WORKING MEMORY: A COMPARISON BETWEEN DYSLEXIC AND NON-DYSLEXIC CHILDREN.

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A research project submitted in partial fulfilment of the requirements for the degree of MA by coursework and Research Report in the field of Psychology in the Faculty of Humanities, University of the Witwatersrand, Johannesburg, June 2009.

DECLARATION

I hereby declare that this research report is my own, unaided work, and has not been presented for any other degree at any other academic institution, or published in any form.

It is submitted in partial fulfilment of the requirement for the degree of Masters of Arts in Research Psychology by Coursework and Research Report at the University of the Witwatersrand, Johannesburg.

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ABSTRACT

Among the variety of deficits that have been related to Dyslexia, impaired working memory has also been implicated as one of the factors that contribute to the deficits associated with Dyslexia. Due to emotional difficulties experienced by children with dyslexia and the trend for these children to behaviourally act out in an attempt to mask their learning problems, there is a need to identify those individuals with dyslexia at an early age before low self esteem, emotional distress as a result of inability to keep up with peers and physical distress can occur as a consequence of late intervention (Fawcett, 2006). In South Africa there has not been as much focus given to Dyslexia and how impairments in working memory contribute to the disability as there has been elsewhere. The present study was designed in an attempt to address the relationship between working memory and Dyslexia and identify aspects that may aid in identifying children with the disability at a younger age. Furthermore, the study endeavours to provide insight as to how individuals with Dyslexia could benefit from intervention at the memory level as part of their remedial programme. Consequently, a sample of eight dyslexic children and eight non-dyslexic matched controls completed the Automated Working Memory Assessment (AWMA) and the Dyslexia Screening Test – Junior (DST-J). The data gathered from these assessments were utilised to investigate two hypotheses. The first hypothesis considered that dyslexic children would present with verbal short-term memory and verbal working memory difficulties when compared to matched controls. An independent samples t-test was conducted to detect group differences between the two groups. The results indicated that the Non-word recall subtest and Verbal short-term memory collective scores for the dyslexic group were significantly poorer when compared to the control group. Furthermore only the Counting recall subtest of the verbal working memory measures was impaired in the dyslexic group compared to the controls. Correlational analysis between the AWMA Verbal scales and the DST-J revealed that the control group presented with considerably more significant relationships than the dyslexic group. Furthermore, no relationships identified in the dyslexic group overlapped with the control group. This was indicative of different memory constructs being utilised in dyslexic and non-dyslexic individuals. Qualitative analysis of the reports of the AWMA and the DST-J was consistent with the quantitative results and further revealed that in terms of the performance on the DST-J, the present South African sample presented with weak literacy and phonological skill indicative of difficulties predominantly in the phonological domain. The second hypothesis considered the difficulties and differences in the visuospatial short-term memory and working memory domains of dyslexic and non-dyslexic children. Results revealed that Visuospatial short term memory and working memory, was affected on a greater number of subscales than the Verbal domain. The scores for the Visuospatial short term memory subscales, Dot Matrix and Block recall were significantly poorer for the dyslexic cohort compared to the controls. With regard to the Visuospatial working memory subscales, only the Odd One Out task presented with marked differences between the groups with the dyslexic group presenting with lower scores. For both the Visuospatial short term memory and working memory composite scores the dyslexic group performed significantly worse than the control group. As with the Verbal scales, correlational analysis of the Visuospatial scales revealed a higher ratio of significant relationships for the control group compared to the dyslexic group with no overlap between the groups. Overall, the results of the study seem to suggest that dyslexic individuals do have short-term memory and working memory difficulties compared to their non-dyslexic peers, and further that dyslexic individuals utilise different memory constructs in their short-term memory and working memory processing within both the verbal and visuospatial domains. These findings have far reaching implications for early diagnosis and intervention.

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CHAPTER 1

LITERATURE REVIEW

1.1 INTRODUCTION

There has been extensive enquiry into dyslexia as a reading disorder, what the underlying impairments might be and whether there are any specific means by which these individuals could be identified and diagnosed at an earlier age. However, theoretical perspectives are not in short supply, ranging from behavioural, biological to cognitive premises as explanations for the reading disorder (Frith, 1999, 2006; Morton & Frith, 1995). From a cognitive perspective, working memory has been implicated as one of the contributing factors that are associated with dyslexia (Baddeley, 1986; Goswami, 1999; Helland, 2006; Jorm 1983; Nicolson & Fawcett, 1995; Palmer, 2000) and will be the focus of this study.

The present study aimed to investigate the possible differences in working memory of dyslexic children compared to their non-dyslexic peers. The choice of investigating working memory draws from the spectrum of theoretical views regarding dyslexia as well as considering the South African context of the current study. Working memory measures bypass reading or writing tasks, which is a major distress for children with dyslexia. The opportunity to utilise working memory measures for early identification before children start the process of learning to read and write, would provide great possibilities for remediation and intervention for these individuals.

Dyslexia has been a reading disorder surrounded by controversy that rises every few years. There has recently again been some debate concerning dyslexia as a reading disability and whether the condition actually exists. This issue will be discussed first and thereafter, in order to logically investigate the vast amount of information relating to both dyslexia and working memory, an overview of the diverse explanations provided for dyslexia will be explored utilising the three level framework proposed by Morton and Frith (1993, 1995). The working memory model to be employed will be considered thereafter, from where the focus will be drawn to a detailed view of the research investigating the relationship between dyslexia and working memory.

Consequently, this research investigated the working memory differences in a South African sample of Grade 1-3 children diagnosed with Dyslexia matched to non-dyslexic controls. Utilising the Automated Working Memory Assessment (AWMA) (Alloway, Gathercole & Pickering, 2004) and the Dyslexia Screening Test for Juniors (DST-J) (Fawcett & Nicolson, 2004), the study aims to contribute to the early identification of children with dyslexia through improved understanding of the role that working memory plays in dyslexia within the South African context. The following section therefore provides an overview of the theoretical and empirical findings of both fields of research.

