascade effect'.

As not all individuals with dyslexia have a motion coherence deficit, some studies may not obtain evidence of reduced global motion sensitivity in dyslexia groups. This has been highlighted within the research literature to occur as a result of small sample sizes, recruitment biases and simply chance (White, Milne et al., 2006). Participant selection criteria may also contribute to the negative results obtained. For example, one study that reported no significant differences in coherent motion sensitivity between groups of children with (n = 20) and without (n =20) dyslexia assessed children based on reading fluency and spelling, and did not provide an assessment of the intellectual ability of their participant groups (Kronbichler et al., 2002). As no significant association has been found between reading fluency and global motion sensitivity (Wilmer et al., 2004), this group may not have had the characteristics associated with an M system deficit.

Of particular interest to the current study are the stimuli parameters that have been used in studies that have assessed sensitivity to global motion, as they also have a significant influence on the results obtained. The importance of specific manipulations in terms of influencing processing capacity at V5 has been highlighted as an important issue when discriminating between dyslexia and control groups (Stein, 2003). If insufficient neural sampling occurs the perceptual load of the task is

too high, and neither dyslexia nor control groups are able to accurately detect the global motion stimuli. If the extent of the neural sampling allowed by the task is too high, producing a low perceptual load, the task may not discriminate between the groups in a sensitive manner. One example of a study where the perceptual load was too high assessed coherent motion sensitivity in a groups of adults with (n = 16) and without (n = 16) dyslexia. The stimulus was of very low luminance, and was produced to maximally stimulate the M system (Ramus et al., 2003). Due to the high perceptual load insufficient neural samples were obtained by either reader group to generate sensitive threshold estimates, with two participants (one skilled reader and one individual with dyslexia) being unable to perform the task even at 100% coherence. A further study that did not find reduced global motion sensitivity in the dyslexia group used high dot density stimuli presented within a small area of the visual field (Hill & Raymond, 2002), allowing the visual system to sample a greater proportion of the signal across a reduced neural area. Despite these findings the influence of stimulus parameters when discriminating between the coherent motion sensitivity of dyslexia and control groups have been largely ignored, possibly explaining some of the inconsistent findings reported.

Evidence that the stimulus parameters used can influence global motion sensitivity in individuals with dyslexia was obtained from a study that manipulated the temporal and spatial properties of a coherent motion stimulus. The influence of dot size, stimulus duration and dot density on motion sensitivity in groups of adults with (n = 10) and without (n = 10) dyslexia was investigated (Talcott, Hansen et al., 2000). The results of the study showed that the dyslexia group was consistently less sensitive than the control group (magnitude of effect was similar) regardless of the size of the dots presented. Sensitivity was also consistently poorer regardless of the

stimulus duration used (ranging from 200msec to1804msec, corresponding to 4 and 36 animation frames). However, increased sensitivity was found for the dyslexia group when dot density was increased. While the skilled reader group was largely unaffected by an increase in dot density, with no improvements found beyond a dot density of 3.1 dots/degree^2, the sensitivity of the dyslexia group continued to increase up to a dot density of 12.2 dots/deg^2. At this dot density there was no significant between group differences in sensitivity, suggesting that the dyslexia group could perform as well as the controls if the signal strength was adequately high. These findings were interpreted as evidence for poor structural integrity of the M stream at V5 in individuals with dyslexia. It was argued that there may be fewer cells at V5. In addition, cell groups may be smaller and more sparsely organised, similar to those found in the autopsy study of the LGN (Livingstone et al., 1991). This may have occurred because due to the poorer structural integrity of the M pathway at the LGN, fewer signals were available to the V5. This would have led to poor cell development. It was argued that the poorer structural integrity of the motion detectors at V5 produced difficulties for individuals with dyslexia when integrating and summating the local motion signals to form a global motion percept when the motion signals in the RDK are sparse (i.e., low dot density). However, when the motion signals are dense (high dot density) a greater number of the smaller and more disorganised individual motion detectors at V5 are activated across a wider area of the visual field, allowing for the detection of global motion despite a sensory deficit (Talcott, Hansen et al.). Based on the findings it was concluded that presentation of RDKs with a dot density equal to or greater than 12.2 dots/deg^2, would not produce sensitivity differences between dyslexia and control groups.

Support for this explanation has been obtained from additional studies that have produced global motion stimuli with high dot densities and have not found significant between group differences (V. T. Edwards et al., 2004; Hill & Raymond, 2002). The dot density used by Hill and Raymond was 45 dots/deg^2, while Edwards et al. used a dot density of 30 dots/deg^2. A further study that manipulated dot density measured sensitivity in dyslexia and control groups using dot densities of 1.0, 2.0 and 3.0 dots/deg^2 (Slaghuis & Ryan, 1999). In each condition the dyslexia group was significantly less sensitive than the control group.

The finding that dyslexia groups show reduced neural activity in the M system based on *f*MRI technology (Demb, Boynton, & Heeger, 1998; Eden et al., 1996), and the finding that dot density influences sensitivity in dyslexia groups (Talcott, Hansen et al., 2000) is compelling evidence for a sensory processing deficit occurring in dyslexia as a result of poor quality signals stimulating the M system. However, not all studies that have used low dot density stimuli have found the coherent motion sensitivity of individuals with dyslexia to be impaired (Huslander et al., 2004). Additionally, some studies have produced evidence that dyslexia groups have additional impairments when performing complex motion computations in the motion pathway compared to controls (Hill & Raymond, 2002; Raymond & Sorensen, 1998). These findings have resulted in an alternative explanation for the motion deficit in dyslexia, which is based on the perceptual processing requirements of the task.

4.3 Selective Deficit in the Extrastriate Dorsal Stream

Reading and writing taxes the perceptual abilities of the visual system to the limit (Stein & Walsh, 1997), requiring the reader to process multiple stimuli simultaneously. Simultaneous processing depends on a number of complex

computational operations within the visual perceptual system, with these operations

needing to function cooperatively. While in skilled readers these processes have

become effortless and automatic, this is not the case for individuals with dyslexia.

The inconsistent findings of reduced temporal contrast sensitivity in groups

with dyslexia (e.g., Williams et al., 2003), and findings of reduced sensitivity only

when specific methodologies are used (Ben-Yehudah et al., 2001) have led to

criticism of the sensory explanation of a magnocellular system deficit in dyslexia.

Reduced capacity of individuals with dyslexia when performing the complex

computations needed to detect global motion in the dorsal visual stream (Cornelissen

et al., 1995; Hill & Raymond, 2002; Raymond & Sorensen, 1998) has further led to

the explanation that individuals with dyslexia have a specific deficit affecting the

integration of motion stimuli across time (Raymond & Sorensen, 1998), with this

deficit selectively occurring in extrastriate visual processing areas in the parietal

cortex (Amitay et al., 2002; Roach & Hogben, 2004, 2007). Supporting evidence for

this explanation comes from electroencephalographic and regional blood flood studies

that have shown abnormal activity in the parietal cortices of individuals with dyslexia

(Duffy, Denckla, Bartles, & Sandini, 1980; F. Wood, Felton, Flowers, & Naylor,

1991).

The first study that suggested the perceptual processing requirements of global

motion tasks could explain reduced sensitivity to global motion in dyslexia

manipulated the stimulus parameters used (Raymond & Sorensen, 1998). Two

experiments that used individuals with and without dyslexia were conducted. In

Experiment 1 the motion stimulus consisted of four 15msec animation frames (total

stimulus duration of 60msec). The dyslexia group (n = 10) were significantly less

sensitive than the control group (n = 10). In Experiment 2 the number of animation

frames and the frame duration presented in the RDK were manipulated. Frame duration was either 32msec (brief-frame condition) or 112msec (long-frame condition), and the following conditions were presented: (1) brief-frame condition consisting of two frames, (2) brief-frame condition consisting of seven frames, and (3) long-frame condition consisting of two frames. The brief seven-frame condition and the long two-frame condition both had total stimulus durations of 224msec, while the stimulus duration in the brief-two frame condition was 64msec. No significant between group effects were found with presentation of the two-frame stimuli, with both groups being more sensitive in the long two-frame condition than in the short two-frame condition. However, a significant between groups effect was found with presentation of the seven-frame condition, with the dyslexia group (n = 12) being significantly less sensitive to global motion than the skilled reader group (n = 12). As the number of frames increased, producing greater capacity for the visual system to sample the motion stimuli over time, there was little improvement in performance for the dyslexia group but increased sensitivity for the control group. These findings were interpreted to suggest that the dyslexia group was unable to integrate the motion signals over time.

From these findings it was concluded that individuals with dyslexia did not have a sensory processing deficit in the low levels of the magnocellular pathway, as no sensitivity deficit was found for the dyslexia group when the motion signals consisted of two-frames only. The reduced sensitivity to global motion found in response to the seven-frame stimulus in Experiment 2, and the four-frame stimulus in Experiment 1, was explained as a specific deficit associated with the processing of global motion at V5 in the dorsal pathway. This was described as a higher-order

deficit affecting the perceptual integration of stimulus elements across time, referred to as abnormal temporal recruitment (Raymond & Sorensen, 1998).

Supporting evidence for this explanation concerns the sensitivity of cells at V5 to motion stimuli presented for two frames. Sequential recruitment with presentation of two frames only, concerns the integration of motion information within motion detectors, and this form of sequential recruitment occurs at lower levels of the M pathway (Snowden & Braddick, 1989a). When more than two frames are presented in an RDK integration occurs across different motion detectors, a process that takes place at V5 (Festa & Welch, 1997). This finding is further supported by physiological research on monkeys that has demonstrated that area MT (the area equivalent to V5 in humans) does not respond well to two-frame RDKs, with neurons at this cortical location requiring multiple frames to elicit a significant response (Mikami, Newsome, & Wurtz, 1986). The poor sensitivity found for both the dyslexia and control groups with presentation of the two-frame stimulus may also be explained by the rapid presentation time for the brief-frame stimulus (64msec), or the slow almost stationary stimulus movement generated for the long-frame stimulus (224msec). These stimulus parameters may have been insufficient to stimulate the motion detectors of the magnocellular system in either the dyslexia or control groups. Moreover, the dot density used by Raymond and Sorensen (1998) was low, and this may contribute to the lack of temporal recruitment effects found in the dyslexia group.

While Raymond and Sorensen (1998) interpreted their findings in favour of a deficit affecting temporal integration in dyslexia groups, abnormal sequential recruitment effects could also be interpreted in support of the magnocellular deficit hypothesis. Talcott, Hansen et al., (2000) suggested that as a result of the low level deficit in the M system, some individuals with dyslexia may also demonstrate poor

integration of motion signals at higher cortical levels. Consistent with this they found that while the sensitivity of both their dyslexia and control groups continued to increase from about 4 to 18 animation frames, the sensitivity of the dyslexia group was consistently poorer than that of the control group across all of the frame conditions when the dot density used was 3.1 dots/deg^2.

The effect of temporal recruitment on global motion sensitivity was investigated further in groups of adults with (n = 7) and without (n = 7) dyslexia (Hill & Raymond, 2002). The effects of temporal recruitment were investigated by presenting either 4 or 10 animation frames in the RDK, each with a frame duration of 33.3msec. No significant reader group differences were found in either condition, and a significant increase in sensitivity was found for the dyslexia group in the 10, compared to 4 frame condition, showing normal temporal recruitment (Hill & Raymond). Interestingly post-hoc analysis revealed that when sensitivity to the leftward direction of motion was tested, there was less recruitment found for the dyslexia group than for the control group.

One explanation of these non-significant results is that the high dot density used (45 dots/deg^2) eliminated the between group effects. Taken together these findings suggest that in a normally operating visual system the integration of visual signals over space is highly efficient regardless of the density of the signal dots. However, for a poorly operating motion system the increased proximity of the signals within a restricted visual space provides greater opportunity for the system to integrate the visual information across space. This means that the high dot density level used by Hill and Raymond (2002) may have increased the capacity of the dyslexia group to integrate information over space and acted to reduce the difficulties experienced when integrating information over time. If this argument is to be

supported the deficit found for the dyslexia group when processing global motion may only be found when the ability to integrate motion information over space and time is restricted. Experiment 1 of this thesis will examine this possibility.

While Hill and Raymond (2002) did not find reduced sensitivity for the dyslexia group on the global motion task, the same group of adults with dyslexia were found to have significantly poorer performance than a control group on a motion transparency task when the dot density was 27dots/deg^2. As reviewed in section 3.3 of the previous chapter, a motion transparency task requires rapid segmentation and grouping of two motion stimuli simultaneously. For simultaneous processing to occur, the visual stimuli cannot be presented for more than 250msec (Mulligan, 1992). The dyslexia group was significantly less accurate when extracting the two motion signals compared to the control group when the stimulus duration was 250msec or less. However, when the stimulus duration exceeded 2656msec no accuracy differences were found between groups (Hill & Raymond). In addition, the skilled reader group reached a 75% accuracy level when identifying both directions of stimulus motion when the stimulus was presented for 144msec (or for 4.37 frames). Comparatively the dyslexia group needed 483msec (or 14.62 frames) to reach this accuracy level. All but one of the individuals with dyslexia had reduced accuracy when they were compared to the control group using the 99% confidence limits. Taken together these results suggest that the dyslexia group was unable to process the bidirectional motion simultaneously, but that they could process the stimuli sequentially if given sufficient time. These findings are consistent with the presence of a complex perceptual processing deficit at V5 in dyslexia.

The finding that the dyslexia group was less sensitive than the control group on the motion transparency task, but not on the global motion task, led to the

conclusion that there was no evidence to support a general sensory processing deficit in the magnocellular pathway of individuals with dyslexia (Hill & Raymond, 2002). Rather, the deficit found on the motion transparency task suggested that the disruption of motion processing mechanisms in dyslexia occurs because of an abnormality within dorsal extrastriate cortical areas that subserve the grouping and segmentation of complex motion signals, a perceptual function. Further, they concluded the greater attentional and perceptual demands of the motion transparency task demonstrated the presence of a deficit in the parietal cortex.

The high dot density used in some studies (V. T. Edwards et al., 2004; Hill & Raymond, 2002; Talcott, Hansen et al., 2000) when measuring global motion sensitivity suggests that with sufficient ability to sample stimuli across space, dyslexia groups have normal global motion sensitivity. However, the findings that dyslexia groups can have normal sensitivity on a global motion task that used high dot density, but not on a motion transparency task that also had high dot density, provides evidence of additional perceptual processing difficulties in the dyslexia group when complex motion tasks are presented.

While the dyslexia group could process the two directions of motion sequentially, they needed more time than the control group to do so. This finding is consistent with research that has suggested the M deficit in dyslexia is related to a higher order attentional deficit referred to as 'sluggish attentional shifting', or an inability to shift or direct the neural components of automatic attention (Hari & Renvall, 2001). While Hari and Renvall proposed that the attentional deficit may be a consequence of a magnocellular visual system deficit in dyslexia, affecting parietal processing through the feedforward model, it could also be the result of top-down influences. Additionally, the explanation of 'sluggish attentional shifting' is consistent

with research that has proposed that the M deficit in dyslexia might be linked to a deficit in processing sequentially, rather than simultaneously, presented visual stimuli (Ben-Yehudah et al., 2001; Conlon et al., 2004; Eden, Stein, Wood, & Wood, 1995).

The current research project aimed to evaluate the different explanations for the motion deficit in dyslexia. While Experiment 1 investigated temporal integration across time and space, Experiment 2 used a motion transparency task to determine whether perceptual difficulties with grouping and segmentation together may explain the global motion deficit in dyslexia. Two versions of the transparency task were presented so that the effect of specific stimulus parameters that should influence the different components of motion sensitivity could be assessed. Both simultaneous and sequential processing accuracy was examined.

4.4 Noise-Exclusion Deficit

A further perceptual explanation for the reduced motion sensitivity of individuals with dyslexia has been proposed. This explanation suggests that the visual motion deficit in dyslexia is not the result of a sensory processing deficit in the magnocellular pathway or the dorsal stream, but is caused by a generalised perceptual impairment that occurs because individuals with dyslexia are unable to efficiently extract signal from noise in complex visual scenes. Evidence supporting this explanation has been obtained from experiments that have investigated phantom contour (Sperling, Lu, Manis, & Seidenberg, 2003, 2006a), contrast sensitivity (Sperling et al., 2005), and global motion sensitivity (Sperling et al., 2006b).

In their phantom contour studies Sperling et al. (2003; 2006a) presented children and adults with two tasks designed to specifically measure M and P processing. In each of the tasks participants were asked to identify one of four shapes

(heart, sailboat, rocket, or fish) created by patterns of dots flickering in counter-phase. In the M task the shape consisted of low luminance flickering black and white dots, while in the P task it consisted of flickering isoluminant red and green dots. The dependent variable was the highest frequency (Hz) at which participants could reliably detect the shape presented. In both experiments the dyslexia and control groups were found to have significantly higher (faster) threshold frequencies in response to the M task compared to the P task. Sperling et al., interpreted this as evidence that the two tasks successfully measured M and P processing, with the black and white dots predominately activating the fast-acting, boundary extracting M cells, and the red and green dots predominantly activating the slower, colour sensitive P cells. Moreover, in both experiments the dyslexia groups were less sensitive to the M stimuli, but not the P stimuli, compared to the control groups. Initially these results were interpreted in favour of the magnocellular deficit hypothesis. However, the results were reinterpreted following a later study (Sperling et al., 2006a). It was suggested the locus of the deficit may be in a stage of processing involving noise exclusion, rather than the M system itself. It was argued that the amount of visual noise contained in the stimuli that assess M or P functioning, rather than whether the task involves M or P processing, is the key to understanding the processing deficit in dyslexia. The results of the M task were explained in terms of participants being required to detect the borders of the shape in a perceptually noisy environment. The lack of a between group effect on their P task was suggested to be due to the nature of the task, with the deficit in noise exclusion being more readily apparent at higher temporal frequencies than what could be reached with the red and green coloured stimuli, as there would be more noise present in the luminant compared to equi luminant stimuli.

The strongest evidence used to support noise exclusion as an explanation of the visual deficit found in dyslexia was obtained from a study that assessed the spatial and temporal contrast sensitivity of groups of children with (n = 28) and without (n = 27) dyslexia (Sperling et al., 2006b). The M stimuli consisted of 2 c/deg sinewaves that rapidly alternated between light and dark (flickering in counter-phase at 15Hz). The P stimuli consisted of 8 c/deg stationary sinewaves. Both tasks were presented with and without the presence of added visual noise. Noise was defined as patches of random bright and dark spots, embedding the signal pattern. No significant differences in sensitivity were found between the dyslexia and control groups for either the M or P task when there was no noise added to the display. However, in the presence of visual noise the dyslexia group was significantly less sensitive than the control group on both tasks. It was concluded that individuals with dyslexia have a deficit in noise exclusion and not a deficit specific to the magnocellular visual system.

There are several methodological problems associated with this study, which were highlighted by Slaghuis and Ryan (2006). First, the contrast thresholds obtained in the no-noise conditions were much higher for both the dyslexia and control groups compared to other studies, and they partly attributed this to the 2 c/deg target stimulus used by Sperling et al. (2005) in the M task. Past research has shown that the M system shows little responsiveness above 2 c/deg, making the stimuli less than optimal. Second, the ramped target stimuli used were likely to have diminished the involvement of the M pathway, as M cells are selectively sensitive to rapid temporal transitions that occur at the onset and offset of target stimuli. Third, the simultaneous two-alternative forced choice (2AFC) paradigm used was criticised, as the set-up of the task involved the distribution of visual attention, as well as the use of a 2-down/1-up reversals staircase with an unspecified level of measurement accuracy. Past CSF

research has commonly measured contrast thresholds using a 3-down/1-up staircase procedure with specified measurement accuracy, along with a sequential 2AFC methodology that allows for visual attention to be focused in the same spatial location. Finally, the no-noise and noise condition trials were combined in a single block of trials, with the possibility of confounding the threshold measurement in each condition as a consequence of continuous changes in the state of luminance adaptation (Slaghuis & Ryan).

Noise exclusion has also been investigated by manipulating the salience of signal and noise elements in a motion coherence task (Sperling et al., 2006b). Groups of children and adults with or without dyslexia were assessed in two experiments. The adult participants were drawn from a university population, while the children were recruited through two schools for children with learning disabilities. The adult group was presented with three tasks. First, a high external noise condition was presented where light grey signal and noise dots with a luminance of 18.3 cd/m^2 were presented on a dark grey background (12.2 cd/m^2). Consistent with other findings, the dyslexia group (n = 27) was significantly less sensitive to global motion than the control group (n = 28). In the second condition the salience of the signal elements was increased. Signal dots were red while noise dots remained light grey. No significant differences in sensitivity were found between the two groups when the signal salience was higher than the salience of the noise elements. In a final condition the stimulus contained red signal dots only, with no group differences found. The child group was presented with the first two conditions used in the adult study, with the background luminance being raised to 13.7 cd/m^2 and the luminance of the dots set at 20.1 cd/m^2. The results were the same as those obtained for the adult sample, with the dyslexia group (n = 32) being significantly less sensitive to motion than the control group (n = 27) in the high

external noise condition, and no significant differences found between groups when the signal was more salient than the noise. While these findings were interpreted in support of noise exclusion explanation, it is important to note that from a methodological point of view the use of red signal dots may have activated the P cells and not the M cells, as the ventral stream has some input into visual area V5 (Merigan & Maunsell, 1993; Tootell et al., 1996).

The results from research into problems with noise-exclusion in dyslexia are far from conclusive. Based on the noise-exclusion deficit explanation dyslexia groups would be expected to be significantly less sensitive to global motion than controls, unless the signal is more salient than the noise, regardless of the stimulus parameters used. Experiment 3 of this thesis will examine this possibility. To ensure maximum stimulation of the M system signal salience was manipulated through changes in the luminance, rather than the colour, of the signal and the noise dots.

4.5 Reading and Temporal Processing

The way that different processes associated with reading are influenced by motion processing has also been debated in the literature. Arguments extend from an explanation that M neurons are unlikely to be involved in the processing of text (Skottun, 2000; Skottun & Parke, 1999), to an explanation that at normal contrast levels the M system is the primary pathway for text perception (Chase, Ashourzadeh, Kelly, Monfette, & Kinsey, 2003). There are also explanations that suggest specific components of the reading process are disrupted by a deficit in the visual magnocellular system.

Studies that have used unselected samples of children with varying reading skills have reported associations between coherent motion detection and the ability to

accurately localise and decode letters (Cornelissen & Hansen, 1998; Cornelissen, Hansen, Gilchrist et al., 1998), a component aspect of orthographic skill. A further study that investigated the association between different word reading skills and motion processing in an unselected sample of children also reported a stronger correlation between visual global motion processing and accuracy of orthographic recognition than between visual global motion sensitivity and phonological decoding (Talcott, Witton et al., 2000a). These findings suggest a role for the motion processing deficit in understanding poor orthographic processing skills in dyslexia. However, strong associations have also been found between motion sensitivity and phonological skills. One recent *f*MRI study reported contrast responsivity at V5 to be strongly associated with phonological awareness in an unselected sample of children (Ben-Shachar, Dougherty, Deutsch, & Wandell, 2007). In addition strong associations have been reported between global motion sensitivity and phonological decoding skills in adult groups with and without dyslexia (Talcott et al., 1998; Wilmer et al., 2004; Witton et al., 1998). Taken together the combined findings from the *f*MRI and psychophysical research suggest an association between phonological processing, orthographic processing and visual motion processing, with V5 responsivity being a strong indicator of healthy reading development.

When assessing the strength of the covariations reported between motion processing and reading it is important to be aware that the associations obtained are dependent both on the stimulus parameters used in the RDKs, and on the range of reading skills evaluated in any single study. For example, one study that reported a strong association between global motion processing, flicker fusion and phonological processing did not examine the associations between motion processing and word reading skills or orthographic processing (Talcott et al., 1998). A further study that

reported strong associations between coherent motion detection and reading also limited their investigation to phonological processing (Witton et al., 1998). This practice may prevent a more complete understanding of the relationship between motion processing and reading, as some researchers have suggested that reading skills in general (i.e., word identification skills), rather than specific cognitive processes (e.g., phonology or orthography), are related to visual motion processing (Conlon et al., 2004; Lilleskaret, 2001; Talcott et al., 2002), particularly in samples of adults with dyslexia. This argument is in part consistent with the suggestion that instead of specific subskills of reading being selectively influenced by a visual deficit, the visual deficit may be a component of a more global difficulty that affects multiple areas of processing such as speech, letter recognition, and phonological representations (Ramus & Szenkovits, 2008; Sperling et al., 2005). As part of the current research a battery of reading and reading related measures were administered, and their associations with visual motion processing will be examined. This investigation may further enhance our understanding of how the motion processing deficit in dyslexia may be related to reading.

Finally, some researchers have proposed that the motion coherence deficit found in dyslexia may not be related to reading per se, rather it may be a non-specific marker of developmental disorders in general (White, Frith et al., 2006). This explanation is based on the high level of comorbidity found between developmental disorders (Lyon et al., 2003), with global motion deficits also being reported in individuals with autism (Milne et al., 2002; Spencer et al., 2000), Williams syndrome (Atkinson et al., 1997) and other developmental disorders (Gunn et al., 2002).

The motion processing deficit in dyslexia has also been associated with a selective deficit in processing sequential stimuli (Ben-Yehudah et al., 2001; Conlon et

al., 2004; Eden et al., 1995; Slaghuis & Ryan, 1999) regardless of whether the information being processed is orthographic or phonological. Poor sequential processing has been associated with impaired short-term verbal memory (Ramus & Szenkovits, 2008; Slaghuis & Ryan, 2006) or the development of specific perceptual anchors (Ahissar, 2007; Ahissar et al., 2006) as core factors underlying the motion deficit. Based on these recent explanations the current research project will administer an Adult Dyslexia Checklist (Vinegrad, 1994) and a Reading History Questionnaire (Conlon & Sanders, 2000) to assess developmental aspects of the reading difficulty. Short-term verbal memory, along with simultaneous and sequential processing abilities was also assessed in the sample.

4.6 Dyslexia Group with a Global Motion Deficit

Due to the controversy that has been generated in the literature concerning the presence of a magnocellular system deficit in dyslexia, and the inconsistent results obtained, there has been a trend in some recent studies to examine individual performances on these measures in dyslexia groups. The validity of these different techniques has not been established, nor their consistency when identifying individuals with dyslexia and specific deficits in the visual domain. In addition, the extent that the different techniques are statistically appropriate when differentiating performances within individual groups has not been evaluated.

Reports that a magnocellular system deficit is found only in a proportion of individuals with dyslexia first appeared in 1985 when it was reported 75% of children with dyslexia had poor visible persistence (Slaghuis & Lovegrove, 1985). A regression technique was used to discriminate between the children with and without a visual deficit. However, prevalence estimates were not routinely investigated again

for over 10 years, when researchers began to descriptively report how individuals in the dyslexia group appeared to vary in sensitivity on tasks such as measurement of global motion. Research findings were interpreted in light of the view that at least some individuals within the dyslexia group had a specific deficit within the visual magnocellular system (Everatt et al., 1999), and explanations of the significant overlap found between dyslexia and skilled reader groups (children and adults) were proposed. Cornelissen et al., (1995) reported that between group overlap in sensitivity occurred because of the subtle nature of the motion deficit found in dyslexia. Interestingly, it was reported that the individual differences found within both reader groups were consistent with past research where individuals with dyslexia were found to show markedly heterogeneous patterns of visual and phonological difficulties in their reading strategies (Seymour, 1986). In terms of specific reading subskills some research suggests that individuals with poor phonological and orthographic skills (mixed difficulties), or the ones with severe phonological deficits, are the ones with a concurrent motion processing deficit (Borsting et al., 1996; Ridder et al., 2001; Slaghuis & Ryan, 1999, 2006).

Based on reports that there is a dyslexia subgroup with a motion deficit, some recent studies have investigated what proportion of individuals may be affected, with suggestions that the motion deficit group may be found within the 'lower end of the tail' in dyslexia distributions (Roach, Edwards, & Hogben, 2004). The tail corresponds to the percentile rank in the continuous distribution sometimes used to categorise individuals with dyslexia. On this basis one technique that has been used selects individuals in the lower 16th percentile of the distribution when using the entire sample (e.g., Heath et al., 2006). Other techniques that have been used include deviance analysis (Conlon et al., 2009; Pellicano & Gibson, 2008; Ramus et al., 2003;

Reid et al., 2007; White, Frith et al., 2006; Wright & Conlon, In Press) and logistic regression (e.g., Solan et al., 2007) or discriminant function analysis (Talcott et al., 2003; Talcott et al., 1998).

The 16th percentile calculations are based on the properties of the distribution of scores in a standard normal distribution using the combined sample of individuals with and without dyslexia (Heath et al., 2006). The logic behind this technique is based on the distance of scores from the mean. When accuracy scores are considered, participants scoring at or above the 84th percentile are considered the most skilled performers on the task, with participants with accuracy scores at or below the 16th percentile forming the group with the poorest accuracy. On measures of accuracy on temporal processing tasks, individuals performing at or below the 16th percentile are considered to have a processing deficit. When measures of sensitivity are used, individuals performing at or above the 84th percentile are considered to have a deficit.

Deviance analysis uses the distribution of sensitivity of a control group to produce a deviance estimate. The deviance estimate is based on the one-tailed 95% confidence limit (1.65 standard deviations) of the control group's sensitivity and is calculated in two steps. First, the sensitivity estimate corresponding to the one-tailed 95% confidence interval (1.65 standard deviations) for the control group is calculated. Second, individuals in the control group with sensitivity estimates greater than this estimate are excluded as extreme scorers and the deviance estimate is recalculated, producing the final deviance estimate (Ramus et al., 2003). Any individuals in the dyslexia group with sensitivity thresholds higher than the recalculated 95 % confidence interval are considered to have a motion processing deficit.

Logistic regression and discriminant function analyses are forms of regression analysis that can be used when the dependent variable is discrete. The simplest

models use a dependent variable with two categories, and it can be used for the prediction of the probability or likelihood that an individual is a member of either a dyslexia or control group based on their psychophysical performance. Logistic regression is based on the 50th percentile of performances. The classification results produced are then compared with the original classification, with a percentage estimate of how well the model classifies individuals into their respective groups.

From a methodological and statistical perspective, the three techniques vary, with each based on different statistical criteria, some of which are more stringent than others. The validity, sensitivity and specificity of the techniques are not yet established. Within the research literature the different classification techniques have been used interchangeably, resulting in very different prevalence estimates regarding the proportion of the dyslexia group that also has a motion deficit. For example, the 75% estimate produced by Slaghuis and Lovegrove (1985) was based on a regression analysis approach. This estimate is consistent with a study that used logistic regression to classify their dyslexia and control groups, reporting 78% of the children in the dyslexia group (N = 23) to have a coherent motion deficit (Solan et al., 2007). Discriminant function analyses, have also produced prevalence estimates of around 67% using coherent motion only (Talcott et al., 2003), and about 72% when contrast sensitivity and coherent motion have been entered together as the predictor variables (Talcott et al., 1998).

Prevalence estimates have been found to drop when the more stringent criteria of the deviance analysis are applied. It has been suggested that the normal range of sensitivity can only be determined accurately by measuring performances in large normative samples (Jacobson & Truax, 1991). A recent deviance analysis study assessed this using both a large normative sample and a smaller control group sample,

reporting the prevalence estimates to be fairly similar for the two groups (Conlon et al., 2009). Using a single threshold estimate they found the prevalence to be close to 50%, with the estimate substantially reducing when a repeat criterion of reduced sensitivity across two thresholds was used. In the small sample (N = 35) the proportion of individuals with dyslexia classified with a global motion deficit was estimated to be about 37%, while it reduced to about 26 % using a large normative sample (N = 141). These results are consistent with the deviance estimates produced by Pellicano and Gibson (2008) who reported 36% of the children in their dyslexia group (N = 41) to have a deficit when processing coherent motion. However, not all studies that have used deviance analyses have reported estimates this high. One study estimated a coherent motion deficit prevalence of 20% (N = 15) in an adult dyslexia group (Reid et al., 2007), while a recent study that determined the proportion of children with dyslexia and a concurrent motion deficit at two points in time, 9 months apart, found that 36.2% had a motion deficit at time I and 27% at time II, with 17.1% having a deficit at both phases of the study (Wright & Conlon, In Press). Finally, 16th percentile cut-offs produce the most stringent statistical criteria out of the three techniques. One study using this technique reported a global coherent motion deficit of 16% (N = 41) in an adult dyslexia group (Heath et al., 2006).

It is important to remember that the cut-off estimates produced from any of the techniques are arbitrary as they only rely on different statistical criteria. Moreover, as demonstrated by past studies (Conlon et al., 2009; Wright & Conlon, In Press) the prevalence estimates also vary depending on whether single threshold or multiple threshold estimates are used to determine who in the sample has a motion deficit. The prevalence estimates produced for the different classification techniques, using repeat classification criterion, were investigated as part of the current research project.

While individuals with dyslexia and a magnocellular processing deficit have been isolated in some studies, few studies have evaluated the differences between this group and other individuals with dyslexia in terms of the different cognitive subskills of reading. A number of studies have not found a specific profile that separates the two groups (e.g., Amitay et al., 2002; Ramus et al., 2003; White, Milne et al., 2006), and the cognitive profile of readers with dyslexia have been found to be heterogeneous, with different individuals showing evidence of quite different cognitive strengths and weaknesses (Erskine & Seymour, 2005; Reid et al., 2007). However, some studies have reported the dyslexia with a motion deficit group to perform less accurately on measures of complex phonological processing and verbal short-term memory compared to the dyslexia with no motion deficit group (Conlon et al., 2009; Johnston et al., 2008; Wright & Conlon, In Press), These findings are consistent with recent reports that have also implicated difficulties with short-term memory as the core underlying factor for the motion processing deficit (Ramus & Szenkovits, 2008; Slaghuis & Ryan, 2006).

The current study will investigate the manner in which 16th percentile performance, deviance analysis and logistic regression successfully discriminate between individuals in the dyslexia group with and without a motion deficit in terms of performance on measures that characterise adults with reading difficulties. The results from the three classification techniques will be compared and contrasted to assess which of the techniques that best separate between individuals with dyslexia with and without motion deficits. The repeatability or stability of these deficits will be evaluated across the different studies.

Chapter 5 provides an overview of the current research project, including specific aims and the methodologies used. Chapters 6 to 9 present the four

experiments, presenting the results and discussion of the between group analyses. Chapter 10 will investigate within group performances, using each of the three classification techniques outlined in this section. Chapter 11 will then discuss the profile of dyslexia groups with and without a motion deficit, while Chapter 12 will provide a general discussion of the findings from this thesis, including theoretical implications and aims for future research.

CHAPTER 5: The Current Research Project

5.1 Aims and Overview

Various hypotheses have been proposed to explain the magnocellular processing deficit found in some individuals with dyslexia. The overall goal of the current project was to investigate specific neural and perceptual processes hypothesised to underlie this deficit. Investigations were based on the theoretical approaches outlined in chapter 3, explaining the impaired motion processing of individuals with dyslexia in terms of: (1) a sensory deficit in the M system affecting the processing of low motion energy stimuli, (2) a deficit within dorsal extrastriate cortical areas affecting temporal integration and the processing of complex bidirectional motion signals, and (3) a perceptual deficit that occurs because of difficulties extracting signal from noise in complex visual scenes.

The focus of the current study was on processes involved in global motion detection, and three experiments using global motion stimuli were conducted. Three measures of global motion processing were obtained. In Experiment 1 the dot density and the number of animation frames presented in the RDK were manipulated to investigate the effects of signal strength and temporal recruitment on coherent motion sensitivity. Experiment 2 investigated the accuracy of dyslexia and control groups on two motion transparency tasks. Experiment 3 manipulated the salience and luminance of the signal and noise dots in an RDK to investigate how extraction of signal from noise may affect the coherent motion sensitivity in individuals with dyslexia. All of the stimulus parameters, except the ones specifically manipulated, were kept constant across experiments so that the effects of the manipulations could be directly interpreted. Experiment 4 was a control experiment where the local motion processing of the sample was assessed.

Participants were adults with and without dyslexia. For each of the experiments between group analyses were conducted together with statistics that evaluated the sensitivity and specificity of the individual tests. This allowed for an investigation of (1) the proportion of individuals with dyslexia with a motion processing deficit and (2) the effectiveness of three classification techniques (deviance analyses, lower 16th percentile performance and logistic regression) in identifying dyslexia subgroups with and without a global motion deficit across experiments.

The associations between motion sensitivity, reading and reading related performances known to characterise adults with reading difficulties were assessed. These measures were used based on the growing evidence that individuals with dyslexia may be affected by a whole range of deficits, including some of which may be unrelated to reading (Reid et al., 2007).

5.2 General Method

5.2.1. Design

A quasi-experimental design was used. In each of the experiments there were two independent groups, adults with dyslexia and skilled readers. The main statistical analyses used to investigate the data were mixed factorial designs, t-tests, sensitivity and specificity analyses, and bivariate correlations.

5.2.2 Participants and Group Classification

Participants were university students, with the majority seeking research participation hours in exchange for course credit. This group was invited to take part in the experiments through advertisements on the Griffith University Website and

through advertisements in lectures. Individuals were also recruited from the Griffith University Disability Office and through a register held in the laboratory. Participants were recruited at different stages throughout the data collection phase, and hence the order in which the experiments were presented to them varied.

All participants had normal or corrected to normal acuity, English as their first language, and were less than 40 years of age. The age restriction was imposed as reduced sensitivity to motion has been found in older, compared to younger groups (Conlon & Herkes, 2006; Trick & Silverman, 1991). Participants reporting high pattern sensitivity on the pattern sensitivity measure, who obtained a visual discomfort score of 45% or above on the Migraine and Visual Discomfort Questionnaire or who reported experiencing migraine (Conlon, Lovegrove, Chekaluk, & Pattison, 1999) were excluded from the experiments. These exclusions were based on findings from past research showing individuals with these conditions either to have a global motion deficit or perform inconsistently on these types of tasks (Conlon et al., 2009; Ditchfield, McKendrick, & Badcock, 2006).

A total of 134 participants were screened, with 85 meeting the research criteria described above. These participants were administered the word identification components of the Wide Range Achievement Test (WRAT-3) (Wilkinson, 1993), the Nonword/Exception Word Test, including multisyllabic nonword reading (Conlon & Mellor, In Preparation) and the Test of Word Reading Efficiency (TOWRE) (Torgesen, Wagner, & Rashotte, 1999). Based on their overall pattern of performance they were classified into their respective groups. All participants had estimated IQ scores falling within or above the normal range on the Block Design and Vocabulary subscales of the Wechsler Adult Intelligence Scales –Third Edition (WAIS-3; Wechsler, 1997).

Individuals were classified with dyslexia using the following combination of criteria; (1) A standard score of 94 or less on the reading component of the WRAT-3 (Wilkinson, 1993), meaning they were reading at a high school level at best, (2) A score of less than 17 out of 25 on the test of nonword reading, and less than 15 out of 25 on the test of exception word reading (Conlon & Mellor, In Preparation). These cut-offs constitute scores of more than two standard deviations below the mean of a normative sample (Conlon et al., 2004), (3) A standard score of at least one standard deviation below the population mean of 100 on the phonological fluency test of the TOWRE (Torgesen et al., 1999).

A standard score of 94 on the WRAT-3 (Wilkinson, 1993) corresponds to a percentile rank of 36. While this is higher than the generally accepted percentile rank of 15 that has been used with children (Snowling, 2000), this cut-off has been used successfully within the research literature to discriminate adults with poor reading skills (Conlon et al., 2009; Lavidor, Johnston, & Snowling, 2006). The group also had high exposure to text, educational opportunity and constituted an accuracy remediated group (Shaywitz et al., 2003). In addition, 80 % of the participants in the dyslexia group reported a childhood history of reading difficulties.

Individuals satisfied criteria for the skilled reader group if they obtained: (1) A standard score of 105 or greater on the reading component of the WRAT-3 (Wilkinson, 1993), meaning they were reading at a post-high school level, (2) An accuracy level of at least 20/25 on the tests of nonword and exception word reading (Conlon & Mellor, In Preparation), (3) Reading fluency at least one standard deviation above the population mean on both components of the TOWRE (Torgesen et al., 1999), and (4) No reported history of reading difficulties.

A total of 25 poor and 27 skilled readers were identified. However, five participants (2 individuals with dyslexia and 3 skilled readers) were removed from the analysis as they perceived the global motion direction as the opposite to what was presented to them in the motion transparency task (i.e., a computational problem or null effect). This left 23 participants in the dyslexia group (19 females; *M* age = 22.87 years; *95% CI* = 20.08-25.66) and 24 participants in the skilled reader group (16 females; *M* age = 19.38 years; *95% CI* =17.98-20.77). Data on the cognitive alibility measures was not available for 1 skilled reader and 2 individuals with dyslexia, as they failed to return for subsequent testing sessions. The reading and cognitive profile of the two reader groups are shown in Table 2.

Table 2

Performance on the Reading and Cognitive Ability Measures for the Dyslexia and

Skilled Reader Groups

	Group							
	Dyslexia (n = 23/21)			Skilled (n = 24/23)				
	Mean	95% CI		Mean	95% CI		t value	p
Measures		Lower	Upper		Lower	Upper	(df 45/42)	
WRAT-3 Reading (scaled score)	91.91	89.75	94.08	111.08	109.20	112.97	-13.870	<.0005
Nonwords /25	14.26	13.02	15.50	22.33	21.59	23.08	-11.696	<.0005
Multisyllabic Nonwords /9	4.48	3.78	5.18	7.88	7.37	8.38	-8.215	<.0005
Exception words /25	10.96	9.51	12.40	19.79	18.98	20.60	-11.200	<.0005
Sight Word Efficiency (standard score)	88.52	84.70	92.34	107.83	104.64	111.03	-8.061	<.0005
Phonemic Decoding (standard score)	81.17	76.89	85.45	113.75	110.63	116.87	-12.829	<.0005
TOWRE Total (standard score)	82.91	79.26	86.56	112.71	109.72	115.70	-13.127	<.0005
Adult Dyslexia Checklist /20	8.96	7.83	10.08	4.13	3.04	5.21	6.417	<.0005
Vocabulary (scaled score)	11.14	10.25	12.03	12.86	12.03	13.70	-2.938	=.005
Block Design (scaled score)	12.52	11.25	13.80	13.95	12.54	15.37	-1.557	**=.127***
Estimated Full Scale IQ	110.62	106.13	115.11	119.73	114.52	124.93	-2.814	=.007
Digit Forward (raw score)	10.33	9.61	11.06	11.86	10.91	12.81	-2.784	=.008
Digit Backward (raw score)	7.10	6.11	8.08	8.68	7.85	9.52	-2.383	=.022
Digit Total (scaled score)	10.00	8.85	11.15	12.27	11.16	13.39	-2.942	=.005

* No significant between group difference at the .05 significance level

A series of independent samples *t*-tests showed the skilled reader group was

significantly more accurate than the dyslexia group on all of the reading and reading

related measures, including the Adult Dyslexia Checklist (Vinegrad, 1994).

Consistent with the 'dyslexic triad' (Ramus & Szenkovits, 2008) the dyslexia group

were significantly impaired compared to the skilled reader group on measures of

phonological awareness (nonword reading), phonological fluency (phonemic

decoding) and phonological (or verbal) short-term memory (Digit Span). The dyslexia

group were also significantly less accurate than the skilled reader group on the

Vocabulary subtest from the WAIS-III (Wechsler, 1997). However, the difference in

cognitive abilities was not deemed problematic, as both groups performed within the normal range on both subtests, and as there was no significant difference in performance between the two groups on the Block Design subscale, a measure of non-verbal ability.

While the same group of participants took part in all four experiments, the total number in each group varied (ranging from 19 to 23 in the skilled reader group and 13 to 21 in the dyslexia group). This was due to difficulties in retaining participants throughout the 12 month data collection period, with participants moving, dropping out of university, or being unable to make the time commitment. It is interesting to note that more individuals in the dyslexia, compared to skilled reader group dropped out of university, or found they could not commit their time to the research project. This suggests the dyslexia group found the requirements of university more taxing than what the skilled readers did. Regardless of changes in participant numbers the profile of the dyslexia and skilled reader groups remained stable throughout all of the experiments, and for this reason the reading and cognitive ability data has not been replicated in the individual experimental chapters of this thesis.

Participants recruited from the Disability Office, as well as participants returning for subsequent testing sessions after having completed the experiment participation hours required for course credit, received $10 per testing session to assist with transport costs.

5.2.3 Measures

5.2.3.1 Screening Measures

Copies of the tasks not commercially available are presented in Appendix A:

Headache and Visual Discomfort Scale (Conlon et al., 1999), and Pattern Sensitivity Rating Scale (Conlon et al., 1999). The Migraine and Visual Discomfort Scale is a self-report measure consisting of 53 questions. It provides a measure of retrospective reports of migraine and visual discomfort, and has an internal consistency of .91. The Pattern Sensitivity Rating Scale consists of a striped pattern of 4c/deg, and participants were asked to view the stimulus and to rate the degree of perceptual and somatic discomfort they experienced with pattern viewing. One rating scale was used for each, with the scales ranged from 0 (Pattern does not appear distorted at all/No problem to view pattern at all) to 3 (Severe distortion/Pattern is so bad I can't look at it).

Revised Adult Dyslexia Checklist (Vinegrad, 1994) combined with items from the Reading History Questionnaire (Conlon & Sanders, 2000). The Revised Adult Dyslexia Checklist was originally produced by the British Dyslexia Association in the mid 1980s and later modified for research. The measure was piloted with 679 adults, mostly undergraduate students, aged from 18 to 68. The sample contained 32 individuals with dyslexia. A score of 9 or more yes answers on the whole questionnaire is taken as a powerful indicator of reading difficulty. The Reading History Questionnaire is a measure used to obtain information regarding past and present reading/spelling difficulties. Information is also obtained about degree of text exposure, reading interests, and any familial reading/spelling difficulties.

The Wechsler Adult Intelligence Scales –Third Edition (WAIS-III) (Wechsler, 1997). The Block Design subtest (Perceptual Orientation Index), and the Vocabulary subtest (Verbal Comprehension Index) were used to obtain an estimate of Full Scale IQ. The Block Design subtest involves putting a set of blocks together to match patterns on cards, while the Vocabulary subtest is a measure of expressive word

knowledge. Participants were also administered the Digit Span subtest from the WAIS-III (Wechsler, 1997). The Digit Span subtest consists of Digit Forward and Digit Backward. The subtest measures short-term memory and sequencing skills, with Digit Backward involving more complex mental manipulations and visuospatial imaging. Digit Span was included in the screening battery, as past research has found the sequencing abilities (Eden et al., 1995) and verbal short-term memory (Amitay et al., 2002; Brosnan et al., 2002) of individuals with dyslexia to be less accurate than that of skilled readers. During administration of the subtests the standardised instructions from the manual were followed.

5.2.3.2 Group Classification Measures

Copies of the tasks not commercially available are presented in Appendix A:

The word identification component (blue forms) of the Wide Range Achievement Test (WRAT-3) (Wilkinson, 1993). The word identification task is a measure of word decoding, consisting of 42 items with increasing difficulty. Internal consistency on the WRAT-3 for the age range 17-64 years has been found to be .90 to .95. Content validity has been measured by the Rasch statistic of item separation, with the highest item separation score possible (1.00) found (Wilkinson). During administration of the subtests the standardised instructions from the manual were followed.

The Nonword/Exception Word Test (Conlon & Mellor, In Preparation). This is a non-timed test of phonological and orthographic awareness. The test consists of 25 nonwords (words that are not real words but can be decoded by applying phonological rules to say the letter string aloud (, e.g., 'deprotenation') and 25 exception words (words that are real words but cannot be pronounced aloud by applying phonological rules, e.g., 'pterodactyl'). Participants were asked to read the

words out loud, and their responses were marked onto a scoring sheet by the experimenter. The following instructions were given "*Look at each of these words carefully* (pointing). *Some of them will be familiar to you and some of them will not. Just try to read them out the way you think they should be read. Read the words across the page so that I can hear you. When you finish the first line, go to the next line and so on*". The test was not timed. The internal consistency of the nonword test is .77 and .84 for the exception word test (Conlon et al., 2004).

Multisyllabic Nonword Test This is an addition to the Nonword/Exception Word Test. It consists of 9 multisyllabic nonwords. Compared to the nonwords in the Nonword/Exception Word Test these nonwords generally have a greater number of phonemes to be decoded, allowing for the investigation of more complex phonological processes. The instructions were the same as for the Nonword/Exception Word Test.

The Test of Word Reading Efficiency (TOWRE) (Torgesen et al., 1999). This is a measure of reading fluency. The TOWRE consists of two subtests: the Sight Word Efficiency (SWE) subtest and the Phonetic Decoding Efficiency (PDE) subtest. The SWE subtest assesses the number of real printed words that can be accurately identified within 45 seconds, and the PDE subtest measures the number of pronounceable printed nonwords that can be accurately decoded within 45 seconds. Because this is a timed task the TOWRE provides information regarding reading fluency, not obtainable from the Nonword/Exception word test. The average alternate forms reliability coefficients (content sampling) all exceed .90, and the test/retest (time sampling) coefficients range from .83 to .96. During administration of the subtests the standardised instructions from the manual were followed.

5.2.4 Procedure

The same procedure was followed for all of the experiments. Testing was conducted on an individual basis, and it took place under controlled conditions in the cognitive neuropsychology laboratory at the university. Prior to participating in the first experiment, participants gave written informed consent after the nature and aims of the research had been explained (copies of the Expression of Consent and the Information Sheet are provided in Appendix B). The research project received approval from the University Human Ethics Committee, which adheres to the guidelines of the National Health and Medical Research Counsel of Australia. All parts of the experiments were self-paced, and breaks were provided between tasks. Different experimental tasks were conducted on different days. Participants could request a break, or withdraw from the experiments, at any time. No individual testing session exceeded two hours.

The experimental tasks were administered in a darkened laboratory, and participants were dark adapted prior to the presentation of any of the tasks. Practice trials were presented to familiarise participants with individual tasks and to control for practice effects. Testing commenced when participants reported they understood and felt comfortable with the procedure. The order of the different experimental conditions was counterbalanced within each of the experiments. The order in which the experiments themselves were presented to the participants also varied. Testing was discontinued if signs of fatigue were displayed.

For all of the experimental measures viewing was binocular. The viewing distance in the global motion experiments was 57 cm. This was controlled using a height-adjustable chair and a chin-rest. The distance ensured the stimulus area subtended 7×7 degrees of visual angle centred on the fovea. A black cardboard frame

was placed around the monitor to avoid glare. For the local motion experiment participants were seated 3.2m away from the computer screen.

For the global motion experiments trials were preceded by a set of oral and written instructions. Trials began with a small white fixation cross signalling its commencement. Participants were asked to indicate the direction of motion they saw by pressing the corresponding button(s) on the Cambridge Research Systems BC2 response box. For the local motion experiment participants were provided with oral instructions, and they were asked to give their responses out loud with the experimenter entering their responses onto the computer screen in view of the participant. As for the global motion experiments, trials began with a small white fixation cross signalling the commencement of each trial. No feedback was provided for correct or incorrect judgements.

5.2.5 Apparatus and Stimulus Parameters

The stimuli for the global motion experiments were generated by a Dell Optiplex GX1 computer, and displayed on a 21 inch Hitachi HM-4721-D monitor. The resolution of the monitor was 800 x 600 pixels, and the frame rate was refreshed every 8.33msec. The tasks were all written in the C++ programming language using the Borland Builder C++ Version 6 Software Package. The programs were run using the Cambridge Research Systems hardware and Operating System Software, VSG Version 6. The stimuli for the local motion task were generated using a Dell computer, and the resolution of the monitor was 1024 x 768 pixels.

For all of the global motion experiments the stimuli were displayed within a borderless area subtending 6 deg x 6 deg presented in the middle of the computer screen. The small display used was consistent with the stimulus used by Hill and

Raymond (2002), and was chosen to avoid pursuit eye movements when viewing the display. A circular display was used to prevent motion detection at the edges. The velocity of the stimuli in each of the global motion and motion transparency tasks was 10.5 deg/sec, a value close to the optimal response of V5 neurons (Chawla, Phillips, Buechel, Edwards, & Friston, 1998). The duration of a single animation frame was 16.67msec (equivalent to two screen refreshes). Both the signal and noise dots had a diameter of one pixel (0.35mm), and the lifetime of the signal dots was 2 animation frames (33.34msec). This was the dot lifetime used in previous target studies (Hill & Raymond, 2002; Raymond & Sorensen, 1998). It was chosen in the current experiment to ensure consistency with previous studies. Where variations occur this is reported in the method for the individual global motion experiments. The parameters for the local motion task are described in Chapter 8.

CHAPTER 6: Experiment 1

6.1 Aims and Overview

The primary aim of Experiment 1 was to investigate how dyslexia and control groups integrate global motion information across space and time. The investigation was motivated by two theoretical explanations of the M system deficit in dyslexia. One explanation proposes that the reduced global motion sensitivity of some individuals with dyslexia is caused by a low level sensory deficit in the M and dorsal streams (Stein & Walsh, 1997). Based on this explanation it is argued dyslexia groups can perform as well as skilled readers if enough signal, seen as dot density or motion energy, is provided within a small area of the visual field. Motion processing deficits are considered to occur because of underdeveloped motion detectors at V5 (Talcott, Hansen et al., 2000). The second explanation proposes that poor temporal integration or temporal recruitment, a deficit across time, explains the reduced motion sensitivity found in dyslexia (Raymond & Sorensen, 1998).

However, not all studies have found the temporal recruitment processes in individuals with dyslexia to be impaired (e.g., Hill & Raymond, 2002; Talcott, Hansen et al., 2000), leaving the question of under what stimuli conditions a dyslexia group can, or cannot, utilise the added information provided to the visual system through an increase in the number of animation frames presented in the RDK. In Experiment 1 both the dot density and the number of animation frames presented in the RDK were manipulated. This allowed for an investigation of whether increased dot density, an increase in the number of animation frames presented in the RDK, or a combination of the two produced the greatest sensitivity for the dyslexia group.