1.2 Dyslexia

1.2.1 The Dyslexia Debate

The debate regarding the existence of dyslexia has resulted in some heated deliberations. Shortly after the Channel 4 *Dispatches* programme *The Dyslexia Myth* in the UK on December 8th 2005(a), controversy regarding the existence of dyslexia surfaced. Elliott, who took part in the programme, suggested that dyslexia does not exist. According to Nicolson (2005), Elliott did clarify that he does not suggest dyslexic children are ‘faking it’ but rather that the difficulties they experience are so wide-ranging that the term dyslexia is not helpful. It appears from his article in The Psychologist, in response to Nicolson, that Elliott’s view is that the term dyslexia as a diagnostic label is meaningless due to the wide range of difficulties experienced by dyslexic individuals. Elliot (2005b) believes that there is little value and no reason to split poor readers into two groups – dyslexics and poor readers - at the present time, or as he stated “dyslexic sheep and ordinary poor-reading goats” (p729).

Nicolson (2005) pointed out that some of the major flaws in the argument for dyslexia being a myth is that the experts in the programme stated that the defining characteristic of dyslexia is the phonological deficit, yet then following up by saying that the phonological interventions are not working, which poses the question of whether the key is phonology or not. The phonological deficit theory is a well known and well documented theory that has not been disproved so far. This broaches the topic of theoretical perspectives, diagnosis and intervention.

However, as Snowling (2005) called attention to, there are very often co-morbidities and behaviours in dyslexic children that are not explained by the phonological theory and are poorly understood. To address Elliott's concern regarding the wide-ranging difficulties of dyslexia, Snowling (2005) directed awareness to the three level theoretical framework by Morton and Frith (1993, 1995) which separates the biological, cognitive and behavioural levels of explanation, while acknowledging the environmental contributing factors present at all levels. There are wide-ranging difficulties and there are certainly many co-morbidities, it is difficult to gather everything under the term dyslexia and does not always "help theory nor practice" (Snowling, 2005, p. 730). One of the arguments raised by Elliott (2005b) is that there is not a specific teaching approach that appears more suitable to dyslexic children than for poor readers in general. Nicolson (2005) deftly addresses this by stating that although both poor readers and dyslexics may benefit from similar interventions, it should not be confused with aetiology. The example Nicolson (2005) uses explains this quite well "Asprin relieves the symptoms of headache and backache, but they're not the same affliction" (p. 659). Nonetheless, with the growing body of evidence and research into biological, genetic, cognitive, and behavioural explanations, the construct of dyslexia will in time surely be refined with the perseverance of experts in the field.

The debate as it stands at the moment seems to be concerned with definition, diagnostic symptomatology, and treatment. All of which are important and constantly being investigated refined and revised. To suggest that dyslexia is a myth as a result of difficulties with definition, diagnosis and treatment is problematic, especially with substantial evidence suggesting that dyslexia is a very real disability with biological, cognitive and behavioural difficulties.

The field of dyslexic research incorporates a number of different research perspectives that evolved in an attempt to understand the underlying causes or deficits of the disability. These range from how the disorder presents itself to what the best treatment may be. The theories and hypotheses dealing with the disability individually all hold valid explanations for the underlying difficulties experienced and most have the research to substantiate their conclusions. However, individually these theories may appear to conflict and contradict each other at times. Morton and Frith (1993, 1995) proposed the 'three level framework' which involves the description of reading disability on three levels, at the biological, behavioural and cognitive level and aims to create a neutral framework to compare different theories of developmental disorders (Frith, 1999). For purposes of discussing the vast amount of literature and theoretical notions with regard to dyslexia, the three level framework will be applied to the discussion once issues relating to definition, comorbidity and subtyping has been covered.

1.2.2 A Definition of Dyslexia

A problematic area with regard to dyslexia is the difficulty in defining the disorder. The current definition of dyslexia involves primarily exclusionary criteria, demanding a discrepancy between the general cognitive ability or intelligence (IQ) of the individual and their reading ability. Consequently, the standing definition of a reading disorder (dyslexia) given by the DSM-IV-TR (2000) used for diagnostic purposes, is stated as follows:

"oral reading is characterised by distortions, substitutions, or omissions; both oral and silent reading are characterised by slowness and errors in comprehension" (p. 51-52).

Although the working definition used by the DSM-IV-TR (2000) was employed in this study, other definitions should be mentioned as they provide a more in-depth understanding of what dyslexia is, rather than stating what it is not. It seems that it has been well established that dyslexia is a confined deficit affecting a specific area of the cognitive-linguistic system that involves aspects of phonological processing (Boada & Pennington, 2006; Palmer, 2000; Snowling, 1995).

Høien and Lundberg (1991, as cited in Lundberg, 1999) proposed a definition of dyslexia which states that dyslexia is a disturbance in specific linguistic functions of critical importance in the encoding of written language according to the alphabetic principle. This disturbance is usually expressed as difficulty achieving automatised word recognition during the process of reading. It is evidently manifested in the individuals' spelling even though an acceptable level of reading may be reached, and it often runs in families, suggesting the involvement of a genetic predisposition. The definition put forward by the International Dyslexia Society in 2002 can be summarised as dyslexia being neurological in origin, a disturbance in the decoding of words in written language reflecting a deficit in the processing ability in the phonological system of spoken language, with difficulty in accurate and fluent word recognition, poor spelling, and reading comprehension.

Lastly, the British Dyslexia Association (BDA) provided an updated definition in 2007 which defines dyslexia as a specific learning difficulty. According to their definition, difficulties are present from birth with persistence throughout the lifespan and affect the development of literacy and language skills. Difficulties are further experienced with a variety of tasks that incorporate the assessment of phonological processing, speed of processing, rapid naming, working memory, and automatic skill development which does not measure up to other skills associated with cognitive development. The dyslexic child finds it difficult to adapt to main stream teaching methods, however the difficulties experienced can be reduced by utilising suitable interventions specifically designed for the individual in combination with counselling and equipment such as computers and software programmes that evolved from the field of information technology.