Two dot density conditions (high and low) were each presented in a five-frame condition and in an eight-frame condition. This resulted in a total of four experimental

conditions; (1) five-frame low dot density, (2) eight-frame low dot density, (3) five-frame high dot density, and (4) eight-frame high dot density. The dot densities used were guided by the findings of Talcott, Hansen et al. (2000). They reported that the performance of their skilled reader group was unaffected by dot density increases past 3.1 dots/deg^2, while the performance of their dyslexia group the reached highest global motion sensitivity with a dot density of 12.2 dots/deg^2. Hence, the high dot density condition was set at 14.15 dots/deg^2, and the low density condition at 3.54 dots/deg^2. This was to allow for the skilled reader group to reach their optimal performance level in the low dot density condition, and the dyslexia group in the high dot density condition.

The number of animation frames presented was also guided by past research. Significant effects of temporal recruitment were found in a dyslexia group when 4 and 10 animation frames were presented in an RDK consisting of high dot density stimuli (Hill & Raymond, 2002), while no temporal recruitment effects were found for the dyslexia group when 2 and 7 animation frames were presented in a low dot density RDK (Raymond & Sorensen, 1998). A two-frame condition was not used as both dyslexia and skilled reader groups have been found to demonstrate poor sensitivity to this condition (Raymond and Sorensen). In addition imaging research has shown MT neurons in monkeys do not respond well to two-frame RDKs (Mikami et al., 1986), with studies suggesting that two-frame stimuli activate lower level motion detectors concerned with the integration of motion within, rather than across, detectors (Snowden & Braddick, 1989a). Hence, five and eight frame RDKs were used in this experiment.

6.2 Hypotheses

If the motion deficit in dyslexia can be explained by a sensory deficit where underdeveloped motion detectors at V5 undersample the incoming motion signals, the dyslexia group will be significantly less sensitive to coherent motion than the skilled reader group when dot density is low, regardless of the number of animation frames presented in the RDK. No significant reader group differences will be found when dot density is high, regardless of the number of animation frames presented in the RDK.

Alternatively, if the motion deficit can be explained by difficulties with temporal integration, dot density will not influence coherent motion sensitivity for either the dyslexia or the skilled reader groups. However, the dyslexia group will not display temporal recruitment effects as the number of animation frames presented in the RDK increases. The magnitude of the between group effect will be greater in the eight-frame conditions than in the five-frame conditions regardless of dot density, as increased sensitivity will be found for the skilled reader group, but not the dyslexia group, as the number of animation frames presented in the RDK increases.

Finally, if the dot density used determines whether temporal recruitment effects are found, no significant effects of temporal recruitment will be found for the dyslexia group when dot density is low. Normal temporal recruitment effects will be found when dot density is high.

6.3 Participants

There were 21 individuals in the dyslexia group (17 females; *M* age = 23.14 years; *95% CI* = 20.10-26.19) and 23 individuals in the skilled reader group (15 females; *M* age = 19.43 years; *95% CI* = 17.98-20.89). Participants were classified as members of the dyslexia or control groups based on the criteria outlined in Chapter 5,

and the groups had the same reading and cognitive ability profile as that presented for the overall sample.

6.4 Stimuli and Procedure

Coherent Motion

The stimuli consisted of 100 (low density) or 400 (high density) white dots (luminance of 20 cd/m^2) presented on a black background (luminance of 0.54 cd/m^2). As described in Chapter 5 under general stimulus parameters, the dot lifetime was 2 animation frames, with a single animation frame being presented for 16.67msec. Either 5 or 8 animation frames were presented consecutively without an interstimulus interval, producing a total stimulus duration of 84msec for the five-frame conditions and 134msec for the eight-frame conditions. At the end of a dot lifetime the signal dots disappeared before being regenerated at a randomly selected stimulus location within the panel. This was to prevent the tracking of any individual dots when detecting the direction of global motion. A standard wrap around technique was used for the signal dots as they reached the side of the screen. The noise dots randomly changed position after each animation frame in a Brownian (random) fashion.

For each of the four experimental conditions (five-frame low dot density, eight-frame low dot density, five-frame high dot density, eight-frame high dot density) two blocks of trials were presented. Separate coherent motion thresholds were obtained for each block. As the intra block consistency was high for all of the experimental conditions (ranging from .66 to .82) the total threshold (average of block 1 and 2) was used in the analyses. Coherent motion thresholds were calculated using an adaptive three-down, one-up staircase procedure. After correctly determining the correct direction of motion on three consecutive trials coherence was halved, while

after each incorrect response coherence was doubled. This allowed for an estimation of the coherence value needed to obtain a correct response on 79% of the trials (Wetherill & Levitt, 1965). For each block of trials the staircase was terminated after eight response reversals, and the coherent motion threshold was defined as the geometric mean of all the reversals. The starting coherency was 50%.

A number of trials were presented to evaluate bias in the response pattern of participants. These trials had a coherence of 1% and were presented at least once every five trials. Participants were expected to respond randomly to these trials, with about half the responses being to the left and half to the right. Response bias either to leftward or rightward directions of motion was investigated using this measure.

The written and verbal instructions provided to the participants at the commencement of the task were as follows; "*In this program you will see a patch of white dots in the middle of the screen. In each trial a certain number of dots can move in one direction. Your task will be to indicate if the dots move to the left or to the right. Sometimes it will be easy to see the movement, at other times it will just look like lots of dots moving randomly. Use a red button if the movement is to the left (<_ _ _). Use a black button if the movement is to the right (_ _ _ >)*". The red button was located on the left side of the Cambridge Research Systems CB-2 response box, and the black button on the right side of the response box.

6.5 Results

A 2 (group) x 2 (dot density) x 2 (number of frames) mixed factorial ANOVA was conducted. Prior to analysis, an investigation of the distributions revealed some positive skew. However, this was not deemed problematic. Levene's Test of Equality of Error Variances was violated in the eight-frame high dot density condition, and the

descriptive data showed the variance was significantly greater for the dyslexia group than for the skilled reader group. As F_{max} (which is the ratio of the largest group variance over the smallest group variance, Hartleys test) exceeded 3, the alpha level was reduced to .025 to avoid any Type I errors. All other assumptions of the analysis were met. Global motion sensitivity for the reader groups in the different experimental conditions are displayed in Figure 8.
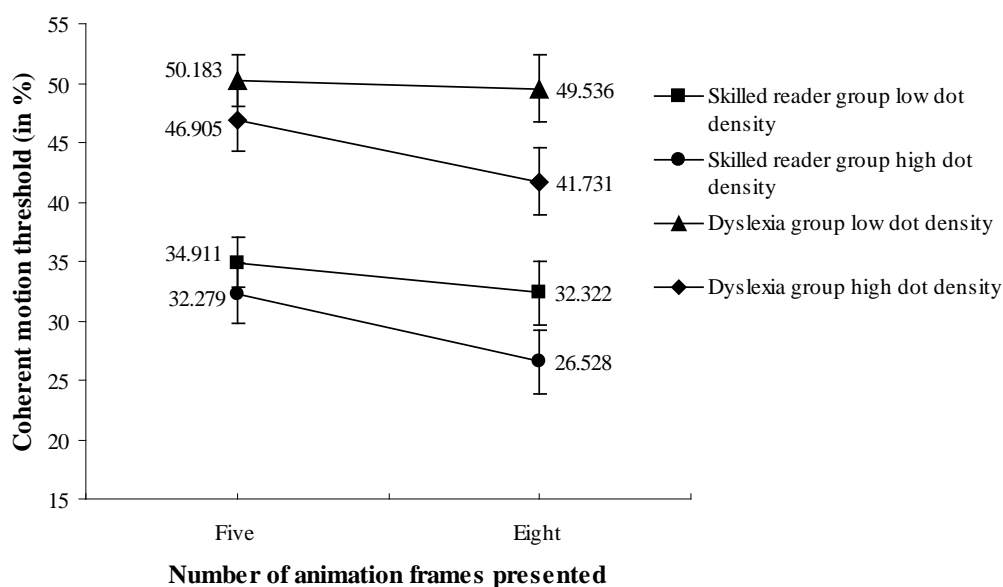
Figure 8. Coherent motion thresholds for the effects of dot density and the number of animation frames presented for the dyslexia and skilled reader groups in each of the four experimental conditions. Error bars represent ±1 standard errors.

The results of the ANOVA revealed a significant main effect of group, $F(1, 42) = 23.25$, $p < .0005$; partial $\eta^2 = .36$, with the dyslexia group ($M = 47.09$; *95% CI =* 42.38-51.80) being less sensitive to coherent motion than the skilled reader group ($M = 31.51$; *95% CI =* 27.01-36.01) regardless of the manipulations conducted. Significant main effects were also found for dot density, $F(1, 42) = 20.24$, $p < .0005$; partial $\eta^2 = .33$, and the number of animation frames presented in the RDK, $F(1, 42) =$

13.11, $p = .001$; partial $\eta^2 = .24$. A significant two-way interaction was found between dot density and the number of frames presented, $F(1, 42) = 6.70$, $p = .013$. Partial η^2 showed that 13.7% of the variance in coherent motion threshold was accounted for by this interaction. Partial η^2 is a measure of effect size, and it refers to the proportion of the variance accounting for the effect. The three-way interaction between group, dot density and number of frames was not significant, $F(1, 42) = .210$, $p = .649$. For all of the comparisons the reduced alpha level was used because of the violation of the homogeneity of variance.

Contrast analysis for the significant dot density by number of animation frames interaction showed that there was no significant effect of temporal recruitment for either group when dot density was low, $t(1, 42) = 1.17$, $p = .250$. However, the sensitivity of both groups was significantly higher in the eight-frame condition than in the five-frame condition when dot density was high, $t(1, 42) = 5.21$, $p < .0005$. These results show that for both groups temporal recruitment effects were found with presentation of high dot density stimuli, but not low. Moreover, while the results showed reduced overall sensitivity for the dyslexia group in each of the stimulus conditions, the effects of the stimulus manipulations were the same for both groups.

Further post hoc analyses were undertaken to determine whether the effects of temporal recruitment differed when the motion stimulus was presented in the leftward or rightward directions. In view of Hill and Raymond's (2002) post-hoc results, where the dyslexia group were found to show less recruitment than the skilled reader group in response to leftward when compared to rightward motion, temporal recruitment effects for the two directions of motion was examined in the high dot density conditions. Two 2 (group) x 2 (number of frames) mixed factorial ANOVAs were conducted, one for leftward and one for rightward motion. Overall threshold scores

were used for each direction of motion (average score across the two blocks). The results revealed a significant main effect of the number of animation frames presented for both leftward, $F(1, 42) = 11.82$, $p = .001$; partial $\eta^2 = .22$ and rightward, $F(1, 42) = 9.46$, $p = .004$; partial $\eta^2 = .18$, motion, with both groups being more sensitive to the eight-frame ($M_{\text{leftwards motion}} = 37.87$; *95% CI* = 32.36- 43.38; $M_{\text{rightwards motion}} = 30.35$; *95% CI* = 25.98 -34.81), compared to five-frame ($M_{\text{leftwards motion}} = 43.63$; *95% CI* = 38.62-48.63; $M_{\text{rightwards motion}} = 35.513$; *95% CI* = 30.20-40.84), stimuli. These results show that the temporal recruitment processes of the dyslexia group did not differ from that of the skilled reader group, regardless of the direction of motion presented.

The effect of response bias was evaluated by obtaining a percentage score for the proportion of leftward responses to trials presented at 1% coherence. The results showed that while a small proportion of individuals in both groups demonstrated a response bias in either direction, there was no consistent bias present within either group. An overall investigation across conditions showed that on average the dyslexia group reported the stimuli to be moving leftwards 46% ($SD = 12.36$) of the time. In comparison the control group reported the direction of motion to be moving to the left about 44% ($SD = 11.07$) of the time. An independent samples *t*-test using the overall response bias as the DV showed no significant differences in left-right response between the two groups, $t(1, 42) = .676$, $p = .503$.

6.6 Discussion

Experiment 1 showed that the dyslexia group was consistently less sensitive to coherent motion than the skilled reader group regardless of the manipulations conducted. The current results did not support the hypothesis that the global motion sensitivity of the dyslexia group would normalise with presentation of high dot

density stimuli in the RDK. In addition, temporal recruitment effects were found in both groups with presentation of high, but not low dot density, failing to provide direct support for the hypothesis of poor temporal integration in the dyslexia group. The results demonstrated that presenting the two variables together altered the effect of each, with temporal recruitment effects only occurring for both groups, when dot density was high. This finding may explain why temporal recruitment effects were found for the dyslexia group in the Hill and Raymond (2002) study, but not in the Raymond and Sorensen (1998) study. Additionally, the lack of any left-right response bias in the dyslexia group in response to the 1% catch trials suggest the reduced sensitivity of the dyslexia group on the coherent motion task cannot be attributed poor vigilance or inattention, suggesting the deficit is neural in origin.

The finding that both groups demonstrated the highest level of sensitivity in the eight-frame high dot density condition is important. From both a sensory and perceptual point of view this condition produced the highest levels of sensory stimulation, as the perceptual system had the greatest opportunity to sample the motion information over both space and time. The finding implies that concurrently increasing the dot density in the RDK and the number of animation frames presented, assisted the visual system in utilising the added information provided by each parameter. The finding that the skilled group did not demonstrate temporal recruitment effects when the dot density was low was unexpected, as past research has shown normal observers to be largely unaffected by dot density changes (Talcott, Hansen et al., 2000). However, it is possible the short total stimulus durations used (84mec for the five-frame conditions and 134msec for the eight-frame conditions), made the task too perceptually difficult even for a well functioning system to detect and fully utilise the added information presented to it through an increase in the

number of animation frames when dot density was low. The brief stimulus duration used may have impacted on the processing capacity of both reader groups when sampling the motion signals. Furthermore, past research has suggested that with frame durations below 20msec a greater number of animation frames may be required to reach asymptotic motion thresholds (Snowden & Braddick, 1989a, 1989b). This, taken together with the dot lifetime of 2 animation frames used in the current study, may explain the findings. While past target studies have used a dot lifetime of 2 animation frames (Hill & Raymond, 2002; Raymond & Sorensen, 1998), another study used a dot lifetime of 4 animation frames, (Talcott, Hansen et al., 2000), making the motion stimuli easier to detect. The increase in sensitivity occurs as single signal dots are available to the visual system for longer (i.e., being 'alive' across more animation frames), giving the system more opportunity to detect the motion stimulus across time.

To further assess the ability of the dyslexia group to process complex motion stimuli, a motion transparency study was conducted in Experiment 2. While this task also used random dot stimuli, simultaneous segmentation and detection of different directions of stimulus motion was required. In this task the two motion signals must be extracted and grouped simultaneously, producing increased perceptual difficulty. The total stimulus duration of the RDK was increased in this study (ranging from 150 to 550msec), and additional manipulations affecting the number of frames presented and the lifetime of the signal dots were conducted.

CHAPTER 7: Experiment 2

7.1 Aims and Overview

The main aim of Experiment 2 was to investigate the performance of the two reader groups on a motion transparency task. This investigation was based on a previous report that adults with dyslexia had significantly impaired accuracy on a motion transparency task, but did not differ in performance from a control group on a global motion coherence task (Hill & Raymond, 2002). Based on these findings it was argued that the temporal processing deficit found in dyslexia is caused by an abnormality within dorsal extrastriate cortical areas, affecting the segmentation and grouping of complex motion signals, a perceptual function.

In a motion transparency task participants are required to extract and group two motion signals simultaneously. When stimuli are presented for less than 250msec the two directions of motion are processed simultaneously. However, when the stimulus duration is greater than 250msec, the two directions of motion can be processed sequentially (M. Edwards & Greenwood, 2005; Mulligan, 1992). In this experiment accuracy on a bidirectional motion transparency task was evaluated, with a specific focus on both the simultaneous and sequential processing of the stimulus. Simultaneous processing of the bidirectional stimulus was evaluated in two conditions using stimulus durations of 150 and 250msec. Consistent with a previous study (Hill & Raymond, 2002) poor accuracy was expected in the dyslexia, but not the skilled reader group in these conditions. Accuracy when sequentially processing the bidirectional stimulus was evaluated using stimulus durations of 450 and 550msec. It was expected that as the stimulus duration increased, the accuracy of the dyslexia group would increase. However, due to poor accuracy of individuals with dyslexia when performing sequential processing tasks (e.g., Ben-Yehudah et al., 2001; Eden et

al., 1995) poorer accuracy was also expected relative to the skilled readers on this component of the study. This is consistent with the results of a previous motion transparency study in dyslexia (Hill & Raymond), where the accuracy of the dyslexia group did not equal that of the skilled reader group until the total stimulus duration reached 2556msec.

Two separate experiments were conducted. In Experiment 2A, the basic stimulus parameters were the same as those used in Experiment 1, while in Experiment 2B the number of animation frames presented was doubled (by halving the duration of a single animation frame from 16.67 to 8.33msec), and the dot lifetime was increased from 2 to 3 animation frames. The increase in the number of animation frames presented, along with the increased in dot lifetime, was expected to produce greater accuracy scores for both reader groups. The increased sensitivity occurs as an increase in the number of animation frames presented and an increase in dot lifetime produce greater neural stimulation to the visual system, giving it more opportunity to sample the signal dots (Festa & Welch, 1997). While an increase in frame duration would also reduce the perceptual difficulty of the task, as each frame is available to the system for longer (Snowden & Braddick, 1989a, 1989b), the reduced frame duration in Experiment 2B was not expected to make much of an impact in the current experiment, with both frame durations used being short (8.33msec and 16.67msec).

7.2 Hypotheses

If the dyslexia group has a deficit affecting the simultaneous processing of bidirectional motion at extrastriate levels, they will not reach the 75% accuracy level in the two true transparency conditions (150 and 250msec). The skilled reader group will reach the 75% accuracy level in the 150msec stimulus duration conditions.

The accuracy of the dyslexia group will increase as the stimulus duration increases, and they will reach the 75% accuracy level in the 550msec stimulus duration condition. However, if the dyslexia group has an additional deficit affecting the sequential processing of bidirectional motion their accuracy score will be significantly poorer than that of the skilled reader group also in the 450 and 550msec stimulus duration conditions.

The same pattern of results will be found for both experiments. However, both reader groups will perform better in Experiment 2B than in Experiment 2A, as the number of frames presented and the dot lifetime was increased in the second experiment, giving the visual system more of an opportunity to sample the motion stimuli.

7.3 Participants

Participants were 20 individuals with dyslexia (17 females, *M* age = 23.35 years; *95% CI* = 20.18- 26.52) and 22 skilled readers (14 females, *M* age = 19.5 years; *95% CI* = 17.98- 21.02) readers. All of the participants, with the exception of two individual with dyslexia, also participated in Experiment 1. One additional individual with dyslexia was recruited in Experiment 2. The reading and cognitive profile of the two groups was consistent with that reported for the overall sample.

7.4 Stimuli and Procedure

Motion Transparency.

Half the participants did Experiment 2A first and half Experiment 2B first. The stimuli used in Experiment 2A were consistent with the parameters used in Experiment 1, with the dot lifetime being 2 animation frames and the duration of a

single animation frame being 16.67msec. For each of the four stimulus durations the number of frames presented ranged from 9-33. In Experiment 2B the dot lifetime was increased to 3 animation frames, and the frame duration was reduced to 8.33msec. This manipulation effectively doubled the number of animation frames making up the RDK (ranging from 18 to 66), while keeping the total stimulus durations the same as in Experiment 2A.

For both experiments the stimulus consisted of 200 black dots (luminance of $0.54cd/m^2$) presented on a white background (luminance of 20 cd/m^2). The number of dots presented corresponded to a dot density of 7.08 dots/deg^2 (or 3.54 dots/deg^2 in each direction). The RDKs appeared as two transparent sheets of dots, where half the dots moved in a horizontal direction (i.e., left or right), and the other half moved in a vertical direction (i.e., up or down). Four directional combinations were presented. These were: (1) left and up, (2) left and down, (3) right and up, and (4) right and down. In each experiment there were four blocks, each consisting of 32 trials. Within each block the directional combinations (e.g., left and up) were presented eight times, with the presentation of the different stimulus durations randomised within blocks.

Accuracy scores were obtained separately for each of the four stimulus duration conditions for each of the experiments. Only trials where both directions of motion were accurately identified were used to calculate accuracy. Consistent with a previous study, 75% accuracy on individuals stimulus duration conditions was used as a determinant of successful task performance (Hill & Raymond, 2002).

The following oral and written instructions were provided: *In this program you will see, in the centre of the screen, a patch made up of lots of black dots. In each trial a number of dots will move left or right, and a number of dots will move up or down. Your task will be to indicate if the dots move to the left or the right, and if the*

dots move up or down. Sometimes it will be easy to see the movement, at other times it

will just look like lots of dots moving randomly. Use a red button if movement is to the

left (<_ _). Use a black button if movement is to the right (_ _ _ >). Use the top white

button if the dots move up. Use the bottom white button if the dots move down.

Responses were given using the Cambridge Research Systems CB-2 response box.

The red button was located on the left side of the box, and the black button on the

right side of the box. The top white button was located in a centred position on the top

of the box, while the bottom white button was located in a centred position on the

bottom of the box.

7.5 Results, Experiment 2A

The analysis of motion transparency accuracy in the skilled and dyslexia

groups was undertaken using a 2 (group) x 4 (frame duration) mixed factorial

ANOVA. All of the assumptions of the analysis were met. The results of the ANOVA

revealed a significant main effect of stimulus duration, $F(3, 120) = 16.07$, $p < .0005$;

partial $\eta^2 = .29$, and a significant main effect of group, $F(1, 40) = 8.57$, $p = .006$;

partial $\eta^2 = .18$. There was no significant interaction found between stimulus duration

and reader group, $F(3,120) = .166$, $p = .917$; partial $\eta^2 = 0.004$. The mean accuracy

scores for each of the groups across the four stimulus duration conditions are

presented in Figure 9.
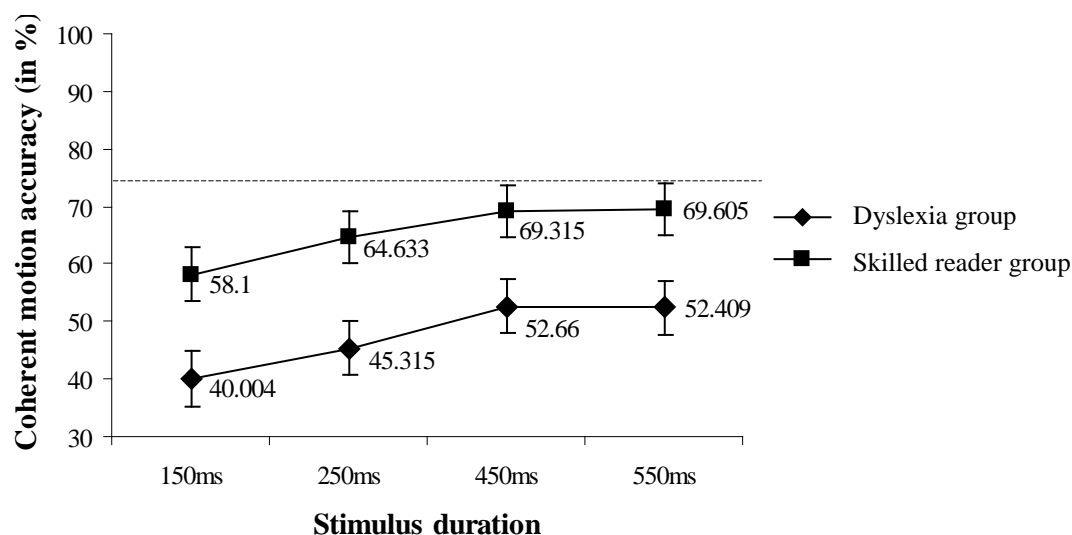
Figure 9. Motion transparency accuracy scores for the dyslexia and skilled reader groups in the four stimuli duration conditions. Error bars represent ± 1 standard errors. The dotted line represents the 75% accuracy mark used as a determinant of successful task performance.

As seen from Figure 9, the 75% accuracy criteria used as a determinant of successful task performance was not reached for either of the reader groups, with the dyslexia group being significantly less accurate than the skilled reader group in processing bidirectional motion regardless of the stimulus duration used. To determine whether accuracy differences were found in the simultaneous and sequential components of the tasks, contrast analysis was conducted on the significant main effect of stimulus duration. There was a significant increase in accuracy as the stimulus duration increased from 150msec (M =49.05) to 250msec (M = 54.97), t(3, 120) = -2.655, p = .011. There was a further significant increase in accuracy as stimulus duration increased from 250msec (M = 54.97) to 450msec (M = 60.99), t(3, 120) = -3.619, p = .001. However, there were no significant difference in performance

between the 450msec (M = 60.99) and 550msec (M = 61.01) stimulus duration conditions, $t(3, 120) = 1.677$, $p = .991$.

7.6 Discussion, Experiment 2A

The results of Experiment 2A supported the hypothesis that the dyslexia group would not reach the 75% accuracy level (used as a determinant for successful task performance) when the stimulus duration was 150 or 250msec. The hypothesis that the dyslexia group would reach an accuracy level of 75% in the 550msec condition was not supported. Surprisingly, neither reader group reached a 75% level of accuracy in any of the stimulus durations presented, also failing to support the hypothesis that the skilled reader group would reach a 75% accuracy level in the 150msec stimulus duration condition.

The current findings are interesting in two ways. First, the dyslexia group was found to be consistently less accurate than the skilled reader group at detecting the two directions of motion regardless of stimulus duration. This suggests the dyslexia group had more difficulty than the skilled reader group extracting and grouping the two directions of motion, with the deficit affecting both the simultaneous and sequential processing of the bidirectional motion. Second, while neither reader group reached the 75% accuracy threshold in any of the stimulus durations presented, accuracy scores for both groups were above a chance level (i.e., 25%), suggesting the visual system was detecting the incoming stimuli but not processing it effectively.

When the stimulus parameters used in the current task were compared to those used in a previous motion transparency study (Hill & Raymond, 2002), it was clear that the perceptual difficulty of the two tasks differed. First, Hill and Raymond did not limit their dot lifetime, and they used high dot density stimuli (54 dots/deg^2, or 27

dots/deg^2 in each direction), with the duration of a single animation frame being 33.33msec. The higher dot density, increased frame duration, and unrestricted dot lifetime would have provided greater stimulation to the visual system than the current task, making it easier for the system to extract and group the two motion signals. Based on these differences it is possible that there was limited opportunity for the visual perceptual system to detect the two directions of motion using the current stimulus parameters. As the motion transparency task requires more complex computations than the coherent motion task, there may have been insufficient motion information available to the visual system to extract and group the two signals across the number of frames presented (ranging from 9-33), when the dot lifetime was limited to 2 animation frames. Experiment 2B examined this possibility by effectively doubling the number of animation frames making up the RDK (18- 66 frames). The dot lifetime was also increased from 2 to 3 animation frames. Both of these changes were predicted to make the segmentation and grouping processes more efficient with increased availability of motion stimuli to the visual system (despite the duration of a single animation frame being reduced from 16.67msec to 8.33msec). These changes in stimulus parameters provided more stimulation to the visual system.

7.7 Results, Experiment 2B

The motion transparency accuracy of the dyslexia and skilled reader groups was assessed by a 2 (group) x 4 (frame duration) mixed factorial ANOVA. The analysis revealed that Mauchley's Test of Sphericity was violated. An investigation of the distributions revealed the experimental variables were moderately negatively skewed. This was partly due to a ceiling effect for the longer duration conditions in the skilled reader group, and partly due to some individual low scores. The removal of

three extreme scores (two individuals from the dyslexia group and one individual from the skilled reader group) did not change the overall results of the analysis so the complete data set was used. To correct for the Sphericity violation, the Huynh-Feldt correction was applied. As F_{max} exceeded 3, the significance level was also corrected from .05 to .025. The mean accuracy scores for the two groups across the four stimulus durations are presented in Figure 10.
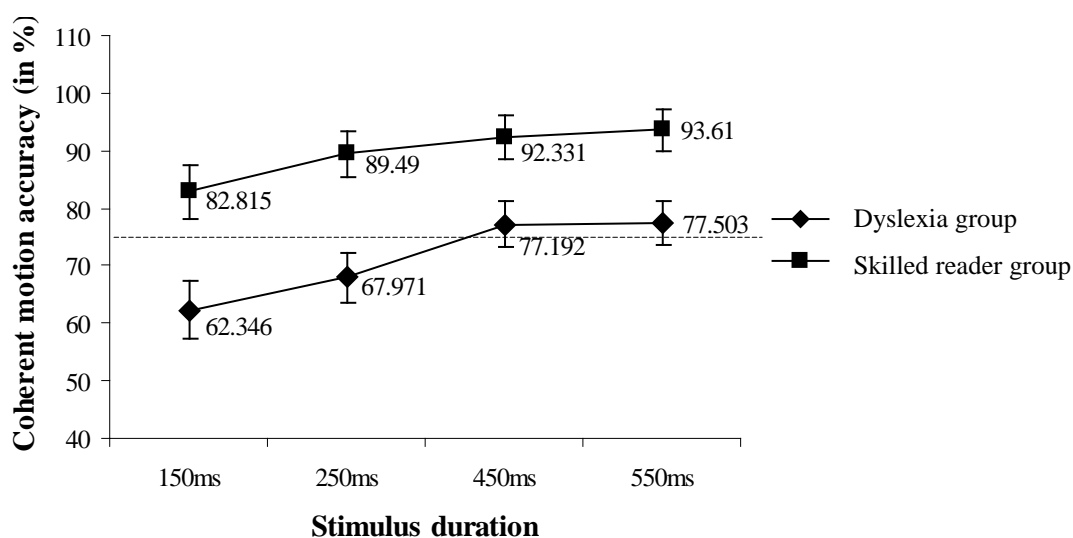
Figure 10. Motion transparency accuracy scores for the dyslexia and skilled reader groups in the four stimulus duration conditions. Error bars represent ± 1 standard errors. The dotted line represents the 75% accuracy mark as a determinant of successful task performance.

Significant main effects were obtained for stimulus duration, $F(2, 89) = 25.879$, $p < .0005$, partial $\eta^2 = .396$, and reader group, $F(1, 40) = 10.85$, $p = .002$, partial $\eta^2 = .21$. Consistent with the findings from Experiment 2A, the interaction between group and stimulus duration was not significant, $F(2, 89) = 1.76$, $p = .173$. As seen from Figure 10 the skilled reader group reached the 75% accuracy criteria in the 150msec stimulus duration condition, while the dyslexia group reached this

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accuracy level in the 450msec stimulus duration condition. The results show that regardless of stimulus duration the dyslexia group was less accurate than the skilled reader group.

As for Experiment 2A, there was an increase in accuracy as the stimulus duration increased. Contrast analysis was conducted on the significant main effect of stimulus duration. The results showed that accuracy significantly improved from the 150 ($M = 72.58$) to the 250msec ($M = 78.73$) stimulus duration condition, $t(2, 89) = -6.99$, $p < .0005$, and from the 250 ($M = 78.73$) to the 450msec ($M = 84.76$) stimulus duration condition, $t(2, 89) = -4.90$, $p < .0005$. There were no significant differences in accuracy between the 450msec ($M = 84.76$) and the 550msec (M = 85.56) stimulus duration conditions, $t(2, 89) = -.619$, $p = .540$.

7.8 Discussion, Experiment 2B

The hypothesis that the skilled reader group would reach a 75% accuracy level in the 150msec stimulus duration condition, while the dyslexia group would not, was supported. This suggests that the dyslexia group had a motion processing deficit affecting the processing of two simultaneously presented motion signals. Furthermore, the hypothesis that the accuracy level of the dyslexia group would improve with increased stimulus duration, reaching a 75% accuracy level in the 550msec stimulus duration condition, while still being significantly less accurate than the skilled reader group was also supported, suggesting that the dyslexia group had an additional deficit affecting the sequential processing of bidirectional motion.

What was most prominent in terms of the current findings was the increase in accuracy scores found from Experiment 2A to 2B. The results showed that an increase in the number of animation frames and an increase in dot lifetime produced greater

accuracy scores for both reader groups. This suggests that increasing the dot lifetime and the number of animation frames presented, provided greater stimulation to the visual motion system, making the task perceptually less difficult. Consistent with the findings of Experiment 2A, accuracy scores improved significantly up until the 450msec condition for both groups. An investigation of the mean score obtained for the skilled reader group in this condition ($M = 92.33\%$; *95% CI* = 84.55-100.11) suggests that they may have reached their optimal performance level at this level. However, while the performance of the dyslexia group also appeared to reach a plateau in the 450msec stimulus duration condition, it is possible their performance would have improved further if the stimulus duration had been further increased. This is inferred from the findings of Hill and Raymond (2002), who reported that the performance of their dyslexia group to continue to improve until the total stimulus duration reached 2 seconds. The longer time required to perform the sequential components of the task is consistent with past research suggesting individuals with dyslexia have more difficulties with sequential processing (Ben-Yehudah et al., 2001; Eden et al., 1995), and the shifting of attention from one stimulus to a second stimulus (Hari & Renvall, 2001). In the longer stimulus durations of the current task this deficit could manifest itself as difficulties shifting attention from the first to the second stimulus captured in the stimulus.

7.9 Summary of the Current Findings

The overall results of Experiments 2A and 2B have two major implications. First, the results demonstrated that regardless of dot lifetime and the number of animation frames presented, the motion transparency accuracy of the dyslexia group was significantly impaired compared to that of the skilled reader group. While the

dyslexia group reached the 75 % accuracy level in Experiment 2B (in the 450 and 550msec stimulus duration conditions), their performance was still impaired compared to that of the skilled reader group. From a theoretical perspective this suggests the motion deficit affected both the simultaneous and sequential processing efficiency of the dyslexia group on the bidirectional task. Second, the results demonstrated that changes in stimulus parameters influenced accuracy in the same way for both reader groups, with none of the groups being able to segment and identify the two motion signals in Experiment 2A to a 75% accuracy level. Theoretically, this means that not even a well functioning system can perform optimally when insufficient stimulation is provided to the visual system, highlighting the importance of stimulus parameters when conducting global motion research.

Further, the combined results from Experiment 1 and Experiments 2A and 2B show that the dyslexia group was significantly less sensitive to global motion than the skilled reader group regardless of the manipulations conducted. The results also showed that while being significantly less sensitive to the stimuli, the performance of the dyslexia group followed the same overall pattern of performance as the skilled reader group, suggesting that the sensory and perceptual processes of integration and segmentation were functional in the dyslexia group, but that the operating efficiency of these processes was significantly impaired.

One common feature of the stimuli used in Experiments 1 and 2 was the presence of multiple elements generating a 'noisy' visual environment. In Experiment 1, signal elements had to be extracted from noise elements, and in Experiment 2, different signals had to be extracted and segmented. One recent explanation of reduced sensitivity in dyslexia groups on visual tasks that measure M system functioning concerns difficulties with noise exclusion. Difficulties excluding

irrelevant motion signals from a visual display has been put forward as an alternative

perceptual explanation of reduced motion sensitivity in dyslexia (Sperling et al., 2005,

2006b). To examine the effect of noise on global motion sensitivity, Experiment 3

investigated whether extracting signal from noise also contributes to the difficulties

found in dyslexia groups. This was done by manipulating the salience of the signal

and noise dots in a coherent motion task.

CHAPTER 8: Experiment 3

8.1 Aims and Overview

Experiment 3 investigated whether signal salience and luminance contrast in a global motion stimulus influenced sensitivity in the dyslexia and skilled reader groups. Recent evidence has been presented suggesting that the visual perceptual deficit found in individuals with dyslexia occurs because of difficulties with extracting signal from noise in complex perceptual stimuli. This is referred to as the noise-exclusion hypothesis (e.g., Sperling et al., 2005, 2006b).

When detecting the direction of global motion, two processes must occur. First a signal-to-noise analysis must be performed where the signal is extracted from the noise elements. Second, these signals must be integrated to form a global motion percept (Braddick, 1993; Snowden & Braddick, 1989b). When extracting the signal from the noise, the perceptual system is required to ignore the noise and attend to the signal, optimising the perceptual filter so that signal is processed and noise excluded (Lu & Dosher, 1998). Signal salience can be manipulated by increasing the contrast of target elements in the motion display.

The salience of the signal and noise elements in an RDK has been manipulated in one previous study (Sperling et al., 2006b). Consistent with previous research (e.g., Cornelissen et al., 1995), when the signal and noise elements were of equal salience (both light grey), the dyslexia group was significantly less sensitive to coherent motion than the control group. However, when the signal was red and the noise grey, no significant differences in motion sensitivity were found between the reader groups. The two reader groups were also equally sensitive when the display contained signal elements only (red signal dots), a no-noise condition. The results of the Sperling et al., study were interpreted in support of the noise-exclusion hypothesis. However, the use

of a coloured signal added an element of parvocellular or ventral pathway processing to the task (Tootell et al., 1996). While research has demonstrated that the parvocellular sensitivity of dyslexia groups does not differ from that of skilled readers (Hansen et al., 2001; Wilmer et al., 2004), there are a small proportion of P cells at V5 that may have been activated in response to the coloured stimuli. In Experiment 3 stimulus salience was manipulated by changing the luminance of the signal and noise elements in the RDK. This manipulation predominantly activated the fast acting cells of the magnocellular/dorsal stream, so parvocellular cell involvement was controlled.

There were a total of four conditions presented. In two conditions the signal and noise dots were of equal luminance, with one condition producing a high luminance contrast stimulus and one condition producing a low luminance contrast stimulus. In the high luminance contrast condition, the signal and noise dots had a luminance of 6 cd/m^2 (dark grey), and were presented on a luminance background of 18cd/m^2 (light grey). In the low luminance contrast condition the signal and noise dots had a luminance of 12 cd/m^2 (medium grey), producing a lower contrast stimulus relative to the 18cd/m^2 (light grey) background. The Weber contrast of the high luminance contrast condition was 0.66, and 0.33 for the low luminance contrast condition. The closer to 1 the higher the luminance contrast. The Weber contrast is calculated by dividing the difference in luminance between the elements and background by the background luminance (Snowden & Edmunds, 1999). The two control conditions allowed for an investigation of (1) coherent motion sensitivity when the signal and noise elements were of equal salience (standard coherent motion task), and (2) the impact of high and low luminance contrast stimuli on coherent motion sensitivity.

Signal salience was manipulated in two ways. The luminance of the background remained constant at 18cd/m^2 (light grey) in both conditions. In one condition, the signal elements (dark grey, 6cd/m^2) were more salient than the noise (medium grey, 12cd/m^2), producing a high signal salience stimulus. In this condition, the signal dots had a Weber contrast of 0.66 and the noise dots a Weber contrast of 0.33. In the second condition, the noise (dark grey, 6cd/m^2) was more salient than the signal (medium grey, 12cd/m^2), producing a low signal salience stimulus. In this condition, the Weber contrast of the noise dots was 0.66, and 0.33 for the signal dots.

8.2 Hypotheses

If the noise exclusion deficit hypothesis is supported, the dyslexia and skilled reader groups will have increased sensitivity to global motion when the salience of the signal dots is higher than the salience of the noise dots. However, reduced sensitivity to global motion will be found in both reader groups when the salience of the noise dots is higher than the salience of the signal dots in the RDK. If difficulties with noise exclusion explain the reduced sensitivity to global motion in dyslexia, there will be no significant between group differences when the salience of the signal dots is higher than the salience of the noise dots. In addition, the dyslexia group will be significantly less sensitive than the skilled reader group in the conditions where the signal and noise dots in the RDK are of equal salience, and when the noise dots are of a higher salience than the signal dots.

Research has demonstrated that in normal readers sensitivity to global motion improves with increased luminance contrast (M. Edwards et al., 1996). In terms of the current experiment, this means the skilled readers will have increased global motion sensitivity when the signal and noise dots have high luminance contrast

(both dark grey), compared to when they have low luminance contrast (both medium grey). If the reduced sensitivity to global motion in dyslexia is explained by an M system deficit, the dyslexia group will be less sensitive to these changes.

8.3 Participants

There were 14 individuals in the dyslexia group (12 females; *M* age = 23.5 years; *95% CI* = 19.39-27.61), 13 of whom also participated in Experiments 1 and 2. There were 19 individuals in the skilled reader group (13 females; *M* age = 19.20 years; *95% CI* =17.62-20.78), 18 of whom participated in Experiments 1 and 2. The reading and cognitive profile of the two groups was consistent with that reported for the overall sample.

8.4 Stimuli and Procedure

Coherent Motion.

The stimulus consisted of 200 dark grey (luminance of 6 cd/m^2) and/or medium grey (12 cd/m^2) dots presented on a light grey (18 cd/m^2) background. As for the other global motion experiments, the signal and noise dots had a diameter of one pixel (0.35mm). The dot density was 7.08 dots/deg^2, which was the dot density used in the motion transparency experiment. Consistent with Experiments 1 and 2A, the duration of a single animation frame was 16.67msec (equivalent to two screen refreshes), and each frame was presented without an interstimulus interval. The lifetime of the signal dots was 2 animation frames, and at the end of its lifetime the dot would disappear before being regenerated at a randomly selected stimulus location within the panel. This was to prevent the tracking of any individual dots in detecting the direction of global motion. A standard wrap around technique was used for the

signal dots as they reached the side of the screen, while the noise dots randomly changed position after each animation frame in a Brownian (random) fashion.

For each of the experimental conditions, two blocks of trials were presented and separate thresholds were obtained for each of the blocks. As the intra-block consistency was high (ranging from .64 to .93), the mean threshold of both blocks of trials was used in the analyses. Coherent motion thresholds were calculated using the same adaptive three-down, one-up, staircase psychophysical technique described in Experiment 1. This produced a threshold estimation of the motion coherence value needed to obtain a correct response on 79% of the trials. The starting coherency, determined by pilot testing, was 25% for each of the conditions. The order in which the experimental conditions were presented was counterbalanced between groups and participants to avoid any practice effects or fatigue effects.

The written and verbal instructions provided to the participants at the commencement of the task were as follows; *"In this program you will see a patch of dots in the middle of the screen. In each trial a certain number of dots can move in one direction. Your task will be to indicate if the dots move to the left of the right. Sometimes it will be easy to see the movement, at other times it will just look like lots of dots moving randomly. Use a red button if movement if to the left (<_ _ _). Use a black button if movement is to the right (_ _ _ >).* The red button was located on the left side of the response box, and the black button on the right side of the response box.

8.5 Results

Inspection of the distributions revealed severe positive skew in the data. A number of outliers and extreme scores were identified in different conditions. A

square root transform was conducted on the coherence thresholds to reduce the impact of the extreme scores. While this improved the distributions, one extreme score remained in the skilled reader group. This participant was excluded from the between group analyses. The transformed data were used in all of the analyses.

8.5.1 Control Conditions

A 2 (group) x 2 (luminance) mixed factorial ANOVA was conducted to examine the motion sensitivity of the poor and skilled reader groups in the high and low luminance contrast conditions. All of the assumptions of the analysis, with the exception of Box's Test of Equality of Covariance Matrices were met. As F_{max} exceeded 3, the significance level was corrected from .05 to .025.

The results of the ANOVA showed a significant main effect of reader group, $F(1, 31) = 14.77$, $p = .001$, partial $\eta^2 = .32$, and a significant main effect of element luminance, $F(1, 31) = 7.18$, $p = .012$, partial $\eta^2 = .19$. There was no significant interaction found between group and element luminance, $F(1, 31) = 1.66$, $p = .207$, partial $\eta^2 = .05$. The global motion sensitivity of the two reader groups in the two luminance contrast conditions is illustrated in Figure 11.

Figure 11. Coherent motion thresholds for the dyslexia and skilled reader groups in the high and low luminance contrast conditions. Untransformed scores are presented[1]. Error bars represent ± 1 standard errors.

Consistent with the hypotheses of the experiment, the dyslexia group were less sensitive than the skilled reader group with presentation of both control conditions, with neither luminance condition influencing sensitivity.

8.5.2 Signal Salience Conditions

To test the noise-exclusion hypothesis, the performance of the dyslexia and skilled reader groups was examined in the high and low signal salience conditions. A 2 (group) x 2 (signal salience) mixed factorial ANOVA was conducted. All of the assumptions of the analysis, with the exception of Box's Test of Equality of Covariance Matrices were met. As F_{max} exceeded 3, the significance level was

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[1] The square root transformed scores as used in the ANOVA showed a mean score of 3.182 (SE = 0.232) for the dyslexia group and a mean score of 2.062 (SE = 0.199) for the skilled reader group in the high luminance contrast condition, and a mean score of 3.305 (SE = 0.185) for the dyslexia group and 2.413 (SE= 0.159) for the control group in the low luminance contrast condition.

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corrected from .05 to .025. The results of the ANOVA produced a significant main effect of reader group, $F(1, 31) = 10.98$, $p = .002$, partial $\eta^2 = .26$, and a significant main effect of signal salience, $F(1, 31) = 447.90$, $p < .0005$, partial $\eta^2 = .94$. There was also a significant interaction obtained between group and signal salience, $F(1, 31) = 8.67$, $p = .006$, partial $\eta^2 = .22$. Figure 12 shows estimates of coherent motion sensitivity for the dyslexia and skilled reader groups in the two conditions.
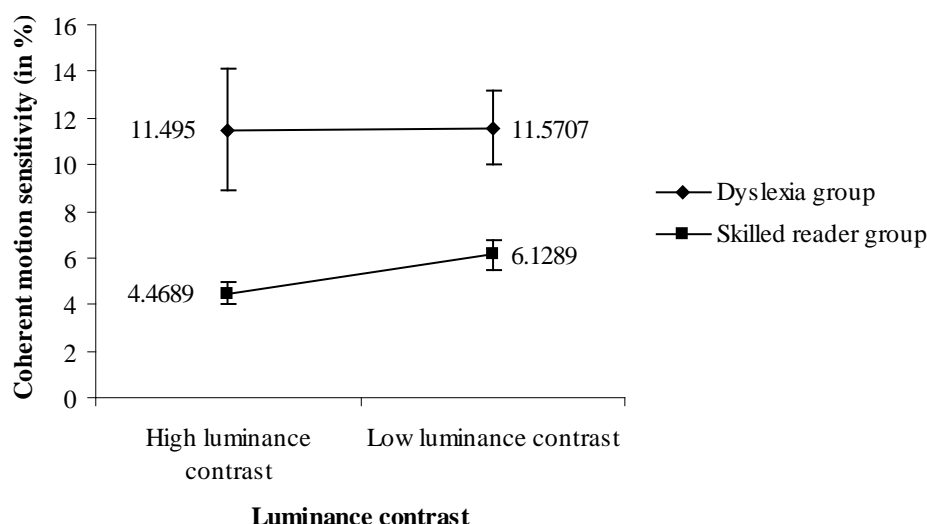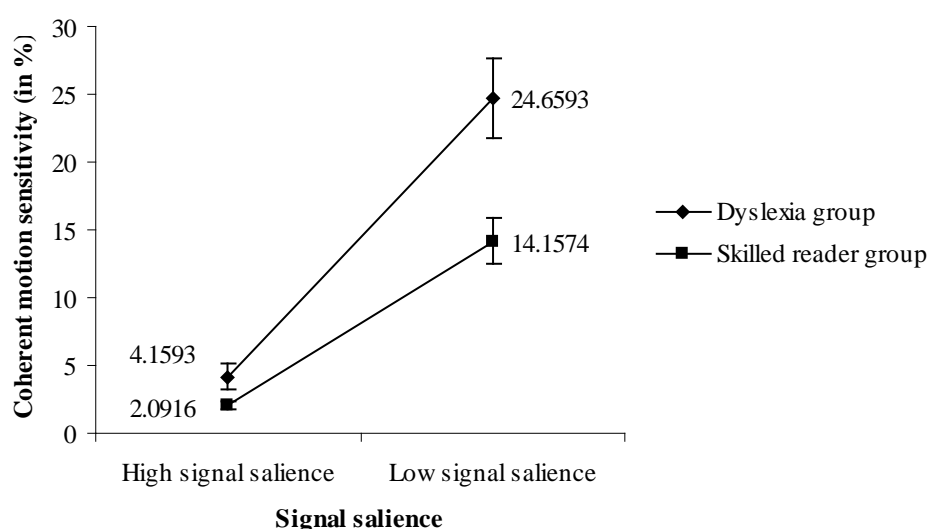

Figure 12. Coherent motion thresholds for the dyslexia and skilled reader groups in the high and low signal salience conditions. Untransformed scores are presented[2]. Error bars represent ± 1 standard errors.

As illustrated in Figure 12, increased sensitivity was found with presentation of high, when compared to low signal salience motion signals. For all of the comparisons, the alpha levels were adjusted to control for the F_{max} violation. Contrast analysis for the significant interaction between salience and reader group showed

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[2] The square root transformed scores as used in the ANOVA showed a mean score of 1.913 (SE= 0.148) for the dyslexia group and a mean score of 1.401 (SE = 0.127) for the skilled reader group in the high signal salience condition, and a mean score of 4.857 (SE = 0.269) for the dyslexia group and 3.645 (SE = 0.231) for the control group in the low signal salience condition.

there was a significant difference in sensitivity between the groups both in the high

signal salience condition, $t(1, 31) = 2.64$, $p = .013$, and in the low signal salience

condition, $t(1, 31) = 3.41$, $p = .002$. However, the magnitude of the between groups

effect was greater in the low signal salience condition (M difference score = 1.212)

than in the high signal salience condition (M difference score = .513). As illustrated in

Figure 12, the difference in mean sensitivity from the low signal salience to the high

signal salience condition was greater for the dyslexia group (M difference score =

2.94) than for the skilled reader group (M difference score = 2.24)[3]. The pattern of

performance for the two reader groups in the low and high signal salience conditions

is further illustrated in the individual dot plots shown in Figure 13.
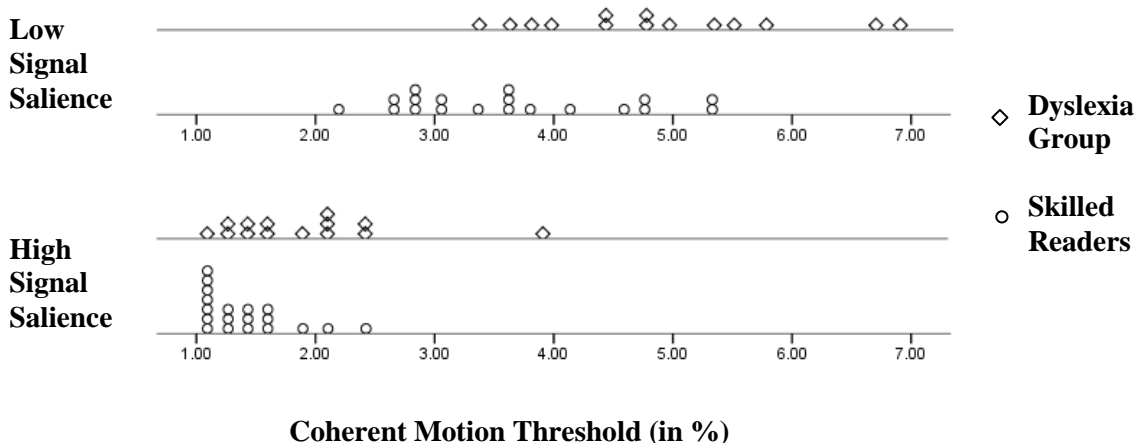
Figure 13. Individual dot plots for the dyslexia and skilled reader groups in the low

and high signal salience conditions.

As can be seen in Figure 13, in the high signal salience condition, a floor

effect occurred in the skilled reader group with 7 of the 19 participants in this group

obtaining a sensitivity score just above 1% (a score of 1 meaning only one single dot

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[3] Mean difference scores using the untransformed data presented in Figure 12, were 20.5 for the
dyslexia group and 12.06 for the skilled reader group.

was moving coherently either leftward or rightward for motion detection). This may explain the statistically significant between groups difference obtained when the signal was of higher salience than the noise elements. In addition, the dot plot showed one individual low score was identified in the dyslexia group in the high signal salience condition. To investigate the effect of this individual score on the between group analyses, this individual was removed from the analyses, and the contrast reproduced. The statistically significant between group effect was maintained in the low signal salience condition, $t(1, 30) = 2.40$, $p = .022$. The dot plot of the motion sensitivity of the dyslexia and skilled reader groups when the motion signals were of low salience and the noise elements of high salience demonstrate the greater difficulties experienced by both groups when extracting global motion from higher salience noise elements.

8.6 Discussion

8.6.1 Control Conditions

The hypothesis that the skilled reader group would have significantly higher sensitivity in the high luminance contrast condition compared to in the low luminance contrast condition was not supported. The lack of a statistically significant effect may be explained by the luminance contrasts used. The Weber contrasts were both above .10, a level of saturation of the M system. However, the hypothesis that the dyslexia group would be significantly less sensitive than the skilled reader group on both the low and high luminance contrast conditions was supported, suggesting the global motion deficit was stable in the dyslexia group.

8.6.2 Signal Salience Conditions

The results supported the hypothesis that increased sensitivity to global motion would be found for both reader groups in the high signal salience, compared to low signal salience condition. While the dot plots presented in Figure 13 produces a similar pattern of sensitivity to the high salience condition presented by Sperling et al., (2006b, p. 1050 Fig 1), the dyslexia group in this study were on average significantly less sensitive than the skilled reader group in the high salience condition. These results show two things. First, that excluding high salience visual noise from a complex visual scene reduces sensitivity to global motion for both reader groups. This suggests that the visual attention of both groups was more easily directed to the higher salience signals. Further, the automatic attention of the dyslexia group may still be impaired relative to the skilled reader group. Second, grouping signals and noise elements as either high or low salience also produced individual groupings. The manipulation may have produced a local motion task where participants were able to detect the direction of motion from single high salience dots, explaining the floor effect in this stimulus condition for the skilled reader group. This suggests that the high signal salience condition operated more like a local motion task, as no integration of signals across frames was required to accurately detect the direction of signal motion. The current findings also have implications for past research that assessed global motion using RDKs consisting of high signal salience dots, or only signal dots (Sperling et al., 2006b). This will be discussed further in the general discussion chapter of this thesis.