An important consideration that should be acknowledged with regard to the definition of dyslexia, which is not specified in a general definition or that of the DSM-IV-TR, is the comorbidity issues and the different subtypes of dyslexia. Two major distinctions can be made with regard to dyslexia subtypes, the first is acquired dyslexia which results from some known type of brain damage, and the second is developmental dyslexia where there is no identifiable indication of brain damage but rather difficulty in the initial learning of reading and generally spelling and writing as well (Rayner & Pollatsek, 1989). Both of these two dyslexia subgroups have different subtypes of dyslexia. Acquired dyslexia will be discussed first before moving to an examination of developmental dyslexia.

1.2.3 Comorbidity issues and Subtypes of Dyslexia

Comorbidity

Comorbidity is common in developmental disorders. Official studies on the comorbidity of dyslexia with other disorders are few. One of the most recent studies is that of Pauc (2005), who conducted a prospective study to examine the comorbidity incidence of a range of disorders. The disorders that were investigated included dyslexia, dyspraxia, attention deficit hyperactivity disorder (ADHD), obsessive compulsive disorder (OCD) and Tourette's syndrome. It was found that these disorders tend to appear in patterns of comorbidity, with ADD present in 62% of the dyslexic group and 38% presented with ADHD. The comorbidity rate for OCD was approximately 17% and 8% for Tourette's syndrome. These findings suggest that some of the difficulties experiences by dyslexic individuals may be related to other disorders that affect performance, such as brain abnormalities which affect a variety of systems involved in attention, processing, comprehension and storage. However, the specifics of these problems that relate to comorbidity and how to address them is a question that deserves further study.

Acquired Dyslexia

In most cases of acquired dyslexia, the severity of the injury and rough location of injury is known (Rayner & Pollatsek, 1989). According to Rains (2002), the different subtypes of acquired dyslexia can be clustered into two major categories, visual word form dyslexias and central dyslexias. The visual word form dyselxias constitute three main syndromes (visual dyslexia or neglect dyslexia, attentional dyslexia, and spelling dyslexia or word-form dyslexia) and the central dyslexias three additional syndromes that follow from the visual word-form dyslexias with an additional processing deficit (surface dyslexia, deep dyslexia – also known as phonemic dyslexia, and phonological dyslexia) (Rains, 2002; Rayner & Pollatsek, 1989).

The first of the visual word-form dyslexias, *visual dyslexia*, is characterised by the individual misreading letters of words. They then substitute the letters they misread with different letters in order to produce an incorrect, but real word (Marshall & Newcombe, 1973;

Newcombe & Marshall, 1981; Rains, 2002). *Attentional dyslexia* was first identified by Shallice and Warrington (1977) and appears to be a very rare condition. Characteristics of this form of dyslexia include visual segmentation errors distinguished by an inability to read words and letters when presented with other written material, while the ability to read words or letters in isolation is intact. In *word-form dyslexia* the ability to recognise words as a complete visual unit is dysfunctional, as a result each word is read letter by letter either aloud or subvocally before the word is identified. The reading speed for these individuals is markedly slow and very dependent on the length of each word (Patterson & Kay, 1982)

Central dyslexias have shared symptoms with the visual word form dyslexias, but tend to have a processing component that is impaired as well. *Surface dyslexics* tend to rely on reading utilising the phonological route, they are able to sound out a word but not recognise words as wholes. They are able to pronounce words correctly but have difficulty with the semantic representation of words (Patterson, Coltheart, & Marshall, 1985). Regular words are pronounced correctly more often than nonwords (Shallice & Warrington, 1980), with errors in phonic approximations of the given word i.e. island as izland, disease as decease, (Patterson et al., 1985) listen as liston, begin as beggin (Marshall & Newcombe, 1973). This often appears as failed attempts to apply the grapheme-phoneme correspondence rules (Patterson et al., 1985; Marshall & Newcombe, 1973) or the use of inappropriate analogies (Henderson, 1982) where the meaning assigned to a word follows from its pronunciation (Rayner & Pollatsek, 1989). Difficulty is experienced with oral reading of irregularly spelled words where the grapheme-phoneme correspondence is unfamiliar and written words that they cannot read aloud are not understood, however, they are able to read nonwords and regularly spelled words (Nolan, Volpe, & Burton, 1997). In other words, individuals with surface dyslexia appear to follow standard print-to-sound rules of language when reading text, but can only manage to read words that follow direct sound patterns and cannot read words that do not follow letter-to-sound correspondence rules (Rains, 2002).

Deep dyslexia has the central feature of individuals making semantic errors when reading single words aloud (Coltheart, 2000; Coltheart, Patterson, & Marshall, 1980), thus errors such as reading ‘stroll’ as ‘walk’ or ‘kitten’ as ‘cat’ occur. Other errors that co-occur with semantic errors include visual errors, reading ‘cat’ as ‘cot’. A combination of visual and semantic errors may occur, thus reading ‘cat’ as ‘rat’ or visual errors followed by semantic errors, for example reading ‘sympathy’ as ‘orchestra’ (most probably via symphony) and derivational errors such as reading ‘keep’ as ‘kept’ (Rains, 2002). They have an almost complete inability to read nonwords and have great difficulty reading abstract or function words, often substituting the function words such as ‘also’ substituted for ‘by’ (Coltheart et al., 1980; Rains, 2002; Rayner & Pollatsek, 1989).