When the noise dots were of higher salience than the motion signals, sensitivity of both reader groups was significantly reduced. This effect was greater for the dyslexia group than for the skilled reader group, suggesting that individuals with

dyslexia may have more difficulties excluding irrelevant noise information in a complex visual scene. This may occur as the dyslexia group has greater difficulty when directing visual attention to the less salient signal dots, while inhibiting automatic attention directed to the more salient noise elements in the low signal salience condition.

In summary, the results of the current experiment suggest difficulties extracting signal from noise in complex perceptual stimuli contribute to the reduced motion sensitivity found in the dyslexia group. Taken together with the findings from Experiment 1 and 2, this suggests that the motion processing deficit in dyslexia affects a wide range of neural processes at V5, including extraction, integration, and bidirectional motion processing. However, research has questioned the neural origin of the motion processing deficit in dyslexia (e.g., Hill & Raymond, 2002; Talcott, Hansen et al., 2000), and the question of whether the deficit also reveals itself at lower levels in the visual system, where less perceptually complex processing is required for successful task performance remains. While the focus of the current research project was on the processes underlying global motion processing, a control task was also administered to determine if the dyslexia group also had significant difficulties when performing a local motion task that did not require the complex integration and extraction processes associated with coherent motion detection.

CHAPTER 9: Experiment 4

9. 1 Aims and Overview

The aim of Experiment 4 was to assess whether the local motion processing efficiency of the dyslexia and skilled reader groups using a minimum motion displacement task (D_{min}) differed. In this type of task participants are only required to extract an overall percept, or a single motion signal, hence this task is proposed to only involve low-level motion detectors.

D_{min} processing has not commonly been investigated within the reading literature, with only two studies reported. The first study administered the task to a group of children with and without dyslexia, and did not find any differences in performance between the groups (Dougherty et al., 1997). This is consistent with recent explanations that the motion deficit in dyslexia is located only at extrastriate or parietal levels (Hill & Raymond, 2002; Sperling et al., 2005). However, an investigation using adult participants reported the D_{min} processing of their dyslexia group to be significantly impaired compared to that of a control group (Everatt et al., 1999). This finding is consistent with the sensory magnocellular deficit explanation of a deficit affecting both M and dorsal stream processing in dyslexia. Due to limited information provided on the D_{min} task used by Dougherty et al., the methodological differences between that task and the Everatt et al., task could not be investigated in any detail.

9.2 Hypotheses

If the dyslexia group has a general motion deficit (i.e., affecting global and local motion processing), they will be significantly less sensitive on the D_{min} task compared to the skilled reader group. However, if the motion deficit occurs at

extrastriate levels, only when more complex global motion processes are involved, the performance of the dyslexia group will not differ from that of the skilled reader group.

9.3 Participants

Participants were 13 poor (11 females; *M* age = 23.92 years; *95% CI* = 19.54 - 28.30) and 19 skilled (13 females; *M* age = 19.26 years; *95% CI* = 17.60 - 20.92) readers. All of the participants, except for one individual with dyslexia, also participated in Experiment 3. The reading and cognitive profile of the two groups wwew consistent with that reported for the overall sample.

9.4 Stimuli and Procedure

Minimum displacement. The minimum displacement task administered was the Dot Motion Task (J. M. Wood, 2002). The stimuli were presented on a standard Dell 17 inch monitor, with a screen resolution of 1024 x 768 pixels. Each stimulus consisted of 3072 white dots (luminance of 100 cd/m^2) presented on a black background (1.5 cd/m^2). Consistent with the global motion experiments, the dots had a diameter of one pixel (0.35mm).

The motion stimulus was displayed within a 4 x 4 deg square (22/4cm x 22.4 cm), with a smaller superimposed square of 2.9 x 2.9 deg (16.2 x 16.2cm) on top of it. In any one trial the larger square remained stationary, while the superimposed square moved coherently in one of four directions (left, right, up, or down). All the dots moved together, and there were no noise elements in the display.

The stimuli consisted of six frames, and the duration of a single animation frame lasted for 150msec, producing a total stimulus duration of 900msec. The speed of the dots was 0.05 deg/s, below the optimal activation range for V5 (Chawla et al.,

1998). The DV was minimum displacement threshold (how many log units the stimulus had to move for the direction of motion to be accurately detected by the participant). Minimum displacement threshold was measured in deg/s as well as in log/s (log transform), and the lower the threshold the more sensitive the individual. Threshold calculations were obtained through an adaptive two-down, one-up staircase psychophysical technique, where the starting value was 0.2 log steps. Displacements were decreased by 0.1 log units after two consecutive correct responses, and increased with the same amount after an incorrect response. The staircase was terminated after seven response reversals.

Participants were seated 3.2m from the computer monitor, with their eyes at the same height level as the computer monitor. The testing took place in a darkened room, after adequate dark adaptation was ensured. A four alternative forced choice procedure was used, and the following instructions were given verbally to the participants: *"In this task you will see a rectangular patch of lots of white dots in the centre of the screen. For each trial there will be a small rectangular patch of dots that will move in one direction. Your task will be to indicate if the patch moves to the left, right, up, or down. Sometimes it will be easy to see the movement, other times it will be difficult. Indicate the direction by saying 'left', 'right', 'up', or 'down'. If you are unsure please give me your best guess"*. The responses were entered into the computer in full view of the participant (i.e., the experimenter used the mouse button to click on the direction corresponding to the participant's response).

9.5 Results

An inspection of the distributions showed some positive skew when the thresholds were measured in deg/s, and the log transformed data were used in the

analyses. The data of the log transform was normally distributed. An independent samples *t*-test found no significant difference in sensitivity in motion displacement thresholds for the dyslexia (*M* = -1.96685; *95% CI* = -2.06678 to -1.86691) and skilled (*M* = -1.98258; *95% CI* = -2.08111 to -1.88405) reader groups, $t(32) = .230$, p = .819.

The linear association between the local and global motion sensitivity measures was also investigated. The thresholds used were (1) the overall coherent motion threshold from Experiment 1 (i.e., average score across conditions), (2) the accuracy score obtained in the 250msec condition from Experiment 2B, and (3) the threshold obtained in the low signal salience condition (noise more salient than signal) from Experiment 3. The reason the accuracy score from Experiment 2B and not 2A was used, was that this task version most effectively separated between the poor and skilled reader groups, with none of the groups reaching the 75 % accuracy threshold in version 2A. The 250msec condition was chosen, as this was the true transparency condition with the longest stimulus duration. The low signal salience condition from Experiment 3 was selected as this was the condition with the highest between group separation, and the condition where the dyslexia group demonstrated the poorest sensitivity. Including only participants that took part in all four experiments (n = 30) no significant linear associations were found between minimum motion displacement threshold and global motion sensitivity (*r* = -.043), motion transparency (*r* = -.076), or motion extraction (*r* = .076).

9.6 Discussion

The results of Experiment 4 revealed that the local motion sensitivity of the dyslexia and skilled reader groups did not differ, suggesting that the processes

involved in local motion processing were unimpaired in the dyslexia group. This finding could be interpreted as supporting the argument that the temporal deficit in dyslexia is linked to higher order processes affecting the processing of complex motion stimuli, with the less perceptually complex processes involved in local motion processing being intact. This is consistent with the finding that local and global motion processing were independent in the current sample, suggesting quite different functional processes to be involved in the local and global motion experiments.

When the results of Experiment 4 are compared to the findings of Everatt et al., (1999), where the dyslexia group was found to be less sensitive to the D_{min} stimulus than the skilled reader group, it is relevant to note that the stimulus parameters used by Everatt et al., were different to those used in the current experiment. They used a two-frame RDK, where the total stimulus duration was 300msec. Hence, it is possible that the longer stimulus duration used in the current experiment (900msec) was sufficient to allow efficient motion detection in the dyslexia group.

Moreover, while the results from Experiments 1 to 3 demonstrate that the dyslexia group was consistently less sensitive to global motion than the skilled reader group, not all individuals with dyslexia have reduced sensitivity when processing stimuli activating the M system (Conlon et al., 2009; Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998; Ramus et al., 2003; Witton et al., 1998), with some studies attributing their between group effects to a subset of individuals within the dyslexia group (Borsting et al., 1996; Demb, Boynton, Best, & Heeger, 1998; Sperling et al., 2003). These findings, along with the high variance within dyslexia (e.g., Cornelissen et al., 1995), suggest considerable heterogeneity within the dyslexia group. This is consistent with the findings of Everatt et al., (1999), who reported

substantial variability in terms of D_{min} sensitivity within their dyslexia group, with some of the individuals in the dyslexia group being more sensitive than some individuals in the skilled reader group.

Chapters 10 and 11 investigated the extent to which there were subgroups of individuals within the dyslexia group, some with and some without reduced sensitivity on the global motion tasks. The consistency of the motion deficit in individuals across the different experiments was also investigated to determine whether individuals with dyslexia and a motion deficit had reduced sensitivity in each of the tasks used. A further question concerned whether individuals in the dyslexia group with a stable global motion deficit also showed impaired processing on the local motion processing task, and on the reading and cognitive ability measures administered.

CHAPTER 10: Classification of Individuals with a Global Motion Processing Deficit

10.1 Aims and Overview

The proportion of individuals in the dyslexia group that could be classified with a deficit on the different measures of global motion processing used were examined. One issue that has produced controversy in the recent literature is how well group mean scores provide an accurate representation of the performance of a target group, for example individuals with and without dyslexia. In dyslexia research, the overlap in sensitivity found between groups has led to an increased application of techniques to provide an indication of the proportion of individuals in the dyslexia group with an M system deficit.

The current project aimed to explore and contrast three of the classification techniques that have been used to differentiate between individuals in the dyslexia group with and without an M deficit. The techniques described in Chapter 4 were (1) 16th percentile estimates (Heath et al., 2006), (2) deviance analysis (Ramus et al., 2003), and (3) logistic regression analysis (Solan et al., 2007). In addition, the consistency of each of the techniques in identifying the same individuals across each of the different global motion tasks was evaluated. Based on the findings from these analyses, Chapter 11 examined whether the dyslexia groups with and without a motion deficit could be distinguished from one another on the reading and cognitive ability measures administered. This allowed for an investigation of which of the classification systems may be more accurate in identifying individuals with a stable motion deficit.

10.2 Sensitivity and Specificity Statistics

The sensitivity and specificity of each of the classification techniques used was investigated. The sensitivity of a test refers to the percentage of individuals in the dyslexia group classified with a global motion processing deficit, while the specificity of a test refers to the percentage of individuals in the skilled reader group classified without this deficit (Riegelman & Hirsch, 1996). Estimates of test sensitivity and specificity are used to produce positive and negative likelihood ratios, which produce indices of the effectiveness of a test in identifying how well the test discriminates between individuals in the dyslexia and skilled reader groups. The higher the positive likelihood ratio, the greater the chance that a global motion processing deficit is present in the target (dyslexia) group and the lower the negative likelihood ratio, the smaller the chance the deficit is present in the control (skilled reader) group (Perera & Heneghan, 2006). A positive likelihood estimate of 10, and a negative likelihood ratio of .1, are regarded an indicator of a gold standard test that effectively discriminates between individuals with and without a deficit.

As discussed in Chapter 4, there has been substantial variability in the proportion of individuals with dyslexia reported to have a motion deficit, suggesting poor sensitivity. While some studies have produced estimates of the proportion of individuals in the dyslexia group with a motion deficit (Everatt et al., 1999; Witton et al., 1998), few have evaluated test sensitivity. The different classification techniques used apply different levels of statistical stringency when determining whether a motion deficit is presence or absent. As the statistical criterion becomes less stringent, more individuals in the skilled reader group are also likely to be classified with a deficit, producing poorer sensitivity and specificity statistics.

10.3 Experiment 1

Within group sensitivity on the coherent motion task presented in Experiment 1 was assessed. In this study, dot density and the number of animation frames presented in the RDK were manipulated. Analyses were conducted for each of the four experimental conditions (five-frame low dot density, eight-frame low dot density, five-frame high dot density, eight-frame high dot density). In summary, 16th percentile estimates are based on the scores in a standard normal distribution using the whole sample, with individuals at or below the 16th percentile being classified with a deficit[4]. Deviance analysis is based on the sensitivity of the control group, with individuals scoring more than 1.65 standard deviations above the mean of the skilled reader group being classified with a deficit. Logistic regression is based on the 50th percentile of performances.

The estimates used to determine the presence or absence of a motion deficit for the three different classification techniques, along with the sensitivity and specificity statistics and the likelihood ratios produced for each of the techniques are presented in Tables 3 to 5. The DV was percentage coherence threshold. There were 21 individuals with dyslexia, and 23 skilled readers included in the analyses.

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[4] As Experiment 1 used a measure of global motion sensitivity, individuals performing at or above the 84th percentile were the ones considered to have a deficit based on the 16th percentile approach. See Chapter 4 of this thesis for a review.

Table 3

Classification Results Based on 16th Percentile Estimates (N =21 in the Dyslexia

Group and N = 23 in the Skilled Reader Group)

Condition	16th percentile estimates	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
5 frame low dot density	53.10	7 (33%)	All (100%)	∞	0.667
8 frame low dot density	57.06	7 (33%)	All (100%)	∞	0.667
5 frame high dot density	57.12	6 (29%)	22 (96%)	6.477	0.747
8 frame high dot density	52.26	9 (43%)	22 (96%)	9.727	0.598

Table 4

Classification Results Based on Deviance Analyses (N =21 in the Dyslexia Group and

N = 23 in the Skilled Reader Group)

Condition	Deviance threshold	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
5 frame low dot density	48.37	13 (62%)	21 (91%)	7.115	0.417
8 frame low dot density	44.19	12 (57%)	20 (87%)	4.392	0.493
5 frame high dot density	44.93	9 (43%)	21 (91%)	4.931	0.625
8 frame high dot density	38.44	10 (45%)	21 (91%)	5.218	0.598

Table 5

Classification Results Based on Logistic Regression (N =21 in the Dyslexia Group

and N = 23 in the Skilled Reader Group)

Condition	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
5 frame low dot density	15 (71**%**)	18 (78%)	3.275	0.365
8 frame low dot density	13 (62%)	19 (83**%**)	3.557	0.461
5 frame high dot density	11 (52%)	17 (74%)	2	0.645
8 frame high dot density	11 (52%)	18 (78%)	2.399	0.609

The results of the analyses demonstrated that the proportion of individuals in the dyslexia and skilled reader groups classified with a global motion deficit was dependent upon the classification technique used. As the sensitivity of the test increased the specificity decreased, as reflected in the likelihood ratios.

Classification estimates based on the 16th percentile produced the most stringent cut-off. Using this technique the dyslexia group was found to be at least 6 times more likely than the skilled reader group to have a motion deficit, and in the two low dot density conditions there were no individuals in the skilled reader group with a motion sensitivity score at or below the 16th percentile. However, this technique also produced the lowest motion prevalence estimates, with motion deficit estimated to range from 29 to 43 % in the dyslexia group. Interestingly, the sensitivity estimate was highest in the eight-frame high dot density condition, which was the condition that produced the highest sensitivity estimates for both the dyslexia and skilled reader groups (see Chapter 6 of this thesis).

Estimates using deviance analyses showed that individuals in the dyslexia group were 4 to 7 times more likely than the skilled readers to have a motion deficit. This method classified between 43 and 62 % of the dyslexia group with a motion deficit, with the five-frame low dot density condition producing the highest level of sensitivity. It is interesting to note that this condition had the shortest stimulus duration, and the lowest visual system capacity to sample the motion signals across space (dot density) and time (temporal recruitment). The proportion of individuals in the skilled reader group classified with a motion deficit also increased using this approach, with 9-13% of the skilled readers classified with a motion deficit.

Finally, logistic regression produced the highest level of sensitivity, classifying 52 to 71 % of the dyslexia group with a motion deficit. Consistent with the results of the

deviance analyses, the five-frame low dot density condition was found to produce the highest sensitivity estimate. However, this technique also produced the lowest positive likelihood ratios, and individuals with dyslexia were only estimated to be 2 to 3 times more likely than skilled readers to have a motion deficit. The negative likelihood ratios also reflected this trade off, with 17-26% of the skilled reader group being classified with a global motion processing deficit.

The results showed that the number of individuals with dyslexia classified with a deficit varied across classification techniques. However, one of the questions of interest for the current research project was whether the same group of individuals were classified with a deficit across experimental conditions. Moreover, it was of interest to assess how well the three different classification techniques identified individuals with a stable global motion deficit. Hence, an investigation of individual scores across condition for each of the classification techniques was conducted.

Based on 16th percentile estimates, 3 individuals with dyslexia (14%) were found to score at or below the 16th percentile in each of the experimental conditions, indicating that this group of individuals had a stable motion deficit. The number increased to 8 (38%) when deviance analyses was used and 10 (48%) based on the logistic regression analyses. Comparatively, no skilled readers were classified with a consistent motion deficit across experimental conditions based on the 16th percentile estimates. However, using deviance analyses and logistic regression analyses 1 skilled reader (4%) was found to have a stable deficit[5]. These results are important in that they show that a proportion of individuals with dyslexia, as opposed to individuals without dyslexia, demonstrated consistently reduced sensitivity across conditions, suggesting the deficit in dyslexia is robust. The extent that individuals in the dyslexia

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[5] The reading and cognitive profile of this skilled reader did not differ from the other members of the skilled reader group.

group with and without a stable motion deficit differ on the reading and cognitive

ability measures will be investigated in Chapter 11.

10.4 Experiment 2

10.4.1 Experiment 2A

Within group performance on the bidirectional motion transparency task

presented in Experiment 2A was assessed. In this experiment the basic stimulus

parameters were the same as in Experiments 1 and 3. Participants were presented with

four stimulus durations: 150msec, 250msec, 450msec, and 550msec. The 150 and

250msec conditions measured simultaneous processing transparency, and the longer

durations provided a measure of sequential processing of the two directions of motion.

The results of the between groups analyses presented in Chapter 7 of this

thesis revealed that none of the groups reached the 75% accuracy level for any of the

stimulus durations presented. However, an investigation of within group performance

revealed that 9 out of the 22 (41%) skilled readers (*M* score = 87.15; *95% CI* = 81.1-

93.21) reached this accuracy level in the 250msec stimulus duration condition. None

of the individuals with dyslexia reached the 75% accuracy level (*M* score = 45.32;

95% CI = 36.71- 53.92) at any display duration.

As previously discussed, the estimates used to determine successful task

performance are often arbitrary, and the 75% cut-off used in the between group

analyses of the current experiment was based on the methodology of Hill and

Raymond (2002). While they also used the 99% confidence interval of the skilled

reader group to determine who in the dyslexia group had a deficit (most being

classified with a deficit), to make the investigation more comparable across studies,

within group performance was also assessed using 16th percentile estimates and

logistic regression. Deviance analyses thresholds could not be calculated due to the high degree of variability within the skilled readers group (*SD* ranging from 22.27% to 34.71% across the four experimental conditions). The results of the 16th percentile estimates and the logistic regression analyses, along with the sensitivity and specificity statistics for each of the experimental conditions are summarised in Tables 6 and 7[6]. There were 20 individuals with dyslexia, and 22 skilled readers included in the analyses.

Table 6

Classification Results Based on 16th Percentile Estimates (N =20 in the Dyslexia Group and N = 22 in the Skilled Reader Group)

Condition	16th percentile estimates	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
150msec	27.75	5 (25%)	21 (95%)	5.434	0.786
250msec	27.75	4 (20%)	20 (91%)	2.197	0.88
450msec	37.12	4 (20%)	20 (91%)	2.197	0.88
550msec	37.50	4 (20%)	19 (86%)	1.459	0.956

Table 7

Classification Results Based on Based on Logistic Regression (N =20 in the Dyslexia Group and N = 22 in the Skilled Reader Group)

Condition	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
150msec	14 (70**%**)	15 (68%)	2.194	0.44
250msec	13 (65%)	17 (77**%**)	2.85	0.454
450msec	12 (60%)	15 (68%)	1.88	0.587
550msec	13 (65%)	16 (73%)	2.38	0.481

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[6] As Experiment 2 used accuracy scores, individuals scoring at or below the 16th percentile were considered the poorest performers on the task

Consistent with the findings from Experiment 1, as the sensitivity of the test increased the specificity of the test decreased. Depending on the stimulus duration presented, the 16th percentile estimates classified 20 to 25% of the dyslexia group with a motion deficit, estimating the dyslexia groups to be 2 to 5 times more likely to have a motion deficit than the skilled readers. Comparatively, 5 to 14% of the skilled readers were classified with a deficit. The highest sensitivity estimate was obtained in the 150msec stimulus duration condition, and the poorest specificity estimate in the 550msec stimulus duration condition, suggesting increased stimulus duration made it more difficult to separate between the two groups, as expected. Consistent with the findings from Experiment 1, the sensitivity estimates increased and the specificity decreased using logistic regression. Based on this technique 60 to 70 % of the dyslexia group, and 23 to 32% of the skilled reader group, were classified with a deficit. The 150msec stimulus duration condition produced the highest sensitivity estimate also for this technique.

An investigation of the results showed that the total number of individuals classified with a motion deficit remained stable across experimental conditions for both of the classification techniques. However, when an investigation of individual scores was conducted, the results showed that based on 16th percentile estimates, only 1 individual with dyslexia (5%) and 1 skilled reader (4%) scored below the cut-off across all of the four stimuli duration conditions. An investigation of the simultaneous (150 and 250msec) and sequential (450 and 550msec) conditions separately did not change the results. However, the number of individuals classified with a deficit increased when logistic regression was applied, with 8 individuals with dyslexia (40%) and 3 skilled readers (14%) identified to score below the deficit cut-off across conditions. No difference was found investigating the simultaneous and sequential

conditions separately, suggesting the same group of individuals had difficulties with the task regardless of stimulus duration.

10.4.2 Experiment 2B

Within group performance on the bidirectional motion transparency task presented in Experiment 2B was also assessed. The same four stimulus durations as those used in Experiment 2A were presented. However, in this experiment the dot lifetime and the number of animation frames presented in the RDK were increased, which resulted in increased accuracy for each of the stimulus durations for both reader groups. The results of the between group analyses showed that as a group, the skilled readers reached the 75% accuracy level in the 150msec stimulus duration, while the dyslexia group did not reach this accuracy level until the stimulus duration was 450msec.

When within group performance was assessed adhering to the 75% accuracy criteria used by Hill and Raymond (2002), the results revealed that 19 out of the 22 (86%) skilled readers (*M* score = 93.92; *95% CI* = 90.53- 97.30), and 13 out of the 20 (65%) individuals with dyslexia (*M* score = 82.45; *95% CI* = 78.26- 86.64) reached the 75% accuracy level in the 250msec stimulus duration condition. This shows that about two thirds of the dyslexia group could process the transparent motion simultaneously 75% of the time, while 7 individuals in the dyslexia group (35%) could not. As for Experiment 2A, within group analyses were conducted using16[th] percentile estimates and logistic regression. The results are summarised in Tables 8 and 9. There were 20 individuals with dyslexia, and 22 skilled readers included in the analyses.

Table 8

Classification Results Based on 16th Percentile Estimates (N =20 in the Dyslexia

Group and N = 22 in the Skilled Reader Group)

Condition	16th percentile cut-offs	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
150msec	46.50	5 (25%)	21 (95%)	5.43	0.786
250msec	59.00	5 (25%)	21 (95%)	5.43	0.786
450msec	74.25	5 (25%)	21 (95%)	5.43	0.786
550msec	71.88	6 (30%)	21 (95%)	6.521	0.733

Table 9

Classification Results Based on Based on Logistic Regression (N =20 in the Dyslexia

Group and N = 22 in the Skilled Reader Group)

Condition	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
150msec	10 (50%)	16 (73%)	1.83	0.687
250msec	12 (60%)	17 (77%)	2.63	0.518
450msec	10 (50%)	17 (77%)	2.192	0.647
550msec	12 (60%)	19 (86%)	4.379	0.463

Based on 16th percentile cut-offs 25 to 30% of the dyslexia group, and 5% of

the skilled reader group was classified with a motion deficit in Experiment 2B.

Individuals with dyslexia were 5 to 6 times more likely to have a deficit than

individuals without dyslexia. When logistic regression analysis was used the number

of individuals classified with a motion deficit increased to 50-60 % for the dyslexia

group and 14-27% for the skilled reader group, with the dyslexia group being 2 to 4

times more likely to have a motion deficit than the skilled reader group. The highest

sensitivity estimates were found in the 250 and 550mec stimulus duration conditions,

suggesting that some individuals in the dyslexia group had difficulties both with simultaneous and sequential processing.

There were 4 individuals with dyslexia (20%) who scored below the cut-off estimates across experimental conditions when using the 16th percentile classification. When logistic regression was used, 8 individuals with dyslexia (40%) were identified to score below the threshold across conditions. When performance on the simultaneous and sequential conditions was examined separately, this did not alter the results, supporting the finding that the same group of individuals had difficulties with the task regardless of stimulus duration. None of the skilled readers were found to have a stable deficit across conditions based on the 16th percentile estimates, while the number increased to 2 individuals (9%) using logistic regression.

The results across Experiments 2A and 2B were compared to assess if the same individuals classified with a stable deficit in Experiment 2A were also classified with a deficit in Experiment 2B. Based on 16th percentile cut-offs, only 1 individual with dyslexia (5%) was identified with a stable deficit across conditions in Experiment 2A, while this number increased to 4 (20%) in Experiment 2B. The results showed that the individual classified with a deficit in Experiment 2A was also classified with a deficit in Experiment 2B. No skilled readers were classified with a stable deficit across conditions or experiments using this method.

Logistic regression classified 8 individuals with dyslexia with a stable deficit in both Experiments 2A and 2B. An investigation of the individuals with dyslexia classified with a deficit in each of the experiments revealed that 7 out of 8 were the same. Comparatively 2 skilled readers were found to have a consistent deficit across condition and across experiments using this technique.

The above findings demonstrate the impact of stimulus parameters and task difficulty on the prevalence estimates obtained. Based on the stimulus parameters used in experiment 2A, 16th percentile estimates appeared too stringent to identify many individuals with a deficit when processing bidirectional motion. However, for the less statistically stringent criteria on which logistic regression is based, stimulus parameters did not have the same impact.

10.5 Experiment 3

Experiment 3 investigated the effect of signal salience and luminance contrast on coherent motion sensitivity. There were four experimental conditions; high luminance contrast, low luminance contrast, high signal salience and low signal salience. Analyses were conducted for each of the experimental conditions. The cut-off estimates produced by the three different classification techniques, along with the sensitivity and specificity statistics and the likelihood ratios produced for each of the techniques are summarised in Tables 10 to 12[7]. There were 14 individuals with dyslexia, and 19 skilled readers included in the analyses.

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[7] As Experiment 3 used a measure of global motion sensitivity, individuals performing at or above the 84th percentile were the ones considered to have a deficit based on the 16th percentile approach.

Table 10

Classification Results Based on 16th Percentile Estimates (N =14 in the Dyslexia

Group and N = 20 in the Skilled Reader Group)

Condition	16th percentile estimates	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
High luminance contrast (signal and noise dark grey)	3.158	5 (36%)	20 (100%)	∞	0.643
Low luminance contrast (signal and noise medium grey)	3.488	5 (36%)	20 (100%)	∞	0.643
High signal salience (signal dark grey and noise medium grey)	2.152	4 (29%)	19 (95%)	5.377	0.755
Low signal salience (signal medium grey and noise dark grey)	5.376	4 (29%)	19 (95%)	5.377	0.755

Table 11

Classification Results Based on Deviance Analyses (N =14 in the Dyslexia Group and

N = 20 in the Skilled Reader Group)

Condition	16th percentile estimates	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
High luminance contrast (signal and noise dark grey)	2.851	7 (50%)	20 (100%)	∞	0 .50
Low luminance contrast (signal and noise medium grey)	3.229	6 (43%)	18 (90%)	4.056	0.637
High signal salience (signal dark grey and noise medium grey)	1.715	7 (50%)	17 (85%)	3.125	0.408
Low signal salience (signal medium grey and noise dark grey)	4.734	6 (43%)	16 (80%)	2.075	0.712

Table 12

Classification Results Based on Logistic Regression (N =14 in the Dyslexia Group

and N = 20 in the Skilled Reader Group)

Condition	Sensitivity of test	Specificity of test	Positive likelihood ratio	Negative likelihood ratio
High luminance contrast (signal and noise dark grey)	8 (57%)	15 (75%)	2.171	0.582
Low luminance contrast (signal and noise medium grey)	10 (71%)	16 (80%)	3.384	0.362
High signal salience (signal dark grey and noise medium grey)	7 (50%)	17 (85%)	3.164	0.594
Low signal salience (signal medium grey and noise dark grey)	9 (64%)	15 (75%)	2.445	0.484

Based on 16th percentile estimates, individuals with dyslexia were at least five

times more likely to have a global motion processing deficit than the skilled readers,

with the positive likelihood ratio reaching infinity in the high and low luminance

contrast conditions. This technique classified 29 to 36 % of the dyslexia group, and 0

to 5% of the skilled reader group, with a motion deficit.

Comparatively, the deviance analyses classified 43 to 57 % of the dyslexia group,

and up to 20% of the skilled reader group with a deficit. Based on the deviance

analyses estimates, individuals with dyslexia were found to be at least twice as likely

as the skilled readers to have a deficit, with the number reaching infinity in the high

luminance contrast condition. Finally, logistic regression classified 50 to 71 % of the

dyslexia group, and 15 to 25% of the skilled reader group, with a motion deficit

producing positive likelihood ratios of 2 to 4.

The same individual scored above the deficit thresholds across conditions for each

of the classification techniques. Based on 16th percentile estimates, 3 individuals with

dyslexia (21%) scored below the 16th percentile for all of the experimental conditions.

This number increased to 4 (29%) when the deviance analyses were used. None of the

skilled readers were classified with a stable deficit across experimental condition

based on either 16th percentile cut-offs or deviance analyses. Based on logistic

regression, 6 individuals in the dyslexia group (43%) and 3 skilled readers (16%)

were classified with a consistent deficit. The investigation of results across condition

showed that the same group of individuals had difficulties with the task regardless of

signal salience and luminance contrast.

10.6 Across Experiments

The data shows that the proportion of individuals with dyslexia classified with

a deficit in each of the experiments varied across classification techniques. Table 13

provides a summary of the number of individuals with dyslexia classified with a

deficit in each of the global motion experiments based on the three classification

techniques. The percentages presented are based on the total number of individuals

participating in each experiment.

Table 13

The Proportion of Individuals in the Dyslexia and Skilled Reader Groups Classified

with a Deficit across Experiments based on the Different Classification Techniques

Classification technique	Experiment 1		Experiment 2A		Experiment 2B		Experiment 3	
	Dyslexia (n = 21)	**Skilled** (n=23)	**Dyslexia** (n =20)	**Skilled** (n =22)	**Dyslexia** (n =20)	**Skilled** (n =22)	**Dyslexia** (n =14)	**Skilled** (n =19)
16th Percentile	3 (14%)	None	1 (5%)	1 (4%)	4 (20%)	None	3 (21%)	None
Deviance Analyses	8 (38%)	1 (4%)	NA	NA	NA	NA	4 (29%)	None
Logistic Regression	10 (48%)	1 (4%)	8 (40%)	3 (14%)	8 (40%)	2 (9%)	6 (43%)	3 (16%)

As shown in Table 13, logistic regression analyses classified 40 to 48% of the

dyslexia, and 4 to 16% of the skilled reader group with a global motion deficit.

Comparatively, deviance analyses classified 29 to 38% of the dyslexia group, and up to 4% of the skilled reader group with a deficit. Finally, 16th percentile estimates classified 5 to 21% of the dyslexia group, up to 4% of the skilled reader group with a deficit. These results show that the three different classification techniques produced quite different results. The current logistic regression estimates were lower than the 75% (Slaghuis & Lovegrove, 1985) and 78% (Solan et al., 2007) reported in past studies, while the deviance estimates and 16th percentile estimates obtained were similar to past reports (Conlon et al., 2009; Heath et al., 2006; Pellicano & Gibson, 2008; Wright & Conlon, In Press) .

As the only difference between the tests is statistical stringency, the question remains as to how effective the different classification techniques are in separating the dyslexia group with and without motion deficits on the reading, reading related and cognitive measures. This will determine whether the profile of dyslexia groups with a motion deficit can be distinguished from that of dyslexia groups without a motion deficit. Chapter 11 investigated this. However, first a series of bivariate correlations were obtained to investigate (1) the relationship between the global motion tasks used in the current research project, and (2) if any associations could be found between the global motion tasks and the reading and reading related tasks administered.

CHAPTER 11: Global Motion Processing and Reading

11.1 Aims

It has been suggested that a deficit in the visual motion processing pathway significantly interferes with the cognitive processes crucial for reading (Stein & Walsh, 1997). However, the association between motion processing and the subskills of reading is still an area of debate, with both sensory (e.g., Talcott, Hansen et al., 2000) and perceptual (e.g., Hill & Raymond, 2002; Raymond & Sorensen, 1998; Sperling et al., 2006b) explanations being posited. The main aims of the current chapter were: (1) to assess the extent of the associations found between the global motion tasks administered as part of the current research, (2) to assess the strength of the associations between the global motion tasks and the word decoding measures, and (3) to evaluate the effectiveness of three classification techniques in differentiating the profile of dyslexia groups with and without a consistent motion processing deficit.

The association between sensitivity on the global motion tasks used in this thesis was of interest as past research has suggested different tests of magnocellular function measure different processes. For example, no significant associations were found between coherent motion sensitivity and accuracy on a speed discrimination task (Wilmer et al., 2004), with only a weak relationship (correlation of 0.3), obtained between coherent motion sensitivity and accuracy on a temporal sequencing task (Conlon et al., 2004). Significant associations were however found between sensitivity to global motion and sensitivity on a flicker fusion task (Talcott et al., 1998). In the current study, the correlations between the global motion tasks were expected to be significant, as the tasks used assessed sensitivity to global motion, and as basic stimulus parameters were held constant across experiments. It has been

suggested that if a subpopulation of individuals with dyslexia has a magnocellular pathway deficit they will show impaired performance across a range of psychophysical tasks relying on M function (Amitay et al., 2002).

The correlations obtained between performance on the global motion tasks and the reading and reading related tasks in adults were of interest as impaired motion processing has been associated with specific reading subskills, such as poor phonology (e.g., Borsting et al., 1996; Talcott et al., 1998), or poor orthography (Cornelissen, Hansen, Gilchrist et al., 1998; Cornelissen, Hansen, Hutton et al., 1998). Other researchers have suggested reduced sensitivity to global motion is associated with more general measures of word decoding (Conlon et al., 2004; Johnston et al., 2008; Lilleskaret, 2001). It is also possible that the motion processing deficit may manifest itself differently in children and adults, and the current study examined the associations in a sample of high functioning adults.

Furthermore, few studies have investigated the cognitive profile of dyslexia groups with and without a motion deficit. While some have not found a distinctive profile that separates the two groups (e.g., Amitay et al., 2002; Ramus et al., 2003; White, Milne et al., 2006), it has been suggested that dyslexia groups with severe phonological difficulties (or a combination of severe phonological and orthographic difficulties) are less sensitive to global motion than dyslexia groups with severe orthographic difficulties only (e.g., Slaghuis & Ryan, 1999). Some recent research has also reported that groups with dyslexia and a global motion deficit are less accurate on measures of complex phonological processing and verbal short-term memory than dyslexia groups without a motion deficit (Conlon et al., 2009; Johnston et al., 2008; Wright & Conlon, 2008). This is consistent with recent reports that have also implicated poor short-term memory as the core underlying factor for the motion

processing deficit (Ahissar et al., 2006; Ramus & Szenkovits, 2008; Slaghuis & Ryan, 2006). An alternative explanation proposes the motion deficit found in some individuals with dyslexia may be a non-specific neural marker of developmental disorders in general (White, Frith et al., 2006), with some studies linking a motion deficit to difficulties with sequencing (Ben-Yehudah et al., 2001; Conlon et al., 2004; Eden et al., 1995; Slaghuis & Ryan, 1999) or automaticity/clumsiness (Nicolson, Fawcett, & Dean, 2001; Sigmundsson, Hansen, & Talcott, 2003).

11.2 Associations between the Global Motion Tasks

The associations between the global motion tasks were assessed using a series of bivariate correlations. The scores used were the overall threshold scores from Experiments 1 and 3 (integration and extraction) and the scores obtained in the 250msec stimulus duration condition in Experiments 2A and 2B (motion transparency). Overall threshold scores were used for Experiments 1 and 3, as the correlations found between individual conditions were high (see Table 14). Only individuals who took part in all of the experiments were included in the correlational analyses (N = 31)[8], 18 out of whom were skilled readers.

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[8] Results were the same using the overall sample. Correlations remained significant when split by reader group.

Table 14

Bivariate Correlations Obtained between Overall Threshold Scores and the

Individual Conditions for Experiments 1 and 3 (N =31)

Experiment 1	5 frame low	8 frame low	5 frame high	8 frame high
5 frame low		.806**	.765**	.740**
8 frame low			.822**	.864**
5 frame high				.881**

** Correlation is significant at the 0.01 level (2-tailed).

Experiment 3	High luminance contrast	Low luminance contrast	High signal salience	Low signal salience
High luminance contrast		.872**	.732**	.773**
Low luminance contrast			.704**	.865**
High signal salience				.822**

** Correlation is significant at the 0.01 level (2-tailed).

Consistent relationships, shown in Table 15, were also found across conditions

for the motion transparency tasks. In Experiment 2A and 2B the score obtained in the

250msec stimulus duration (longest true transparency condition) strongly correlated

with the scores obtained in the other conditions. The bivariate correlations between

the three global motion tasks are presented in Table 16.

Table 15

Bivariate Correlations Obtained between the 250msec Stimulus Duration Condition

and the Other Stimulus Duration Conditions for Experiments 2A and 2B (N =31)

250msec	150msec	450msec	550msec
Experiment 2A	.832**	.914**	.847**
Experiment 2B	.902**	.929**	.868**

** Correlation is significant at the 0.01 level (2-tailed).

Table 16

Bivariate Correlations Obtained for the Global Motion Tasks Using Overall

Threshold Scores for Experiments 1 and 3, and Accuracy Score Obtained in the

250msec Stimulus Duration Condition for Experiment 2A and 2B (N =31)

	Experiment 2A: Motion Transparency	Experiment 2B: Motion Transparency	Experiment 3: Extraction
Experiment 1: Integration	-.617**	-.651**	.863**
Experiment 2A: Motion Transparency		.618**	-.484**
Experiment 2B: Motion Transparency			-.640**

** Correlation is significant at the 0.01 level (2-tailed).

As can be seen in Table 16, a strong positive correlation was found between the integration and extraction tasks, suggesting that poor sensitivity on either of these tasks would predict poor sensitivity on the other task (the higher the score the poorer the sensitivity). Moderate negative linear correlations were found between motion sensitivity on the integration task and accuracy on the motion transparency tasks, and between motion sensitivity on the extraction task and accuracy on the motion transparency tasks. These findings suggest that poor sensitivity on either of the coherent motion tasks would predict a low accuracy score on the motion transparency tasks. These findings also suggest that the global motion tasks assessed similar neural processes, with participants performing poorly on one task generally also performing poorly on the other tasks. As reported in Chapter 9, neither sensitivity to motion nor accuracy on the motion transparency tasks were associated with sensitivity on the local motion task.

11.3 Global Motion Processing and Reading

Bivariate correlations between global motion sensitivity and the reading and reading related measures were also investigated using the overall threshold scores from Experiments 1 and 3 (integration and extraction), and the accuracy scores obtained in the 250msec stimulus duration condition from Experiments 2A and 2B (motion transparency). The results are summarised in Table 17.

Table 17

Bivariate Correlations for the Reading Measures and the Global Motion Measures

(N = 44 for Experiment 1, N = 42 for Experiment 2, and N = 33 for Experiment 3)

	Experiment I: Integration	Experiment IIA: Motion Transparency 250msec	Experiment IIB: Motion Transparency 250msec	Experiment III: Extraction
WRAT-3 Reading (scaled score)	-.599**	.416**	.447**	-.628**
WRAT-3 Spelling (scaled score)	-.360*	.262	.355*	-.367*
Nonwords/25	-.393**	.345*	.418*	-.386*
Multisyllabic nonwords/9	-.511**	.363*	.499**	-.501**
Exception words /25	-.473**	.327*	.334*	-.489**
Sight Word Efficiency (standard score)	-.417**	.293	.295	-.306
Phonemic Decoding Efficiency (standard score)	-.517**	.341*	.417**	-.434*
TOWRE Total (standard score)	-.497**	.309*	.412**	-.406*
Adult Dyslexia Checklist Score	.430**	-.322*	-.407**	.345*

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The results show weak to moderate significant correlations between the reading and reading related measures and sensitivity or accuracy on the measures of global motion processing and motion transparency. As expected, the relationships between motion sensitivity and reading skills were negative for the integration and extraction tasks and positive for the motion transparency task. The negative

correlations showed that poorer reading skills were associated with reduced motion sensitivity. The positive correlations showed that poorer reading skills were associated with poorer accuracy on the transparency task. In contrast, significant positive linear associations were found between performance on the Adult Dyslexia Checklist (Vinegrad, 1994) and the coherent motion measures (Experiments 1 and 3), showing that an increase in the number of positive responses on the Checklist (more positive responses meaning greater degree of difficulty) was associated with an increase in the number of coherently moving dots needed to detect the motion (i.e., decreased sensitivity). Similarly, a significant negative relationship was found between performance on the motion transparency task and the Adult Dyslexia Checklist, demonstrating that a decrease in accuracy score on the transparency task was associated with an increase in the number of positive responses on the Checklist.

For the integration task, the correlations reached significance with all of the reading measures, while for the extraction task and the motion transparency tasks, the relationship obtained with the Sight Word Efficiency (SWE) subtest of the TOWRE (Torgesen et al., 1999) was not significant. This may be explained by the SWE subtest being a speed of processing measure, found in the past not to be associated with global motion sensitivity (Ben-Shachar et al., 2007; Wilmer et al., 2004). The high correlations obtained between the SWE subtest and the integration task may in part be due to this task having measured some components of speed of processing, as the total stimulus durations used were short. These findings illustrate that the associations found between reading and motion processing may be related to the stimulus parameters used in the different tasks.

Consistent with past research (e.g., Conlon et al., 2004; Lilleskaret, 2001; Talcott et al., 2002) the current findings suggest that both orthographic and

phonological processing were associated with performance on the global motion processing tasks. The percentage of the variance accounted for in single word reading (WRAT-3) by performance on the global motion tasks ranged from 17 to 39%. Similar amounts of variance were accounted for by the motion tasks when either phonological or orthographic processing tasks were considered.

The associations between reading skills and self-report on the Checklist was also assessed. The results of the bivariate correlations are reported in Table 18. The complete sample was used (N = 47), with 24 of the participants being skilled readers.

Table 18

Bivariate Correlations for the Reading Measures and the Adult Dyslexia Checklist (N = 47)

	WRAT-3 Reading (scaled score)	WRAT-3 Spelling (scaled score)	Non-words/ 25	Multi-syllabic non-words/9	Exception words/ 25	Sight Word Efficiency (standard score)	Phonemic Decoding Efficiency (standard score)	TOWRE Total (standard score)
Adult Dyslexia Checklist	-.685**	-.576**	-.612**	-.561**	-.623**	-.602**	-.614**	-.674**

** Correlation is significant at the 0.01 level (2-tailed).

As shown in Table 18, strong negative correlations were obtained between self-report of symptoms of dyslexia on the Adult Dyslexia Checklist, and each of the reading and reading related measures. This demonstrated that a decrease in reading skill was associated with an increase in the number of self-reported difficulties on the Checklist. This finding suggests the Adult Dyslexia Checklist may be a useful tool to include in the assessment of dyslexia in adult populations. In summary, the bivariate correlations obtained in the current study showed that in an adult sample, poor reading skills were associated with reduced global motion sensitivity and an increase in reported difficulty as assessed by the Adult Dyslexia Checklist.

11.4 Profile of Dyslexia Groups with a Motion Deficit

While a total of 23 individuals with dyslexia participated in the current research, only 13 took part in all of the experiments. To more effectively compare how well the different classification techniques distinguished between dyslexia groups with and without a motion deficit across experiments, only individuals that participated in all of the experiments were included for comparison purposes. To ensure that only the poorest performers on the motion tasks were included in the motion deficit group a repeat deficit criterion was used, and only individuals that demonstrated consistently reduced sensitivity across both Experiments 1 and 3 were classified as having a motion deficit. Performance on Experiment 2 was not included, as no deviance analysis could be conducted for this experiment.

Using 16th percentile estimates, 1 individual with dyslexia demonstrated a consistent deficit across Experiments 1 and 3. No skilled readers were identified with a consistent deficit. Due to the restricted number of participants available for analysis using this criterion, no subgroup analysis could be conducted. When deviance analyses and logistic regression analyses were used, the same 4 individuals in the dyslexia group were classified with a deficit across Experiments 1 and 3. This shows that when the stringency of the criteria was increased by using a repeat criterion, both techniques identified 30% of the dyslexia sample with a motion deficit, an estimate only produced by the deviance estimate previously. In terms of the skilled reader group, no skilled readers were classified with a deficit across Experiments 1 and 3 using the deviance analyses, while 1 skilled reader was classified with a consistent deficit using logistic regression. Taken together these results suggest deviance analyses may be the most effective method out of the three to determine who in the dyslexia group has a consistent motion deficit, with the 16th percentile estimates being

too stringent, and logistic regression not sufficiently stringent. However, the usefulness of a classification technique ultimately depends on how well the method separates between the profile of dyslexia groups with and without a motion deficit, and this was the next step of investigation.

When the profile of the dyslexia group with a motion deficit (n = 4) was contrasted with the remainder of the dyslexia group, hereafter labelled the no motion deficit group (n = 9), all of the individuals in the motion deficit group reported a history of reading difficulties. Comparatively, only about half of the individuals in the no motion deficit group reported a history of reading difficulties, suggesting the motion deficit may be related to a lifelong history of developmental dyslexia. While the power was low, as a result of the small sample size, a series of independent samples t-tests showed there were no significant differences in performance between the two groups on any of the word reading or phonological processing measures. The results of the independent samples *t*-tests, along with the relevant descriptive statistics are shown in Table 19.

Table 19

Performance on the Reading and Cognitive Ability Measures for the Dyslexia

Subgroup with a Motion Deficit and the Dyslexia Group without a Motion Deficit

	Group							
	Motion Deficit (n =4)			No Motion Deficit (n =9)				
	Mean	95% CI		Mean	95% CI		t value	p
Measures		Lower	Upper		Lower	Upper	(df 45/42)	
WRAT-3 Reading (scaled score)	90.50	83.44	97.56	92.89	89.25	96.52	-.855	=.411
Nonwords /25	16.00	11.89	20.11	13.44	10.81	16.08	1.320	=.214
Multisyllabic Nonwords /9	5.00	2.75	7.25	4.44	3.16	5.73	.577	=.575
Exception words /25	10.75	7.22	14.28	10.89	8.08	13.70	-.070	=.946
Sight Word Efficiency (standard score)	93.75	87.21	100.29	89.00	80.48	97.52	.816	=.432
Phonemic Decoding (standard score)	82.50	76.34	88.66	78.89	67.79	89.98	.482	=.639
TOWRE Total (standard score)	85.75	83.75	87.75	83.56	75.01	92.10	.384	=.708
Adult Dyslexia Checklist /20	8.00	4.56	11.44	8.56	7.33	9.78	-.524	=.611

Performance on the local motion task was also assessed. While there were no

statistically significant differences in sensitivity between the motion deficit (M = -

2.11; SD = .14) and no motion deficit (M = -1.91; SD = .16) groups, $t(10)$ = -1.92, p =

.083, the power would have been affected by the small sample, as only 3 out of the 4

individuals identified with a stable motion deficit took part in the local motion

experiment. An investigation of the means and the p value, suggests a trend towards

poorer local motion sensitivity in the motion deficit group.

The performance of the two groups was also compared on the cognitive ability

subtests from the WAIS-III (Wechsler, 1997). The motion deficit group (M = 9.00;

SD = .816) was significantly less accurate than no motion deficit group (M = 11.33;

SD = 1.225), $t(11)$ = -3.44, p = .006; Cohen's d = 2.24 on the Digit Forward

component of the verbal short-term measure. Poorer verbal short-term memory was

also found for the motion deficit group (M = 8.50; SD = 1.92) compared to the no

motion deficit group (*M* = 11.67; SD = 2.12), *t*(11) = -2.55, *p* = .027; Cohen's *d* = 1.57 on the overall measure of Digit Span. The motion deficit group (M = 10.50; SD = 2.517) also had a significantly lower standard score on the Block Design measure than the no motion deficit group (*M* = 14.56; *SD* = 1.99), *t*(11) = -3.19, *p* = .009; Cohen's *d* = 1.80, suggesting their performance on this task was impaired compared to that of the no deficit group. Cohen's *d*, calculated by using the pooled standard deviations for the two groups, was large for all of the measures, producing a strong effect size.

While there were no significant differences between the motion deficit group and the no motion deficit group in terms of the number of positive responses on the Adult Dyslexia Checklist (Vinegrad, 1994), responses to individual items were examined to determine if the profile of the two groups differed. A qualitative analysis was conducted where the frequency of yes/no responses to the various items was examined for each of the groups. The results showed all of the individuals in the dyslexia group with a motion deficit reported having difficulties getting all the sounds in the right order when saying a long word. Comparatively only 33% of the individuals in the no motion deficit group reported this difficulty. This finding suggests the dyslexia group with a motion deficit are more likely to report difficulties with sequencing than the no motion deficit group, a finding consistent with the results on the Digit Forward subtest of the WAIS-III (Wechsler, 1997). In addition to measuring verbal short-term memory, the Digit Span test also measures sequencing ability. The poorer performance of the motion deficit group on the Block Design subtest may indicate that this group had greater difficulties with visual-motor-spatial integration, visual-perceptual problems, and spatial orientation than the no deficit group. The Block Design subtest measures the ability to analyse and synthesise

abstract visual stimuli. It involves nonverbal concept formation, visual perception and organization, simultaneous processing, visual-motor coordination, and the ability to separate figure and ground in visual stimuli, all of which are relevant to visual global motion processing and reading. The implications of these findings will be discussed further in the final chapter of this thesis.

11.5 Evaluation of the Classification Techniques

The results of the current research demonstrate that different classification techniques produce different prevalence estimates regarding the proportion of individuals in the dyslexia group with a motion processing deficit. When the number of individuals with a motion deficit was estimated for each of the experiments separately, the results were quite consistent within each technique. As shown in Chapter 10, logistic regression classified about 40 to 48% of the dyslexia group with a deficit, deviance analyses 29 to 38%, and 16th percentile cut-offs 5 to 21%. This demonstrates a how different classification criteria produce very different prevalence estimates. However, the current research went one step further and investigated how consistently the deficit found in individuals with dyslexia occurred across two experiments. Consistent with past reports, this repeat deficit criterion resulted in a drop in the proportion of individuals classified with a deficit (Conlon et al., 2009). Using 16th percentile cut-offs, no individuals were identified with a stable global motion deficit, suggesting this technique did not select all of the individuals with a global motion deficit. This is consistent with the finding that the less stringent deviance criterion identified 4 (30%) individuals with a stable motion deficit, with significant differences in performance found between this motion deficit group and the no motion deficit group. While logistic regression identified the same 4

individuals in the dyslexia group with a deficit, this technique also classified 1 skilled reader with a deficit, suggesting deviance analyses may be the most effective out of the three approaches in classifying individuals with a stable motion deficit. However, the use of a repeat classification criterion appeared to increase the sensitivity of both the deviance and logistic regression techniques, without having to rely on the restrictive criteria used with the 16th percentile estimation technique.

The results from the current research project will be discussed in more detail in the next, and final, chapter of this thesis. Both implication and limitations of the current research will be discussed, along with recommendations for further research.

CHAPTER 12: General Discussion

12.1 Summary of the Current Project

A large number of studies have reported that dyslexia groups have reduced sensory sensitivity in the magnocellular and dorsal streams when compared to skilled readers. Evidence has come from anatomical (e.g., Galaburda & Kemper, 1979; Livingstone et al., 1991), electrophysiological (e.g., Demb, Boynton, & Heeger, 1998; Eden et al., 1996; Lehmkuhle et al., 1993), and psychophysical studies (e.g., Everatt et al., 1999; Hansen et al., 2001; Wilmer et al., 2004). An association has also been reported between motion sensitivity and reading skills (e.g., Conlon et al., 2004; Cornelissen & Hansen, 1998; Talcott et al., 1998; Witton et al., 1998). These findings have been consolidated into the magnocellular deficit hypothesis, positing that the motion deficit found in dyslexia is caused by a low level sensory deficit in the M system, which increases in magnitude at extrastriate visual levels (Stein, 2003; Stein & Walsh, 1997).

However, not all studies have found an association between motion sensitivity and dyslexia (e.g., Huslander et al., 2004; Kronbichler et al., 2002; Vanni et al., 1997). This has led to alternative explanations of reduced motion sensitivity. The first of these is that the motion deficit in dyslexia is perceptual, rather than sensory in nature. This explanation proposes that the motion deficit arises from abnormalities at extrastriate cortical levels in the parietal cortex (Amitay et al., 2002), affecting only complex global motion processing (Hill & Raymond, 2002; Raymond & Sorensen, 1998). A second explanation has defined the reduced motion sensitivity found in dyslexia in terms of a noise-exclusion deficit (Sperling et al., 2005; 2006b). In the current research a number of measures of global motion processing were administered to groups of adults with and without dyslexia. Specific stimulus parameters expected

to discriminate between the different explanations were systematically manipulated. A local motion control task was also used.