Phonological dyslexia is characterised by a marked deficit in reading nonwords or pseudowords (Beauvois & Derouesne, 1979; Rains, 2002; Rayner & Pollatsek, 1989). Phonological dyslexics are able to read and understand familiar real words utilising a learned sight vocabulary, hence why this subtype of dyslexia is also known as ‘reading by sight vocabulary’. These individuals have lost the ability to convert graphemes to phonemes or use the letter-to-sound conversion rules, thus they are unable to decode phonetic information (Beauvois & Derouesne, 1979; Funnell, 1983; Plaut, McClelland, Seidenberg & Patterson, 1996; Rains, 2002)

Developmental Dyslexia

Developmental subtypes have evolved from the similarities in symptoms presented in the acquired dyslexia subtypes. Developmental dyslexia has been defined as the inability to learn to read and perform the reading activity sufficiently despite above average intelligence and adequate education (Heim et al., 2008). Subtype classification for developmental dyslexia has generally been characterised as having to divide dyslexics into phonological or surface subtypes (Castles & Coltheart, 1993) mirroring the pattern of symptoms from the acquired dyslexias (e.g. Beauvois & Derousene, 1979; Coltheart et al., 1980) or visual and auditory categories, utilising the Boder’s (1973) subtyping system. The developmental surface dyslexia subtype presents with difficulty accessing the meaning or semantic representations of words, reading irregular words are problematic while nonwords that follow direct letter-to-sound rules can be read. Developmental phonological dyslexics have problems with nonword reading yet have a relatively intact ability to read real words. As such, they rely on sight vocabulary due to difficulties decoding phonological information and the impairment in the capacity to convert graphemes to phonemes (Castles & Coltheart, 1993; Thomson, 1999). Boder (1973) classifies dyslexics into one of three subtypes, dysphonetic, dyseidetic, or mixed. The dysphonetic subtype presents with grapheme-phoneme conversion difficulties, the dyseidetic group with an inability to visually recognise whole words, and the mixed subtype presenting with both grapheme-phoneme conversion and visual recognition difficulties.

Considering that there are different subtypes of dyslexia with specific characteristics associated with them, investigation in terms of the underlying cause of these difficulties has been extensively researched. The three level framework is utilised to aid in the discussion of the theoretical positions with regard to deficits associated with developmental dyslexia.

1.2.4 The Three Level Framework for Dyslexia

Drawing from Høien and Lundberg's (1991, as cited in Lundberg, 1999) and the BDA's (2007) definition, dyslexia is a multi-faceted disability that presents itself at different levels which links very well with Morton and Frith's (1993, 1995) three level framework. The first indications of dyslexia are experienced at the behavioural level when teachers and parents deal with children who have difficulty with reading, writing, rhyming, spelling and/or breaking down words into their constituent sounds and phonemes (Lundberg, 1998). Explanations for the behavioural aspects seen in dyslexia are explored by looking at the brain or biological aspects as well as the cognitive processes that may be dysfunctional or different in these individuals.

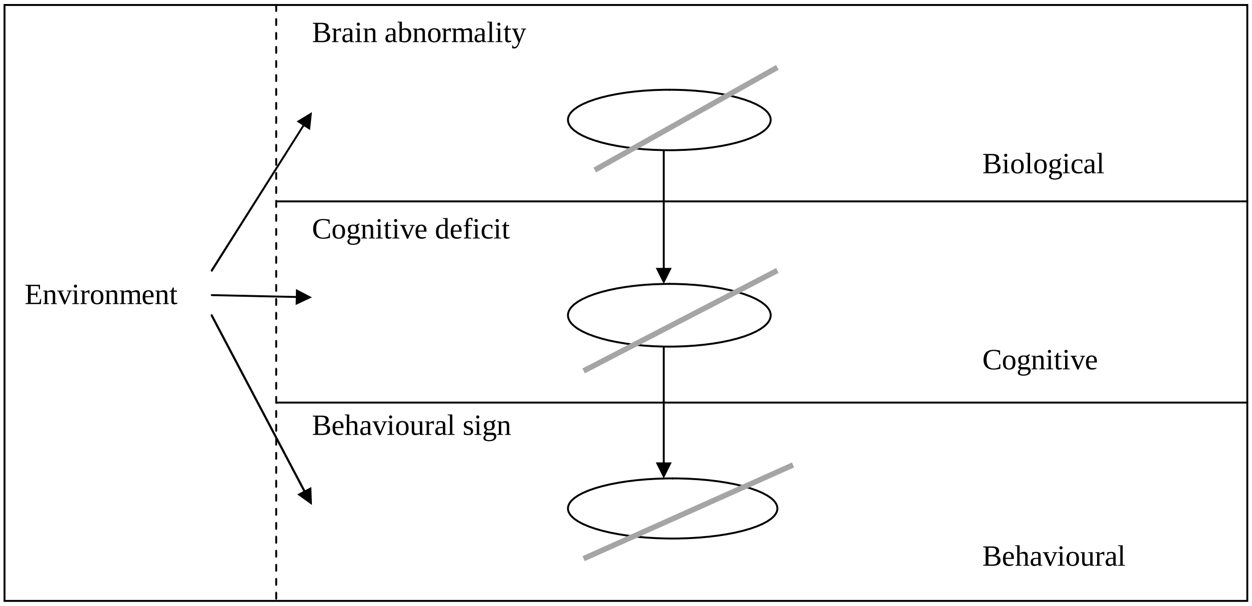

Figure 1: Morton and Frith's Three Level Framework depicting a general causal model of developmental dyslexia adapted from Paradoxes in the Definition of Dyslexia (p. 196), by U. Frith, 1999, *Dyslexia*, *5*, 192 – 214.

In Figure 1 the arrows represent the probable causal links of the weaknesses that are experienced in individuals with dyslexia and the crossed out fields symbolise the assumed dysfunction. What the causal modelling of the framework suggests, is that a singular definition of dyslexia at a specific level is not more desirable than another at a different level. But rather a given dysfunction at any level would have implications across all levels of functioning and subsequently would provide a deeper understanding with regard to comorbidity, definition, diagnosis and intervention related to dyslexia (Frith, 1999, 2006).

Behavioural level

Dyslexia at the behavioural level incorporates a variety of 'symptoms' which dyslexic readers are agreed to have. These include problems in reading and spelling, difficulty learning rhymes and they generally are slower to learn to read and write, often reversing the orientation of letters or omitting letters when writing. They present with impairments in balance and motor development, reading fluency and comprehension, typically exhibiting specific difficulties in decoding and recognising single words. Abnormalities in phonological processing and phonological awareness of written and spoken language are evident (Goswami, 2000; Lundberg, 1999; Nicolson & Fawcett, 1990; Snowling, 1981; Zeffiro & Eden, 2000). The observed behavioural manifestations are generally due to a combination of underlying causes that contribute to the observed symptoms along with environmental factors that impact the behavioural outcome (Frith, 1999, 2006).

Biological level

Investigations into the underlying cause of dyslexia have focussed on a variety of aspects looking at the genetic origin and physiological dysfunction of the dyslexic brain. A brief overview of the core arguments are discussed below, these include the investigations into the structure and cortical development of the brain, genetic susceptibility to the disorder, the magnocellular pathway theory and the cerebellar deficit theory.

Genetics, Cortical development and Brain structure

Various structural differences have been identified predominantly in the left perisylvian cortex in post-mortem analysis when dyslexic and control brains were compared (Brown et al., 2001; Eliez et al., 2000; Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985; Leonard et al., 2001; Rae et al., 1998). The thalamus (Galaburda, Menard, & Rosen, 1994) the cerebellum (Finch, Nicholson, & Fawcett, 2002; Rae et al., 2002) and the corpus callosum (Rumsey et al., 1996) have also been implicated. It is not yet clear whether all structural differences are associated in dyslexia itself or rather form part of the overarching comorbidity found with dyslexia and other learning or reading disorders (McArthur, Hogben, Edwards, Heath & Mengler, 2000). Some of the structural and biological anomalies are discussed in conjunction with the theoretical positions of a biological basis for dyslexia below.

Some of the earliest descriptions of developmental dyslexia indicated that there may be a familial component to the disorder, and it has been largely accepted that dyslexia runs in families. Twin studies have indicated a significantly higher correlation of developmental dyslexia in monozygotic compared to dizygotic twins, with heritability estimates ranging from .45 to .61 in processes that are associated with reading such as word recognition, orthographic coding, phonological decoding and phonological awareness (DeFries, Fulker & La Buda, 1987; Gayan & Olson, 1999). In addition Plomin and DeFries (1998) indicated that if one identical twin (monozygotic) is dyslexic, the probability for the other twin to be dyslexic is 68% whereas for fraternal twins (dizygotic) the risk is 38%. Behavioural genetic analyses such as the above mentioned few fuelled the search for a causative gene by providing irrefutable evidence that developmental dyslexia may be treated as a phenotype (Marino & Molteni, 2006).

Evidence of a major gene with dominance was established through segregation analysis and at least one copy of this alleged allele is carried by 57% of the population (Gilger, Borecki, DeFries & Pennington, 1994). Segregation analysis further revealed that developmental dyslexia has a transmission pattern consistent with the Mendelian pattern of inheritance (Pennington et al., 1991), this simply means that one has a three out of four chance of inheriting the gene if a parent has the homogenous gene for developmental dyslexia. Molecular genetics investigation into chromosome 15 revealed a dyslexia susceptibility gene DYX1C1/EKN1 (Taipale et al., 2003; Wigg et al., 2004). Investigations into the cellular functioning of the DYX1C1 protein indicated that the interruption of this protein expression disrupts normal neuronal migration in the developing cerebral neocortex (LoTurco, Wang & Paramasivam, 2006). Abnormal cell migration known as ectopias and microgyri have been found in the cortex of dyslexic individuals (Galaburda & Kemper, 1979; Galaburda et al., 1985) as well as the thalamus where cortical areas are connected, specifically the lateral geniculate nucleus (Livingstone, Rosen, Drislone & Galaburda, 1991) and the left medial geniculate nucleus (Galaburda et al., 1994). It is thought that these abnormalities are the cause of some of the visual, auditory, attention and phonological deficits (Ramus, 2006) present in dyslexic individuals.

Magnocellular pathway theory

The magnocellular theory suggests that the underlying cause of dyslexia may very likely not be a difficulty that is language specific but could be related to a more general impairment in the magnocellular and parvocellular visual and auditory systems (Hansen, Stein, Orde, Winter &

Talcott, 2001; Stein, 2001; Stein & Talcott, 1999; Stein & Walsh, 1997). Post-mortem studies have provided further biological evidence for the magnocellular theory. Galaburda et al. (1994) found that the magnocellular neurons in the visual nuclei in the thalamus were selectively disarrayed in dyslexic individuals. Their magnocells were also significantly more distorted and smaller than that of non-dyslexic controls. The magnocellular pathway is sensitive to low contrast, rapidly changing, moving stimuli, whereas the parvocellular pathway responds to slow changing information, coloured and detailed stimuli (Everatt, 2006). Most of the focus of magnocellular theory has been with unsteady binocular fixation (Stein, 2001) and reduced motion sensitivity (Hansen et al., 2001) related to the visual system.

According to Stein and Walsh (1997) the magnocellular system plays an important role with the control of eye movements. They suggest that the impaired function of this system in dyslexics may destabilise the binocular fixation of the eyes, resulting in convergence of words during reading. The letters cause visual confusion by appearing to move around on the page (Stein, 2001; Stein & Walsh, 1997). Cornelissen, Bradley, Fowler and Stein (1991) suggested that visual errors in the form of binocular instability, becomes evident when dyslexics attempt to read small letters. They also find it difficult to read if letters are very close to each other (Atkinson, 1993).