Interpretation of the equivocal results reported in the literature has been made difficult by the wide range of psychophysical tasks (e.g., global motion, speed discrimination, contrast sensitivity), and stimulus parameters used to assess motion sensitivity in dyslexia. Reports that only a subgroup of individuals with dyslexia also have a motion deficit (Cornelissen et al., 1995; Everatt et al., 1999; Slaghuis & Lovegrove, 1985) have further complicated the interpretation of the research findings. Most previous studies have only relied on the average differences found between dyslexia and skilled reader groups to conclude the presence or absence of a motion deficit. In addition, the few studies that have assessed sensitivity within the dyslexia group have used different classification techniques with different levels of statistical stringency to determine which individuals with dyslexia also have a motion deficit. Hence, in addition to investigating between group differences, the current study also generated within group analyses for the global motion experiments using three classification techniques that have been used in recent research. These were 16th percentile estimates (Heath et al., 2006), deviance analyses (Ramus et al., 2003), and logistic regression (Solan et al., 2007). Based on the results of these classification techniques, the cognitive profile of dyslexia groups with and without persistent motion deficits was assessed. Recent research has suggested individuals with dyslexia and a motion deficit have greater difficulties with complex phonological processing and verbal short-term memory tasks when compared to dyslexia groups with no motion deficit (Conlon et al., 2009; Johnston et al., 2008; Wright & Conlon, In Press).

12.2 Motion Sensitivity of the Dyslexia and Skilled Reader Groups

The results of Experiments 1 to 3 showed that regardless of the tasks presented, and regardless of the specific manipulations conducted, the global (coherent) motion sensitivity of the dyslexia group was significantly poorer than that of the skilled reader group. The results from Experiment 1, suggest that the motion processing deficit in dyslexia cannot be explained by a specific deficit in temporal recruitment (as proposed by Raymond & Sorensen, 1998) or a specific deficit in processing low motion energy stimuli (as proposed by Talcott, Hansen et al., 2000) alone. Rather, the sensory and perceptual processes of integrating motion signals across space and time were functional, but less efficient, in the dyslexia group compared to the skilled reader group. This conclusion was supported by the finding that both reader groups demonstrated the same pattern of performance across manipulations, with the overall sensitivity of the dyslexia group being reduced.

The same overall pattern of results was found on the motion transparency tasks presented in Experiments 2A and 2B. While the accuracy of both groups increased as the stimulus duration increased, the dyslexia group failed to reach the same level of accuracy as the skilled reader group. In Experiment 2B, where increased accuracy scores were found for both reader groups compared to in Experiment 2A, there was evidence that the dyslexia group had difficulties both with the simultaneous and sequential processing of bidirectional motion. While the dyslexia group could reach the 75% accuracy level (used as a determinant of successful performance) in the two longest stimulus durations presented (where the two signals could be processed sequentially), the accuracy levels obtained in these conditions were significantly lower than those of the skilled reader group. While a previous motion transparency study did not separate between simultaneous and sequential processing efficiency in

their sample (Hill & Raymond, 2002), the finding that the sequential, as well as simultaneous processing abilities of the dyslexia group were impaired was significant. This is because past research has proposed the motion deficit in dyslexia may be explained by a deficit affecting the processing of sequentially presented visual information (Ben-Yehudah et al., 2001; Conlon et al., 2004; Slaghuis & Ryan, 2006). While the current research did not find the deficit to be limited to the sequential processing of bidirectional motion, the results indicate that the dyslexia group had more difficulties shifting the automatic components of neural attention than the skilled reader group, a finding consistent with previous reports (Hari & Renvall, 2001). The performance of the dyslexia group may have improved further if the stimulus duration had been extended past 550msec, as Hill and Raymond found the accuracy score of their dyslexia group to improve until the total stimulus duration reached 2sec. However, the overall results suggest that the visual perceptual system of the dyslexia group was less efficient than that of the skilled reader group in segmenting and grouping two motion signals, regardless of whether the motion signals could be extracted simultaneously or sequentially.

The results of Experiment 3, where the salience of the signal and noise dots in the RDK were manipulated, differed from the pattern of motion sensitivity found in Experiments 1 and 2. While the dyslexia group were significantly less sensitive to the stimuli than the skilled reader group in all of the conditions presented, a significant interaction was found between reader group and signal salience. This interaction revealed that the presence of high salience noise in the RDK produced greater difficulties for the dyslexia group than for the skilled reader group. The dyslexia group had greater difficulties extracting the signal from the noise when the signal salience was low and the salience of the noise high. This finding corresponds to

reports that difficulties extracting signal from noise in complex perceptual stimuli contribute to the reduced motion sensitivity found in dyslexia groups. Consistent with the findings of Experiment 2, the reduced motion sensitivity may be explained by 'sluggish attentional shifting' (Hari & Renvall, 2001). In the noise exclusion study, this was manifested as difficulty directing attention to the less salient signal dots while inhibiting automatic attention to the more salient noise dots in the RDK (Lu & Dosher, 1998). The current results support a role for the noise exclusion deficit in explaining the motion deficit in dyslexia. However, the results do not support the argument that noise exclusion on its own can explain the motion deficit (as proposed by Sperling et al., 2005; 2006b), as the dyslexia group was also less sensitive than the skilled reader group in the high signal salience condition.

Investigation of the individual dot plots for the high signal salience condition revealed a floor effect in the skilled reader group, with a number of skilled readers obtaining a coherent motion threshold close to 1%, meaning that only 1 to 2 signal dots were required for these individuals to detect the direction of motion presented. This finding was critical as it suggests that the high signal salience condition may have acted as a local motion task. As the signal dots could be identified both on the basis of salience and of movement, the processes required when (1) extracting the signal from the noise, and (2) integrating the motion signals across space and time were not used to accurately detect the direction of motion presented. Interestingly, the coherent motion thresholds obtained in a previous study that separated the signal and noise dots on the basis of colour showed similar results (Sperling et al., 2006b). In the Sperling et al. study, two high signal salience conditions were presented, and no significant between groups differences in sensitivity were reported. The coherent motion thresholds obtained were 2% for the dyslexia group and 1.6% for the skilled

reader group when red signal dots were surrounded by light grey noise dots. Similarly, the thresholds obtained were 1.7% for the dyslexia group, and 1.5% for the skilled reader group, when the stimuli consisted of red signal dots only. Comparatively, when light grey signal and noise dots (luminance of 18.3 cd/m^2) were presented on a darker grey background (luminance of 12.7 cd/m^2), significant between group differences in performance were found, with the dyslexia group obtaining a mean coherent motion threshold of 11.7%, and the skilled group a mean coherent motion threshold of 8.8% (Sperling et al.).

If the argument that RDKs consisting of salient signal dots surrounded by less salient noise dots effectively act as a local motion task is accepted, this has important implications for the interpretation of both past and current research findings. First, the results of the Sperling et al. (2006b) study may be interpreted in support of a global, but not local, motion processing deficit in adult dyslexia groups. Second, the current results may be interpreted in favour of both a local, and a global motion processing deficit in the current sample, with the local motion deficit being subtle (i.e., the magnitude of the effect is stronger using global motion measures). This interpretation is consistent with the magnocellular deficit explanation and the 'cascade effect' (Stein & Walsh, 1997). The fact that Sperling et al. did not find any significant between group differences in their high signal salience conditions could be explained by the use of coloured stimuli, allowing the reader group to segment the stimuli in such a way that any motion signal with the correct attribute (red) could be used to detect the direction of motion. In addition, involvement of the P system cannot be ruled out.

The suggestion of a low level sensory motion deficit in the current sample was not supported by the results of Experiment 4, where the local motion processing of the current sample was assessed with a D$_{min}$ task. The results showed that there were no

significant differences in sensitivity between the dyslexia and skilled reader groups, suggesting it may be more complex functional processes associated with global, and not local motion processing that are impaired in adults with dyslexia. However, the lack of significant between group results on the local motion task may also be explained in terms of the stimulus parameters used. While the current task used a six-frame stimulus, with a total stimulus duration of 900msec, one study that reported impaired sensitivity in the dyslexia group on this task used a two-frame stimulus with a total stimulus duration of 300msec (Everatt et al., 1999). These differences in stimulus parameters would have made the current task less difficult from a perceptual point of view, as there would have been greater opportunity for the visual system to detect the local motion signals. The effect of stimulus parameters on psychophysical task performance is an important issue, and will be discussed further in section 12.3. However, first the associations between reading and global motion processing will be addressed.

12.2 The Associations between Reading and Motion processing

Consistent with previous research (Conlon et al., 2004; Lilleskaret, 2001; Talcott et al., 2002), the results from the current study showed significant associations between word decoding, phonological and orthographic processing skills, and global motion sensitivity. Sensitivity on the global motion tasks and accuracy on the reading measures were also found to be significantly associated with responses on the Adult Dyslexia Checklist (Vinegrad, 1994), with higher scores on the Checklist being associated with poorer motion sensitivity and poorer reading. These associations suggest the Adult Dyslexia Checklist is a useful additional measure that should be

incorporated into the assessment of reading difficulties and global motion deficits in adults.

12.3 The Impact of Stimuli Parameters on Psychophysical Task Performance

The stimulus parameters used are commonly ignored when research results are interpreted in the reading literature, and the lack of consistency across experimental paradigms is likely to explain some of the equivocal results reported. The current study demonstrated that changes in the stimulus parameters used had a significant impact on the psychophysical task performance of both the dyslexia and skilled reader groups. For example, in Experiment 1, neither the dyslexia nor skilled reader group benefitted from the added information provided to the visual system through an increase in the number of animation frames presented (from 5 to 8), when the dot density was low (3.54dots/deg^2). However, both groups demonstrated temporal recruitment effects when the dot density was high (14.15 dots/deg^2), showing that concurrently increasing the dot density and the number of animation frames presented in the RDK assisted the visual system in utilising the added information provided by each parameter.

The unexpected lack of temporal recruitment in the low dot density condition for the skilled reader group can also be explained by the stimulus parameters used. Previous studies that failed to find significant reader group differences at high dot densities used a different methodology to that used in the current study. One study that did not find significant reader group differences when the dot density was 12.2 dots/deg^2, used long stimulus durations ranging from 200 to 1800msec (Talcott, Hansen et al., 2000), with a dot lifetime of 4 animation frames. Comparatively, in Experiment 1, the duration of a single animation frame was 16.67msec, and the total

stimulus duration of the RDK was 84msec (5 frames) or 134msec (8 frames). The dot lifetime was limited to 2 animation frames. This means that the stimuli used in Experiment 1, produced a much faster and more perceptually difficult stimulus than the stimuli used in the previous study, with the visual system being unable to detect, and integrate, the motion stimuli across time when the motion signals were sparse. Other studies reporting no significant between group differences in sensitivity between dyslexia and skilled reader groups have used dot densities of over 30 dots/deg^2 (Edwards et al., 2004; Hill & Raymond, 2002), providing greater sampling in space. The current findings suggest that the ability to sample motion stimuli over space and time both contribute to sensitivity in dyslexia groups. Future research should increase the dot densities further but hold the other stimulus parameters used in Experiment 1 constant to clarify this issue.

The impact of the stimulus parameters on motion sensitivity was further demonstrated in Experiment 2, where two versions of a motion transparency task were presented. The results showed that the accuracy of sampling the two motion signals, both simultaneously and sequentially, was affected in both reader groups based on the stimulus parameters used. When the frame duration was limited (9 to 33 animation frames), and the signal dots moved across two animation frames only (i.e., dot lifetime of 2 animation frames), neither of the reader groups could reach the 75% accuracy threshold used as a determinant for successful task performance on the motion transparency task (Experiment 2A). However, when the stimulation to the visual system was increased, by doubling the number of animation frames presented and increasing the dot lifetime, the skilled reader group reached the 75% accuracy level in the 150msec stimulus duration condition, and the dyslexia group in the 550msec stimulus duration condition (Experiment 2B). This increase in sensitivity

was found even though the stimulus duration of a single animation frame was reduced from 16.67 to 8.33. This suggests that an increase in the number of animation frames presented, and an increase in dot lifetime, produced greater stimulation to the visual system because of the availability of an increased number of motion samples. These increased samples allowed both reader groups to segment and group the two motion stimuli presented more efficiently.

The current results highlight the importance of the stimulus parameters used, and the impact these have on global motion sensitivity and motion transparency accuracy. Under some conditions the visual system's ability to effectively sample the motion signals was so poor that neither the skilled nor dyslexia groups were able to perform efficiently (e.g., Experiment 2A). In other tasks the perceptual difficulty may have be so low that all individuals could effectively perform the motion processing task (e.g., Experiment 4). This conclusion is consistent with a past report where the low luminance levels used (to maximally stimulate the M system), made the task so perceptually difficult that sensitive coherent motion estimates could not be obtained either for the dyslexia or skilled reader group (Ramus et al., 2003). Taken together, these findings suggest that the stimulus parameters used can determine whether significant sensitivity differences are found between dyslexia and skilled reader groups.

The stimulus parameters used in a global motion, or motion transparency task, may also influence the associations found with different subskills of reading. For example, the strong associations obtained between the TOWRE speed of processing measure and performance on the short stimulus duration task used in Experiment 1, suggest the current task had some characteristics similar to a speed of processing measure. In previous studies speed of processing has not been significantly associated

with global motion processing (Ben-Shachar et al., 2007; Wilmer et al., 2004). For example, in the global motion task used by Wilmer et al. that failed to obtain evidence of an association between processing speed and coherent motion sensitivity, the stimulus duration was 2.3 seconds, a much longer stimulus duration than that used in Experiment 1. On this basis the associations found, or not found between different measures of reading and motion processing may be explained by the specific stimulus parameters used. Hence, one implication of the current findings concerns careful selection of stimulus parameters when evaluating sensitivity of both dyslexia and skilled reader groups, as these may have a substantial impact on the research outcome. While a number of studies (e.g., Conlon et al., 2009; Reid et al., 2007; Solan et al., 2007; Wright & Conlon, In Press), have used the double panel coherent motion task developed by Hansen et al. (2001), this task may not be ideal as it involves the shifting of automatic attention (from one panel to the next), and uses a long stimulus duration. Research has shown that many individuals with dyslexia have unsteady eye control (Stein, 2003), and a single panel task with a small stimulus field (as used in the current research) is more likely to avoid the impact of these difficulties when assessing sensitivity to global motion in dyslexia and skilled reader groups.

12.4 Motion Deficit Subgroup

While the dyslexia group used in the current research were less sensitive to global motion than the skilled reader group, individual estimates of motion sensitivity revealed that only a proportion of the individuals in the dyslexia group demonstrated consistently poor sensitivity. Moreover, the results showed that the proportion of individuals classified with a motion deficit varied based on the classification technique used. This finding highlights the impact of the varying statistical stringency

of the classification procedures used. Based on consistently poor performance across one experiment, logistic regression (based on the 50th percentile estimates) classified approximately 40 to 48% of the dyslexia group, and 4 to 16% of the skilled reader group with a motion deficit. Comparatively, deviance analyses (based on 95% confidence from the control group mean) classified 29 to 38% of the dyslexia group, and up to 4% of the skilled reader group with a motion deficit. The 16th percentile cut-offs classified 5 to 21% of the individual in the dyslexia group, and up to 4% of the skilled reader group with a motion deficit.

To ensure that only the poorest performers on the task were identified with a motion deficit a repeat criterion, where impaired performance on both Experiments 1 and 3 were used to determine which individuals with dyslexia had a deficit. The results revealed that no individuals could be identified with a stable motion deficit based on 16th percentile estimates. Comparatively, the same group of individuals with dyslexia (n = 4) were identified with a stable deficit based on the deviance analyses and the logistic regression approach. While no skilled readers were classified with a deficit using deviance analyses, logistic regression classified 1 skilled reader with a consistent deficit.

The finding that the same group of individuals were classified with a motion deficit across experimental conditions and across experiments, suggests the deficit in this subgroup of individuals was stable. It affected the integration and extraction of signal from noise, as well as the segmentation and grouping of more complex motion signals. While the results of the between group analyses suggested a role for noise exclusion in explaining the motion processing deficit in dyslexia, the results of the within group analyses confirmed that noise exclusion on its own cannot explain the deficit. While the dyslexia group as a whole, had more difficulties extracting signal

from noise in the low signal salience condition of Experiment 3, the results of the within group analyses showed that individuals who had difficulties with this condition also had difficulties with the other experimental conditions, including the high signal salience condition. Overall, the findings lend support to an underlying vulnerability in the motion system of these individuals with dyslexia.

When the reading and cognitive profile of the dyslexia group with a stable motion deficit (n = 4) was further assessed, this small group did not differ significantly from the dyslexia group without a motion deficit (n = 9) on the different subskills of reading. However, the motion deficit group had significantly poorer accuracy on measures of verbal short-term memory, sequencing, and the localisation of visual information in the spatial domain compared to the no motion deficit subgroup. These results indicate that there were some cognitive characteristics that separated the two groups. The finding that the dyslexia group with a motion deficit had poorer verbal short-term memory than the no motion deficit group is intriguing, and replicates recent reports (Conlon et al., 2009; Johnston et al., 2008; Wright & Conlon, In Press). The finding that the motion deficit group also had greater difficulties with sequencing, and the localising of visual information in the spatial domain than the no motion deficit group was also of interest, as the dyslexia group demonstrated reduced accuracy both on the simultaneous and sequential processing components of the motion transparency task. This finding supports previous research that has suggested the motion deficit in dyslexia may be explained by a deficit affecting the processing of sequential stimuli (Ben-Yehudah et al., 2001; Conlon et al., 2004; Slaghuis & Ryan, 2006). Both sequencing and the localisation of visual information are processes that involve M stream processing (Slaghuis & Ryan, 1999),

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with area V5 and the parietal lobe key motion processing areas in the dorsal visual stream (Milner & Goodale, 1995).

Research has reported that adults with concurrent motion and verbal short-term memory difficulties also have difficulties on complex phonological discrimination measures, such as spoonerism tasks (Conlon et al., 2009). However, the current research did not find any significant differences in phonological processing between the two groups. As phonological discrimination was not assessed in the current research this may explain the failure to replicate. Phonological discrimination, assessed using a spoonerism task, has been found to discriminate most strongly between adults with and without dyslexia in terms of advanced phonological processes (J. Hatcher et al., 2002; Paulesu et al., 1996). In addition, the size of the sample of individuals with dyslexia and a consistent motion deficit used in the current research may have been too small to reveal consistent differences.

The finding that adult dyslexia groups with a motion deficit may have increased difficulties with phonology and verbal short-term memory compared to the no motion deficit group is consistent with reports suggesting the motion deficit may be explained by poor access to phonological representations (Ramus & Szenkovits, 2008). The deficit in short-term memory has also been conceptualised in terms of poorly formed perceptual anchors that negatively affect the ability to retain and explicitly retrieve recently presented stimuli (Ahissar, 2007; Ahissar et al., 2006). The latter argument is consistent with previous findings that a disorder in sequential and temporal order processing in dyslexia may reflect difficulties in retaining sequences of non-meaningful auditory and visual stimuli in short-term working memory (Slaghuis & Ryan, 2006). The range of deficits found within a particular individual may depend on the spatial extent of their cortical dysfunctions (Ramus, 2004).

12.5 Classification Issues

12.5.1 Motion Measures

The prevalence estimates obtained for the different classification techniques used in the current study were lower than the estimates obtained in past studies using the same techniques (e.g., Heath et al., 2006; Pellicano & Gibson, 2008; Slaghuis & Lovegrove, 1985; Solan et al., 2007). This difference can be explained by the use of a single versus repeat criteria to determine the presence or absence of a motion deficit in the dyslexia group. Previous studies have commonly only assessed sensitivity to motion in one experimental condition, with sensitivity estimates being obtained as an average score across two or more blocks of trials. When this single deficit criterion was applied to the current research the prevalence estimates increased, with 16th percentile estimates producing estimates as high as 43% (eight-frame high dot density condition in Experiment 1). Comparatively, deviance estimates increased to 62% (five-frame low dot density condition in Experiment 1), and logistic regression estimates to 77% (250msec stimulus duration condition in Experiment 2A). Consistent with studies that have used repeat criteria across time (Wright & Conlon, In Press), and across threshold estimates (Conlon et al., 2009) the prevalence estimates decreased when repeat criteria were used.

While past research has not assessed the specificity of the classification techniques used, the current results showed that as the sensitivity estimates increased (i.e., the proportion of individuals in the dyslexia group classified with a deficit) the specificity estimates decreased (i.e., the proportion of individuals in the skilled reader group without a deficit). This is important because both estimates provide information about the effectiveness of the classification procedure used and about the statistical appropriateness of the different techniques in differentiating performances within

individual groups. The current results suggest that use of repeat criteria, or repeatability of the motion deficit, may be more important than the technique used when determining the proportion of individuals with a stable motion deficit. While 16th percentile estimates appeared to be too stringent, both deviance analyses and logistic regression analyses identified the same group of individuals with a motion deficit in the dyslexia group when a repeat criterion across experiments and experimental conditions was used. In terms of the statistical criteria used, it is not surprising that 16th percentile estimates may be too stringent to classify the presence or absence of a global motion deficit, as a WRAT reading score at the 35th percentile is commonly used to classify whether a reading deficit is present in the dyslexia group or not.

While the use of a single criterion appears to be accepted in the reading literature to determine the presence or absence of a motion deficit, this is not the case when determining the presence or absence of for example, a phonological deficit. Considerable research effort has been expended into the identification of the different subcomponents of phonological processing (e.g., Snowling, 2000; Wagner & Torgesen, 1987), and the association of these different processes to the development and maintenance of dyslexia. Comparatively, much emphasis has been placed on classifying individuals with phonological and/or orthographic difficulties, and these components have been used to identify different subtypes of individuals with dyslexia, for example phonological and surface dyslexia (e.g., Boder, 1973; Castles & Coltheart, 1993). Based on these results, one avenue for future research would be to identify which of the subcomponents of motion processing that may be impaired in dyslexia groups with a motion deficit. While the current results suggest both sensory and perceptual processes play a role in explaining the reduced global motion

sensitivity found in some individuals with dyslexia, there is a need for replication and further investigation of these effects.

The current research project also demonstrated the impact of different stimulus parameters in estimating the proportion of individuals in the dyslexia group with a motion deficit. The results showed that certain experimental conditions produced higher prevalence estimates than others. For example, based on both deviance analyses and logistic regression analyses the five-frame low dot density condition in Experiment 1 produced the highest prevalence estimate. Of the four experimental conditions presented in that experiment, this was the condition with the highest level of perceptual and sensory difficulty as there were limited opportunities for the visual system to integrate the information across space (dot density), and time (animation frames). The stimulus parameters used also affected the different classification techniques in different ways. For example, 16th percentile estimates appeared too stringent to identify many individuals with a deficit when processing bidirectional motion. However, for the less statistically stringent criteria on which logistic regression is based, stimulus parameters did not have the same impact.

12.5.2 Dyslexia in Adult Populations

As outlined in the introduction of this thesis, different terminologies have been used in the research literature to describe the dyslexia group. Some of these terms include 'poor readers', 'impaired readers', and 'reading disabled'. Throughout this thesis the sample has been referred to as adults with dyslexia, and the classification methods used were consistent with those used in some other studies (Conlon et al., 2009; Lavidor et al., 2006; Talcott, Hansen et al., 2000). However, whether the term dyslexia is the most appropriate term, or whether this type of sample instead should be

referred to as adult poor readers is an important question. Previous research using children with dyslexia has used a variety of classification techniques. For example, in some studies the lag between reading and chronological age has been up to four years (Lovegrove et al., 1986), while in other studies it has been 12 to 18 months (Williams & Lovegrove, 1992; Williams et al., 2003). In adults, the use of differences between reading age and chronological age is more problematic. First, there is no well established criterion used to determine the presence or absence of dyslexia, and many psychometric tests do not provide normative data for adult samples (Cornelissen et al., 1995). Second, in adults, single word reading scores are influenced both by exposure to text and the level of reading remediation (e.g., Fink, 1998).

Consistent with the current study, adults are often classified as reading below expected levels if they demonstrate single word reading skills in the low average to average range, have poor performance on measures of reading fluency and phonological processing, and a reported childhood history of reading difficulties. While in some studies the word reading skills of individuals with dyslexia have been in the high average range (e.g., Talcott, Hansen et al., 2000), this group may represent an accuracy remediated (or partially compensated) dyslexia group (Shaywitz et al., 2003). Further, adults with a profile of persistent difficulties across a range of reading tasks (i.e., phonology, orthography and fluency) may be the ones with a specific vulnerability on measures of complex visual processing. The strong associations found between responses on the Adult Dyslexia Checklist (Vinegrad, 1994), reading performance, and global motion sensitivity add support to this argument. In this regard it is worth noting classification issues such as the whether the ability-achievement discrepancy criterion should be used are still under debate (Gustafson & Samuelsson, 1999; M. S. Meyer, 2000). While one study showed little qualitative

difference between two groups of adult participants, one group classified with dyslexia based on a previous history of reading difficulties and one based on the ability-achievement criteria (Kinsbourne, Tocci Rufo, Gamzu, Palmer, & Berliner, 1991), it is concerning there are no clear guidelines for the classification of adults with dyslexia within the field of reading research, as it further complicates cross-study comparisons and the interpretations of the obtained results.

12.6 Limitations of the Current Research

The overall results of the current study suggest that the complex motion processing deficit found in dyslexia occurs at extrastriate levels, supporting explanations that poor motion sensitivity is a manifestation of a parietal level deficit. However, the presence of a low level sensory deficit cannot be completely discounted. While the focus of the current research was on neural and perceptual processes underlying global motion processing only D_{min} performance was assessed in terms of low level functioning. The local motion task used in the current study effectively separated between younger and older age groups (J. M. Wood & Bullimore, 1995), and between individuals with and without glaucoma (Bullimore, Wood, & Swenson, 1993), in previous research. This suggests that the task is a sensitive measure of low level visual processing. However, it is possible the task was not sufficiently sensitive to detect the subtle local motion deficit, if present in the dyslexia group. While outside the scope of the current study, it would have been beneficial to measure contrast sensitivity function in the sample, as this might have provided additional data on local motion processing capacity at the level of the LGN and V1. A further limitation of the current study was that phonological discrimination (spoonerisms) was not assessed, as

this may have better identified the phonological deficit, if present in the motion deficit subgroup.

It is also important to recognise the effect of the relatively small sample size on the statistical power of the analyses when interpreting the results. To assess the stability of the global motion deficit in the current sample a number of individuals had to be excluded from the analyses, as they did not participate in all of the experiments. Hence, the comparison of the profile of the dyslexia groups with (n = 4) and without (n = 9) a stable motion deficit must be interpreted with caution as there are (1) unequal, and (2) small sample sizes. The small sample size, along with the skew found in parts of the data sets must also be considered in terms of 16th percentile and deviance analyses estimates. The validity of obtaining estimates using relatively small samples sizes can be questioned. These issues are also relevant when considering some previous studies that have used these individual statistics to determine the proportion of individuals with dyslexia with a specific motion deficit (White, Frith et al., 2006; White, Milne et al., 2006).