Cornelissen et al. (1991) further found that if these individuals were given larger print, the frequency of errors was reduced. Studies on the motion sensitivity of dyslexics have shown that the perception of consistent motion is lower for dyslexics than controls (Cornelissen, Richardson, Mason, Fowler & Stein, 1995; Everatt, Bradshaw & Hibbard, 1999). Eden and colleagues (1996) reported that the ability to perceive coherent motion is lower in dyslexics than controls, providing evidence for the notion that there is a lack of task-related activation of the cortex responsible for motion detection.

Cerebellar deficit hypothesis

The cerebellar deficit hypothesis was first formulated as an automatisation deficit theory which suggests that dyslexic children find it difficult to become automatic in any skill, not exclusively reading (Nicolson, Fawcett, Moss, Nicolson & Reason, 1999; Nicolson, Fawcett & Dean, 2001; Nicolson & Fawcett, 1990). Nicolson et al. (1999, 2001) and Nicolson and Fawcett (1990) suggest that the weakened ability to automatise processes in dyslexic individuals is related to the observed reading disability. These automatised abilities refer to articulatory and auditory skills important for grapheme-phoneme correspondence and the control of eye-movements (Fawcett, Nicolson, & Dean 1996; Nicolson, Daum, Schugens, Fawcett & Scultz, 2002). However, the findings in terms of the automaticity hypothesis have been mixed, with Ramus, Pidgeon and Frith (2003) and Heim et al. (2008) finding no differences on automatisation tasks.

Focussing on balance, it was found that dyslexic children struggle with the balancing task when they are given a second task at the same time to stop them from concentrating on the balancing activity. Also known as the dual task paradigm, the results indicated that dyslexic children could balance as well as controls when presented with the dual task, but tended to be significantly poorer at the balancing task when compared to controls (Nicolson & Fawcett, 1990). In contrast, Stoodley, Fawcett, Nicolson and Stein (2005, 2006) found that dyslexics tended to perform worse than controls, however the dyslexic children significantly differed from controls with balancing tasks, dropping a foot more often than controls (Stoodley et al., 2005) while dyslexic adults did not differ significantly from controls (Stoodley et al., 2006), yet, both studies reported that the low-level motor dysfunction may be associated with literacy development and poorer literacy skills.

The search for an underlying cause that would be able to include the pattern of difficulties experienced by dyslexics, such as balance, speed and phonological skill, linked the automatisation deficit hypothesis to the cerebellum which was brought under scrutiny because of its involvement in speed, learning and motor skill (Fawcett, 2006; Nicolson & Fawcett, 1994). The hypothesis was tested indirectly at first using clinical tests of muscle tone and stability which provided strong evidence for abnormalities in cerebellar functioning (Fawcett et al., 1996).

The cerebellar hypothesis was tested by Nicolson and colleagues (1999) directly utilising a PET study of motor learning tasks, known to activate the cerebellum, and the results showed that adults with dyslexia had reduced activation of the cerebellum (only 10 – 20% of the expected level) providing strong support for the cerebellar deficit hypothesis (Nicolson et al., 1999). It has further been reported that dyslexics present with a variety of dysfunctions such as eye-blink conditioning (Nicolson et al., 2002), motor skill (Fawcett & Nicolson, 1999; Stoodley et al., 2005, 2006), and time estimation (Nicolson, Fawcett & Dean 1995) which are all dependent on cerebellar processing.

Biological evidence supporting the cerebellar deficit hypothesis was discovered in 2002 when Finch et al. (2002) established that the number of large and small cerebellar neurones of dyslexics and controls were significantly different after they re-analysed the brain specimens of dyslexic individuals originally investigated by Galaburda et al. (1994). The cerebellar deficit hypothesis therefore proposes that theoretically there is a causal chain linking impairments of the cerebellum with phonological deficits and difficulties in reading and spelling (Nicolson et al., 2001).

In sum, there is strong biological evidence that pertain to some of the behavioural signs associated with dyslexia. The neurobiological brain abnormalities and structural differences provide insight into the cognitive deficits associated with the disorder.

Cognitive level

As the present study is concerned with the cognitive difficulties experienced by dyslexic children in terms of working memory, a brief overview will be provided here before a more detailed account is discussed in the following sections of this chapter. At the cognitive and biological level, phonological processing and working memory are very interdependent as working memory subserves speech perception and speech production (Singleton, 2006). Both short-term memory and working memory have been found to be significant predictors of reading comprehension (Swanson, 1994) and it is assumed that working memory enables an individual to hold the constituent sounds and phonological codes in short-term store until they can be recognised as a word or sentence and its meaning extracted from long-term memory (Wagner, Torgesen, Laughon, Simmons & Rashotte, 1993). As a result, phonological skills are one of the most extensively researched areas when considering the cognitive domain in dyslexic research (Goswami, 1999; Rack, 1997; Snowling, 2000).

The relationship between phonological deficits, reading and working memory has been well established (Baddeley, 1986; Jorm, 1983). It is argued that phonemic processes such as the alphabetic correspondence between grapheme and phoneme, underpins the development of a recoding strategy in reading that requires working memory involvement (Gathercole & Baddeley, 1993). With regard to dyslexia the deficits in phonological segmentation, rhyming (Nicolson & Fawcett, 1995), the retrieval process within the phonological loop, impaired language comprehension (Helland, 2006), impaired central executive (Reiter, Tucha, & Lange, 2005) and impaired storage within the verbal store (Helland, 2006) all indicate that working memory deficits play an important role in the reading development of dyslexic individuals. However, deficits in visuospatial short-term and working memory function have been associated with difficulties experienced by dyslexic children (Palmer, 2000; Poblano, Valadez-Tepec, de Lourdes Arias & Garcia-Pedroza, 2000; Swanson, 1999). Furthermore, Del-Guidice and colleagues (2000) indicated that although they did not find any differences on spatial cognition tasks, they did identify one child with relevant visuospatial deficits, which provides some evidence for the existence of a visuospatial deficit and visuospatial subtype in developmental dyslexia.

In view of the above overview relating to the cognitive level of the three level framework, working memory deficits are implicated in dyslexia. The following section therefore will discuss the working memory model within which the relationship with dyslexia may be contextualised.

1.3 The structure and Function of Working Memory

Working memory refers to the system in memory that has a limited capacity to store information temporarily and manipulate the stored verbal, visual and spatial information over brief periods of time while performing a variety of cognitive tasks (Baddeley, 1986). Working memory can therefore be thought of as the "moment-to-moment monitoring, processing, and maintenance of information" (Baddeley & Logie, 1999, p 28).

There are two major theoretical perspectives of how working memory functions, the domain-specific account and the domain-general account. Working memory capacity in the domain-specific model is supported by two separate verbal and visuospatial domain-specific resources that independently manipulates and processes verbal and visuospatial information (Miyake, Friedman, Rettinger, Shah & Hegarty, 2001; Shah & Miyake, 1996). Therefore proficiency in verbal working memory tasks would not be predictive of visuospatial abilities, nor would visuospatial ability be indicative of verbal ability (Shah & Miyake, 1996).

However, the multi-component model of working memory is certainly the most prominent account that has been provided, first proposed by Baddeley and Hitch (1974) and further developed by Baddeley (1986, 1990, 2000), which consists of four main components. These components are the central executive, the phonological loop (or verbal store), the visuospatial sketchpad and the episodic buffer. This working memory model supports a domain–general account of working memory. In this account there is a domain-general component responsible for coordinating information of two independent domain-specific storage components. The domain-specific storage components are split into two storage systems, a verbal store and a visuospatial store (Pickering, 2001).

1.3.1 Baddeley's Working Memory Model

The structure of Baddeley's (1986) multi-component working memory model is schematically presented in Figure 2 below and shows the interaction of the components with each other as well as long term memory (LTM).

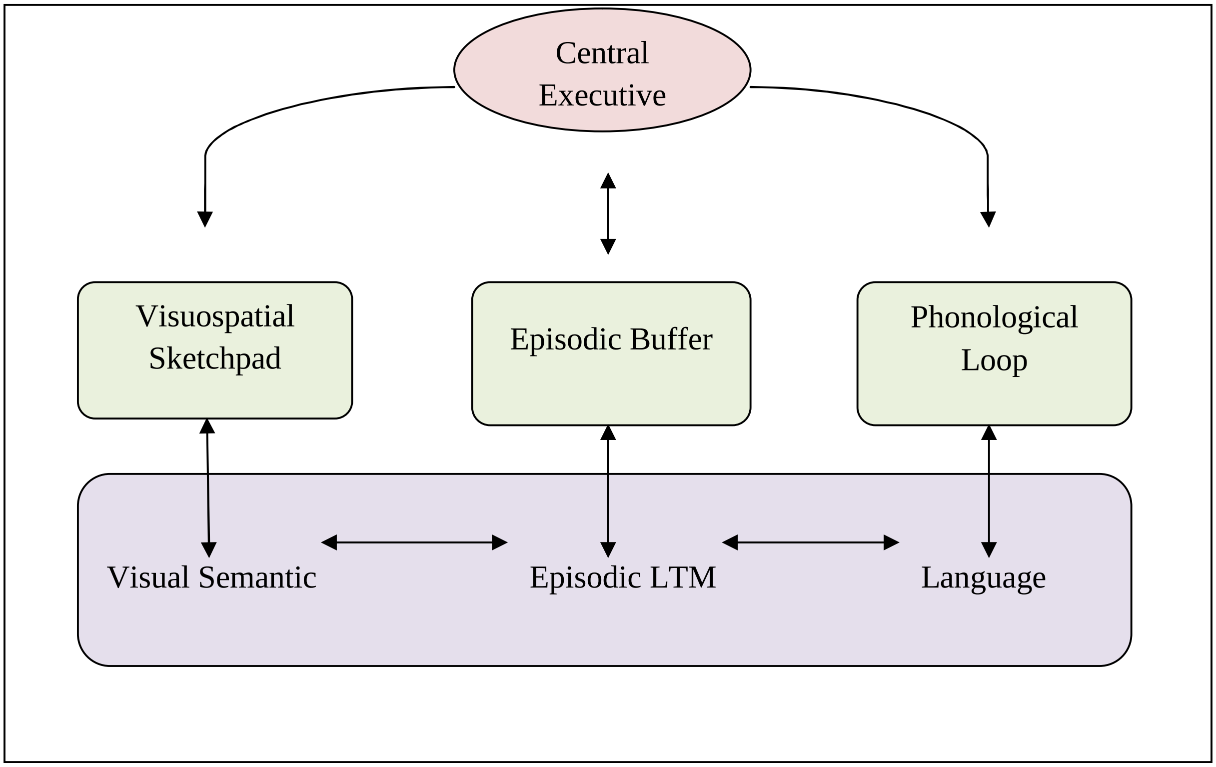

Figure 2: Baddeley's Multi-component model of Working Memory from Working Memory: Looking Back and Looking Forward (p. 836), by A. Baddeley, 2003b, *Neuroscience, 4*, 829-839.

As Figure 2 illustrates, Baddeley's (1986, 2003b) working memory model comprises the central executive, which functions as the limited capacity attentional controller and its two subsystems. The phonological loop processes acoustic and verbal information while the visuospatial sketchpad is responsible for visual and spatial information. Each of the subsystems that make up Baddeley and Hitch's (1974) and Baddeley's (2000, 2003b) working memory model is described below.