12.7 Implications for Future Research

The findings of the current study are consistent with past research suggesting there may be different underlying causes of dyslexia (Reid et al., 2007), and with research reporting that the profile of adults with dyslexia is heterogeneous (Erskine & Seymour, 2005). Consistent with past reports of a motion deficit subgroup (e.g., Cornelissen et al., 1995; Slaghuis & Lovegrove, 1985), the results of this thesis suggest that motion processing like reading (Shaywitz et al., 1992), may exist on a continuum, with impaired motion processing not being sufficient to cause dyslexia. These findings suggest that it is not meaningful to talk about a global motion deficit in

dyslexia, but rather to talk about a motion deficit subgroup with certain characteristics.

An area of importance for future research is the investigation of the characteristics that may separate the motion deficit subgroup from dyslexia groups without motion deficits. As the current results suggest the motion deficit affects both sensory and perceptual processes at V5, it will be important to continue the research into these higher-order processes to investigate what perceptual, and possibly attentional, processes that may be associated with the motion deficit. It is essential to note that in adults the motion deficit appears to affect both simultaneous and sequential processing, and this is important knowledge both for educators and employers. When creating a supportive and conductive work environment this information can be used to develop alternative strategies to deal with tasks that require extensive multi-tasking and that relies heavily on verbal short-term memory processes.

As the dyslexia group with a stable motion deficit had more difficulties with sequencing and verbal short term memory compared to the dyslexia group without a motion deficit, it may also be important for future research to assess performance on the Digit Symbol subtest of the WAIS-III (Wechsler, 1997). This subtest assesses the ability to learn which symbol corresponds to what digit, where it is placed, and how efficiently it is written. Research has reported dyslexia groups are significantly impaired on this measure compared to skilled reader groups (Slaghuis & Ryan, 1999). Many of the components of the Digit Symbol task, such as the localisation of visual information in the spatial domain and the sequencing of eye movements, are also involved in the reading process. Hence, adding this type of measure may shed further light onto the difficulties experienced by individuals with dyslexia. Linked to this, is

the need to work towards remediation training that is tailored to the pattern of difficulties experienced by the individual. As emphasised by past research it is essential that treatments for dyslexia focus on impairments actually observed in particular individuals, rather than claiming to cure all individuals with dyslexia indiscriminately (White, Milne et al., 2006). This means that for the motion deficit subgroup basic movement direction discrimination training may be an effective treatment program, as recent research has reported improved reading fluency and improved word identifications skills in response to this approach (Lawton, 2007). This type of remediation training would be beneficial both from a cost and time perspective, as it could be administered to groups of individuals simultaneously.

A short version of the coherent motion and motion transparency tasks, that use clearly defined stimulus parameters, may also be developed. Developments of tasks that consistently measure the same components of motion processing in individuals with dyslexia may allow greater consistency among research groups when assessing the presence or absence of motion deficits. If a group of individuals with dyslexia and a motion processing deficits is found, these tasks can be developed into tools that will add to the dyslexia screening process in the education system. When considering the covariance consistently found between reading skills and global motion sensitivity, it seems worthwhile to utilise this knowledge as a preventative screening measure.

The tasks conducted in this study were administered to adults with poor reading skills. Further research should replicate these findings in other adult samples, and administer the tasks to children with and without dyslexia. These strategies will determine whether the same pattern of performance is detected in these additional groups. In the current research it is possible the neurological deficit found occurred because of persistent reading difficulties, including poor reading fluency. It is possible

that children with deficits on these measures may also be those children who will develop persistent difficulties with reading in the future.

The lack of methodological consistency within the research literature makes it difficult to compare results across studies, and to determine the consistency of the relationships between motion processing and reading. The vast differences in stimulus parameters, tasks, and the group classification procedures used have also contributed to the controversial nature of the M deficit in dyslexia. Therefore, it is important that a standardised group of stimulus parameters and tasks are used for screening procedures. These are needed not only for the motion measures, but also for the assessment and classification of dyslexia in adults. In terms of the motion measures, the classification techniques currently available (e.g., 16th percentile and deviance analyses), rely heavily on the performance of individual skilled reader groups and assume that the groups used represent the population of skilled readers. In addition, the statistical assumptions underlying the use of these techniques, for example normal distribution of sensitivity scores, do not always occur and there is little reliability and validity data available. Hence, there is a need to develop normative data that can provide guidelines for determination of normal and abnormal sensitivity to motion. These norms would then provide a standard against which to evaluate the performance of individuals in a more objective manner when the same motion processing measures are used.

Finally, it should be noted that in the current sample a greater proportion of individuals with dyslexia than skilled readers dropped out of university, or found they could not commit their time to the current research project, despite expressing verbally how valuable they found this research to be. This suggests that the dyslexia group found the requirements of university study more demanding than individuals in

the skilled reader group. This is consistent with anecdotal reports provided by participants. In addition, while some of the individuals in the dyslexia group were clients of the University Disability Service, hence receiving support in terms of extra time on exams and course work, the majority of the individuals in the dyslexia group were not. When information about this service was provided the majority of the individuals in the dyslexia group stated they did not believe they needed, or were entitled to extra assistance. Some also expressed not wanting to affiliate with a 'disability service'. This information may shed light onto some of the challenges faced by individuals with dyslexia when entering higher education. It is also hoped it conveys the need for more effective retention strategies directed at this group to ensure their progression throughout the university system.

12.8 Conclusion

The current research evaluated a number of theoretical explanations for the reduced global motion sensitivity in dyslexia. The results demonstrated that the dyslexia group, as a whole, was less sensitive to global motion than the skilled reader group. Further, the results demonstrated the effect of specific task parameter changes on motion sensitivity and motion accuracy estimates in both reader groups. Manipulations of dot density, the number of animation frames presented in the RDK, and dot lifetime affected the dyslexia and skilled reader groups similarly. However, the dyslexia group had more difficulties extracting signal from noise in a complex visual scene compared to the skilled reader group, suggesting they may have 'sluggish attentional shifting'.

However, only a subgroup of individuals in the dyslexia group had a stable motion deficit, suggesting it may not be meaningful to talk about the presence or

absence of motion deficits in dyslexia groups. The current results suggest the use of a repeat deviance analyses classification criterion provides a sensitive estimate of the proportion of individuals in the dyslexia group with a motion deficit. Based on the repeat deviance analyses criteria about 30% of the individuals in the dyslexia group were classified with a stable motion deficit. This subgroup showed reduced sensitivity across the global motion tasks, demonstrating difficulties with motion extraction, motion integration, and simultaneous and sequential processing of bidirectional motion. This suggests the global motion deficit in dyslexia affects both sensory and perceptual processes. While there were no significant differences in local motion sensitivity found between the two dyslexia groups, there was a trend towards a local motion processing deficit in the dyslexia group with a global motion deficit. The cognitive profile of the two groups also differed, with the motion deficit group having greater difficulties with verbal short-term memory and visual-motor-spatial integration than the no motion deficit group. While the profile of the dyslexia group with a motion deficit was consistent with previous research, the small sample size used must be acknowledged as a limitation.

Future research should further investigate what higher order, and possibly perceptual processes that may be impaired in dyslexia groups with persistent motion deficits. This is important to enhance our current knowledge of the aetiology of dyslexia. It also has significant implication for the treatment of dyslexia, as remediation strategies will need to be tailored to the specific difficulties experienced by the individual.

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Appendix A:

Headache and Visual Discomfort Scale (Conlon et al., 1999), and Pattern Sensitivity

Rating Scale (Conlon et al., 1999)

Revised Adult Dyslexia Checklist (Vinegrad, 1994) combined with items from the

Reading History Questionnaire (Conlon & Sanders, 2000).

The Nonword/Exception Word Test, including the Multisyllabic Nonword Test

(Conlon & Mellor, In Preparation)

HEADACHE AND VISUAL DISCOMFORT SCALE

Have you had at least two bad headaches in the last two years that did not occur following too much alcohol or an accident?   Yes ☐   No ☐

If no, please go to page 6.
If yes, please answer the following questions using the worst headache that you have experienced.

For how many years have you been getting bad headaches? _____

How many bad headaches have you had in the last month? ☐ year? ☐

What are the main strategies that you use to alleviate your headaches? Please specify?
_____
_____
_____
_____
_____

If you take medication to alleviate headache please specify what you take.
_____
_____
_____

During the worst headaches that you get, please specify the parts of the head where you feel pain during the headache?

☐ On one side of the head   ☐ At the back of the head
☐ On both sides of the head   ☐ On the forehead
☐ All over the head   ☐ Around both eyes

Please describe the pain _____

What are the main factors that bring on the headaches?

Please specify _____

Do you have any warning signs that tell you that
a headache is about to begin? Yes ☐   No ☐

If yes, please describe what these are: _____

_____

Prior to, or during, a headache do you experience any of the following problems?
(Please estimate the frequency and mark it on the scales below.)

	Almost always	Often	Occasionally	Never
(a) Sensitivity to odour / smells	☐	☐	☐	☐
(b) Sensitivity to lights	☐	☐	☐	☐
(c) Sensitivity to sounds	☐	☐	☐	☐
(d) A continuous discharge from the eyes	☐	☐	☐	☐
(e) Feeling nauseous and/or vomiting	☐	☐	☐	☐
(f) Pulsating/pounding pain	☐	☐	☐	☐
(g) Part of your body tingling or going numb	☐	☐	☐	☐
(h) Tight muscular pain around the head	☐	☐	☐	☐
(i) Visual disturbances, like flashing lights, patterns or blind spots	☐	☐	☐	☐

In the following questions, please tick the box beside the response that is most similar to what happens to you when you get a bad headache. (Base your response on what happens most frequently.)

10.   When I have a headache, performing daily activities is:

☐ Impossible.
☐ A major problem. I can only perform limited normal activities.
☐ Uncomfortable, but can be done.
☐ Produces little or no problems with performance.

11.   When I have a headache, performing physical activity (e.g., walking up and down stairs, exercise, etc.):

☐ Makes the pain unbearable
☐ Makes the pain worse
☐ Is uncomfortable, but can be done
☐ Does not produce any problems

12. Have you ever sought medical advice for your headaches?

☐ No
☐ Yes. If yes, what diagnosis was made? _____

13. Have you ever had any of the following conditions?

☐ No   ☐ Yes   Neurological disorders
☐ No   ☐ Yes   High blood pressure or heart disease
☐ No   ☐ Yes   Back or neck pain
☐ No   ☐ Yes   Motion sickness
☐ No   ☐ Yes   Eye disorders, please
                specify_____

14. Does anyone in your family have migraine?

☐ No
☐ Yes. If yes, what members of your family experience migraine?
_____

In the following questions, please tick the box beside the response that best applies to

you.

15. The visual disturbances I have experienced, normally:

☐ precedes the onset of a headache.
☐ occurs during a headache.
☐ develops together with the pain of a headache, reaching a maximum as
   the headache gets worse.
☐ develops together with the pain of a headache, and subsides as the
   headache gets worse.
☐ Other? Please specify
   _____
   _____
☐ I don't ever experience visual disturbances

16. On average, for often are your headaches accompanied by visual disturbances?
_____

Could you please draw, as accurately as you can, the typical appearance of the visual disturbances you experience. If you experience visual disturbances which move or spread, please try to indicate the directions of motion (or spread) with arrows, notes etc. If you experience visual disturbances which consist of patterns of coloured light, please indicate which colours are involved by way of notes on the drawing or in the margins.

●

centre of gaze
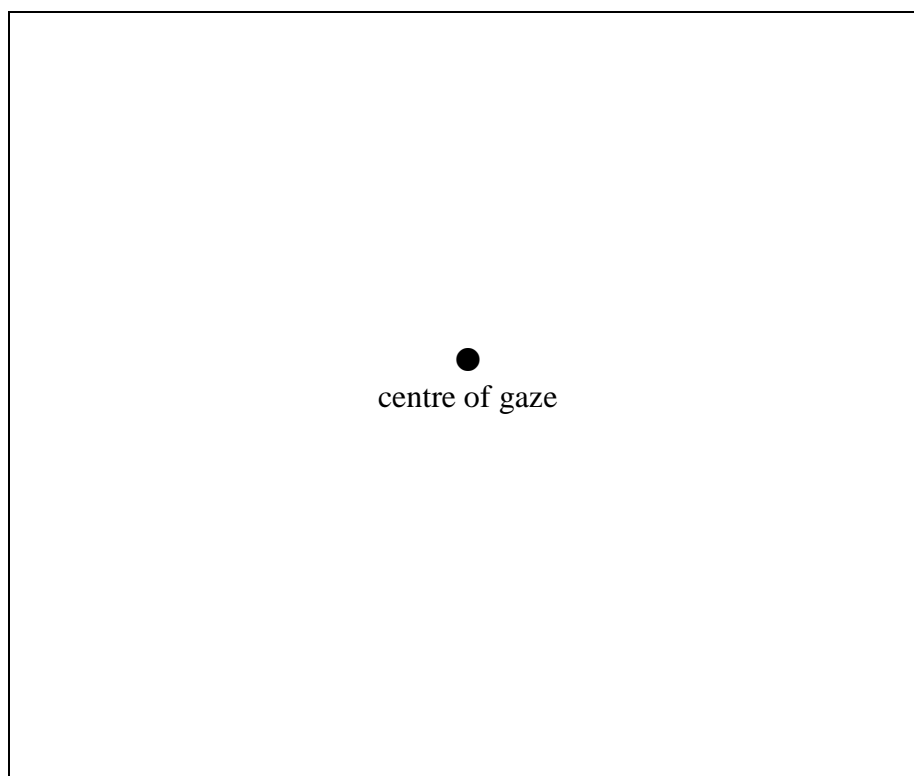
The following questions ask about the extent to which you experience different sorts of problems when reading or performing other tasks. In all cases, please assume that you are not tired, and that the lights are working normally.

	Almost always	Often	Occasionally	Never
17. After reading for a short time do your eyes ever feel tired, strained, or sore when reading a book or magazine with clear print?	☐	☐	☐	☐
18. After reading for a short time do you ever get a headache from reading a book or magazine with clear print?	☐	☐	☐	☐
19. Do you avoid working in areas where there is fluorescent lighting because it gives you eye-strain or headache?	☐	☐	☐	☐
20. When you are reading a page of text, which consists of black print on a white background, does the background ever appear to overtake the letters, making them hard to read?	☐	☐	☐	☐
21. Does the glare produced from the page of text ever make it difficult for you to concentrate on the letters and words?	☐	☐	☐	☐
22. When reading, do you ever have difficulty keeping the words on the page in focus?	☐	☐	☐	☐
23. When reading, do you ever unintentionally reread the same line?	☐	☐	☐	☐
24. Do you ever have difficulty seeing more than one or two words on a line in focus?	☐	☐	☐	☐
25. When reading, do the words on the page ever begin to move or float?	☐	☐	☐	☐
26. When reading, do the letters or words ever seem to disappear into the background and then reappear?	☐	☐	☐	☐
27. When reading, do the words that you are reading ever go blurry?	☐	☐	☐	☐
28. When reading, do you ever have to use your finger or a pencil to keep from losing your place?	☐	☐	☐	☐
29. When reading, does the white background ever appear to flicker or shimmer, making the letters or words hard to read?	☐	☐	☐	☐
30. For how long can you read before it becomes hard to view the letters and words?				
31. As a result of any of the above difficulties, do you find reading a slow task?	☐	☐	☐	☐

	Yes	No

32. Do you wear glasses or contact lenses?
    If yes, please answer the following questions

(a) When do you wear them? _____

(b) When wearing your optical correction do you have normal vision?

A MEASURE OF PATTERN SENSITIVITY
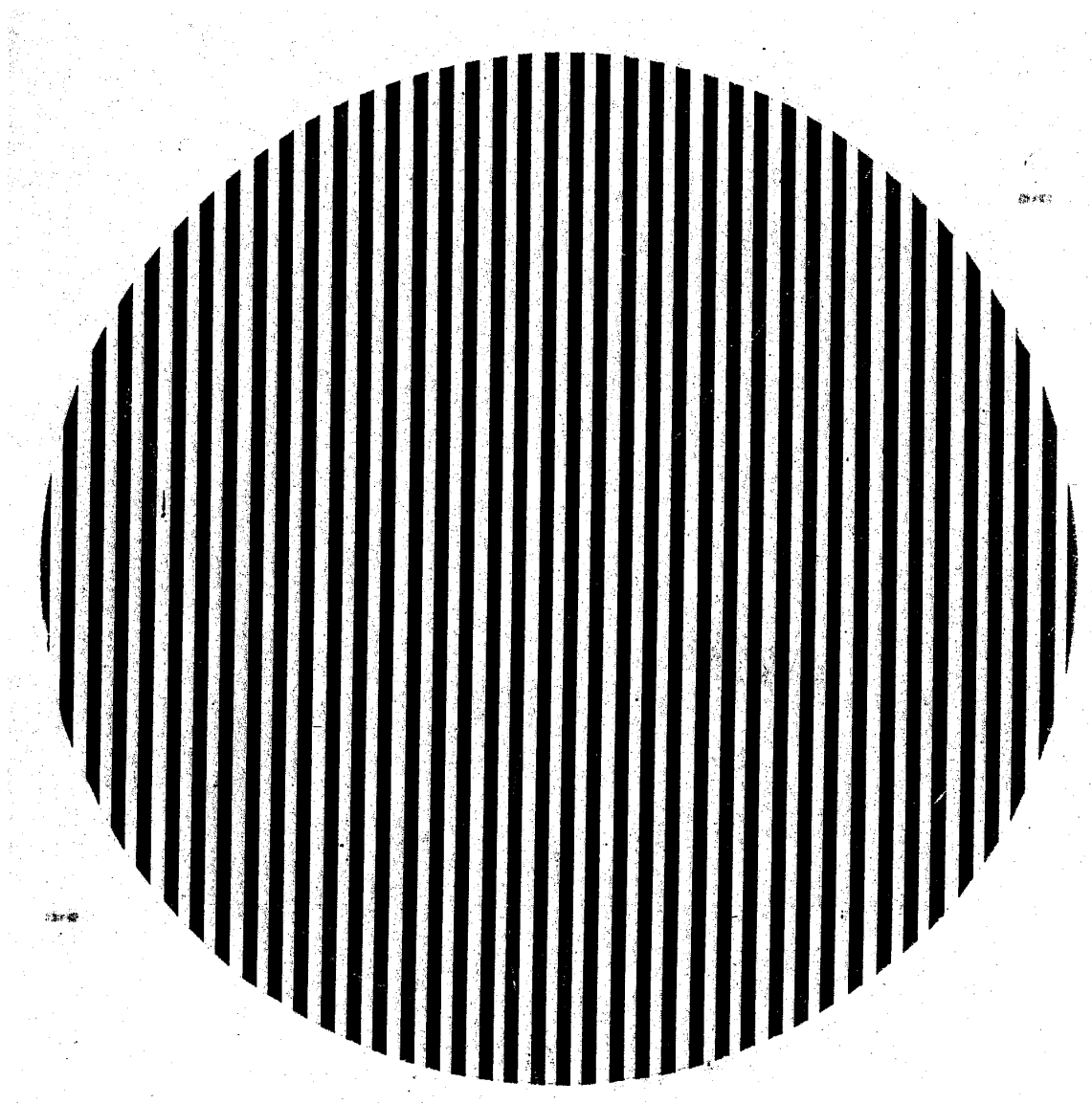
PATTERN SENSITIVITY RATING SCALE

Subject Number: _____   Group:_____

4 c / deg square wave

1)   How perceptually unpleasant was viewing this pattern ?

0	1	2	3
Pattern does not appear distorted at all	Some movement or colour	Lots of distortion	Severe distortion

2)   How physically unpleasant was viewing this pattern ?

0	1	2	3
No problem at all	A little unpleasant e.g. tired/strained eyes	Moderately unpleasant	So bad I can't look at it

3)   What are the major patterns that you see? If pattern please draw it.

4)   What are the major physical symptoms you experience ?

Nonword / Exception Word Test

Nonwords	Exception words
molsmit	besiege
brigbert	meringue
wheeg	ennui
ruddet	brooch
noppel	orchid
lindify	brusque
apertuate	facetious
deprotenation	paediatrician
mafreatsun	stochastic
venstor	acreage
duncren	matinee
kepstud	inertia
pedbim	euology
skelven	cologne
klepse	tsetse
tholingful	pterodactyl
taidness	echidnas
plines	euchre
thobbford	crustaceans
grocktinous	coelacanths
nazz	heir
snidge	gaoled
lission	colonel
beveral	acacias
inhobited	etiquette

/ 25   / 25

time taken: _____   time taken _____

New Non words
kipthirm
twamket
stansert
hinshink
bobiludded
develode
gralidet
borgubide
waplatore

/9   time taken:

Correct pronunciation is required for a correct response

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Appendix B:

Expression of Consent

Research Information Sheet

Expression of Consent

Chief investigators:
- Ms. Gry Lilleskaret (PhD candidate)   Phone: 55528756
- Dr. Elizabeth Conlon (supervisor)   Phone: 55528981

Project Title: Visual processing and reading: The impact of perceptual load and visual attention on global motion and form processing in adult skilled and poor readers.

I understand that by participating in the research I consent to:
- Provide information regarding my reading history and undergo screening for visual discomfort and migraine.
- Undertake a number of reading, cognitive and visual tasks (described in more detail in the information sheet, which I have read, and obtained a copy of).

By signing below I confirm that I have read and understood the information package and in particular that:
- I understand that my initial involvement in this research will include the completion of a number of reading, cognitive and visual measures, and that testing will be conducted over a 1-2 hour period.
- I understand that each of the four sets of tasks (described in more detail in the information sheet) will be conducted as separate studies, and that I may or may not participate in all of them.
- I have had any questions answered to my satisfaction.
- I understand there will be no direct benefit to me from my participation in this research.
- I understand that my participation in this research is voluntary.
- I understand that if I have any additional questions I can contact the research team
- I understand that I am free to withdraw at any time, without comment or penalty.
- I understand that I can contact the Manager, Research Ethics, at Griffith University Human Research Ethics Committee on 3875 5585 (or research-ethics@griffith.edu.au) if I have any concerns about the ethical conduct of the project, and
- I agree to participate in the project.

Signatures:

…………………………………………. ………………………
Participant Name and Signature   Date

…………………………………………. ………………………..
Investigator Name and Signature   Date

Information sheet

Chief investigators

Ms. Gry Lilleskaret (PhD candidate)   Phone: 55528756
Dr. Elizabeth Conlon (supervisor)   Phone: 55528981

Project Title: Visual processing and reading: The impact of perceptual load and visual attention on global motion and form processing in adult skilled and poor readers.

Background

This study is about the way individuals with different reading skills process visual information about movement and form (pattern). This research forms part of the postgraduate degree Doctor of Philosophy In Clinical Psychology conducted by Ms. Gry Lilleskaret. The aim of the study is to investigate the relationship between different types of reading skills and sensory sensitivity to visual processing of movement and pattern. This relationship will be further investigated by manipulating the attentional and perceptual components of the visual tasks, and this will help enhance our understanding of the neurological processes underlying dyslexia.

What participation in this study involves

In your initial involvement in this study you will be asked to complete a number of different reading and visual processing tasks that will take between 1 and 2 hours to complete. Four sets of tasks will be conducted as separate studies, and you may or may not participate in all of these studies. All testing will be conducted in the Neuropsychology Laboratory at Griffith University on the Gold Coast. The tasks that will be administered to you are as follows:

A. Reading measures

To obtain a measure of your reading skills you will be asked to:
1. Answer some questions concerning your reading history.
2. Look at a visual pattern and report what you see.
3. Answer some questions regarding whether you experience migraine or visual discomfort.
4. Read a number of single words.
5. Pronounce words that are not real words. These are called non-words.
6. Read words that are not spelt the way they sound. These are called exception words.
7. Write down a number of words that are read out loud to you.

If you suffer from visual discomfort or migraine you will not be able to participate in the study. This is because individuals suffering from these conditions have been found to process visual information differently to the general population. Moreover, the viewing of the visual tasks might cause discomfort for migraine or visual discomfort sufferers.

B. Cognitive measures
To obtain a measure of your cognitive abilities you will be asked to:
1. Give the meaning of some words.
2. Put some patterns together using a series of blocks.

C. Visual measures
To obtain a measure of your sensitivity to motion and form stimuli you might be asked to perform various motion and form tasks. Each of these tasks will be conducted as separate studies, and you may or may not participate in all of them. All tasks will be presented to you on a computer screen, and you will be asked to attend to displays of moving dots and displays of stationary lines. For each tasks there will be some practice where the task is explained to you. Each task will consist of two blocks of trials, and the requirements of the tasks will vary somewhat.

1. In the first task you will be presented with displays of moving dots. Your task will be to determine the direction of motion in the display. The number of dots moving coherently in one direction will vary, and sometimes it will be easy to detect the direction of motion while other times it will be hard. This task will show us how sensitive your visual system is to sensory movement.

2. In the second task you will also be presented with displays of moving dots, and again your task will be to determine the direction of motion in the display. Furthermore, in this study you will also be presented with a parallel form task. The only difference between the form task and the motion task is that you will be asked to view displays of stationary lines that form patterns instead of viewing moving dots. Your tasks will be to determine the location of the patterns in the display. Both these tasks will show us how sensitive your visual system is to sensory movement and sensory form.

3. In the third task you will also be presented with displays of moving dots, but in this task the dots will be moving in two directions at the same time. One direction of motion will always be horizontal (i.e., left or right), while the other direction will always be vertical (i.e., up or down). Your task will be to detect the two directions of motion presented in the display (e.g., left and up). This task will show us how sensitive your visual system is to movement when the task is harder.

4. In the fourth task you will be presented with a visual cue telling you to attend to a particular direction of motion (i.e., vertical or horizontal). Based on the direction specified in the cue you will be asked to determine the direction of motion in a subsequent display of moving dots (e.g., if cue states vertical you have to determine if the direction of motion in the subsequent display is up or down). You will then be presented with a second display of moving dots where you will be asked to determine whether the direction of motion is up, down, left or right. In this study you will also be presented with a parallel form task. The only difference between this task and the motion task is that you will be asked to view displays of stationary lines that form patterns instead of viewing moving dots. These tasks will show us how sensitive your visual system is to sensory movement and sensory form when attentional components of the tasks are manipulated.

Benefits

The results of the research will significantly contribute to the current theoretical understanding of the neurological processes underlying dyslexia. No direct benefits to participants are expected.

Risk

Participation in this research poses no risks. The types of measures administered have been used in previous research and no difficulties have been found with any procedure.

Confidentiality

All the data obtained will be confidential and no one will have access to your results. While your name or initials will be used to identify you in different tasks these data will be kept in a locked filing cabinet. After you have completed testing you will be assigned a number on all data files so your data will be anonymous. At the end of the study, we will publish the results of the experiment outside the Neuropsychology Laboratory.

Consent to participate

Participation in this project is completely voluntary and refusal to participate will involve no penalty or loss of benefits that you might be otherwise entitled. You will only be used in this study if you have given written informed consent. If you wish to withdraw from the study at any time, you may do so without providing an explanation.

You may contact Dr. Liz Conlon if you have any matter of concern regarding the research that you wish to discuss, or if you prefer an independent person you may contact:

the Manager, Research Ethics, Office for Research, Bray Centre, Nathan Campus, Griffith University.
Telephone; (07) 3875 5585
Email; research-ethics@griffith.edu.au

Griffith University thanks you for your consent and participation in this research project.