The Central Executive

Evidence from patients with frontal lobe lesions (Baddeley, Della Sala, Papagno & Spinnler, 1997; Shallice & Burgess, 1991; and Alzheimer's Disease (Baddeley, Bressi, Della Sala, Logie & Spinnler, 1991) who displayed difficulties with executive control, suggests that anatomically the central executive appears to reside largely but not exclusively within the frontal lobes (Stuss & Knight, 2002). The central executive has most recently been associated with a supervisory attentional subsystem to account for the focussed attentional control of actions (Baddeley, Emslie, Kolodny & Duncan, 1998), the executive capacity to divide attention in dual tasks (Baddeley, Baddeley, Bucks & Wilcock, 2001), and switching attention (Baddeley, Chincotta & Adlam, 2001).

The central executive however is yet to be fully understood; it is believed to be the most important component of the working memory model and can be fractioned into a number of executive sub-processes (Baddeley, 2003b). In its current state, the central executive acts as the domain–general component of working memory and operates as the mechanism that is responsible for controlling cognitive resources, regulating cognitive resources and temporarily activating and retrieving information from long term memory (Baddeley, 1986, 1990, 1996). The central executive is also responsible for the coordination of multiple tasks, regulating attentional control, regulating inhibition, monitoring information processing, updating tasks, shifting between tasks, and shifting between retrieval strategies (Baddeley, 1986; Baddeley, 1996; Baddeley et al., 1998; Miyake, Emerson & Friedman, 2000). These processes have been shown to be associated with a range of complex cognitive abilities such as comprehension of language and reading (Baddeley, 2003a; Daneman & Merikle, 1996; Gathercole & Pickering, 2000).

Two ‘slave systems’, a verbal store – the phonological loop, and a visuospatial store – the visuospatial sketchpad supplement the central executive. These two specialised systems are responsible for the temporary storage and manipulation of information in their respective domain (Baddeley, 1986) with the central executive coordinating the functions of the two subsidiary systems. The main functions of the different subsystems in the working memory model are outlined below.

The Phonological Loop

The phonological loop is at this stage the most developed component of the working memory model (Baddeley, 2000). This verbal storage system is responsible for the short-term storage and manipulation of speech-based information (Baddeley, 1986). The phonological loop comprises two parts, the first is a temporary phonological store and the second an articulatory rehearsal system. The short-term phonological store is a limited capacity system with the ability to maintain speech-based information. The phonological store is subject to rapid decay of information, with memory traces fading within a period of approximately two seconds unless refreshed through sub-vocal rehearsal, which is dependent on the articulatory rehearsal system. This system acts as the inner ear and helps restore the decaying representations and information in the phonological store, furthermore it serves the function of registering and encoding visual information as long as it can be named (Baddeley, 1986, 2003a; Baddeley, Lewis & Vallar, 1984). Therefore, while written words or visual objects must be converted into an articulatory code within the articulatory rehearsal system before it enters the phonological store, auditory information in the form of spoken words have direct access due to acoustic input (Baddeley et al., 1984).

The Visuospatial sketchpad

The visuospatial sketchpad is a limited capacity temporary memory system, typically able to store three to four objects over a short period of time (Baddeley, 2003b). The maintenance and processing of patterned or spatial stimuli and the retaining and manipulation of various images is dealt with by the visuospatial sketchpad. The visuospatial storage system deals with all pictorial representations which include any visuospatial material, such as colour, movement, object shape, letter shape, and word shape (Baddeley, 1986; Baddeley & Hitch, 1974). Logie (1995) recently proposed that the visuospatial sketchpad is fractionated similarly to that of the phonological loop with two distinguishable subcomponents, the visual store component or visual cache and the inner scribe. The visual cache is a passive system responsible for the temporary storage of visual information and their spatial locations representing the physical characteristics of objects and events. The inner scribe temporarily stores spatial information and acts as a rehearsal and retrieval system to reactivate the decaying information in the visual cache, actively maintaining the spatial order of locations and planning movements.

Episodic buffer

Put forward by Baddeley in 2002, the episodic buffer adds a new element to the original model. The buffer is considered to be responsible for the amalgamation and binding of information across the information domains and memory subsystems. The episodic buffer is controlled by the central executive and stores information in a multidimensional code. The episodic buffer forms a temporary interface between the verbal and visuospatial slave systems as well as long term memories that are consciously retrievable. According to Baddeley (2002), the episodic buffer may present an important gateway for learning by providing direct inputs into episodic long term memory.

1.4 WORKING MEMORY DEFICITS AND DYSLEXIA

The process of reading, especially early reading is by no means easy and is often slow and effortful for the beginning reader. The novice reader has to recognise letters in the alphabetic system and associate them with their sounds while blending the sounds to reach an understanding of how sounds are put together to form words. The child therefore is required to form connections between letters and sounds of spoken words, and with spelling decode the information by pulling the sounds of words apart in order to associate the letters with their respective sounds (Hatcher & Snowling, 2006).

Working memory is intrinsically involved in the reading process as the child is required to converge the graphemes (letters) and phonemes (sounds) of a segment of a word while holding the remaining segment in memory (Seidenberg & McClelland, 1989). Learning to read can therefore be seen as the phonological decoding of printed text (Adams, 1990). The complex working memory demand of text and language comprehension becomes an essential component in the task of reading and in order to understand the combination of words and sentences, as well as comprehend the text, words and sentences must be held in memory (Nation, Adams, Bowyer-Crane & Snowling, 1999; Seigneuric, Ehrlich, Oakhill & Yuill, 2000).

Dyslexia is a reading disability and is commonly thought of as a problem with the decoding of written language regardless of average intelligence, normal education and a reasonable socioeconomic status, (Demonet, Taylor & Chaix, 2004; Ramus, 2003; Ramus, Rosen, et al., 2003; Vellutino, Fletcher, Snowling & Scanlon, 2004). One of the most widely accepted views of dyslexia is that it is a language disorder with a specific deficit in phonological and verbal tasks (Ramus, Rosen, et al., 2003; Snowling, 1995). The most consistently reported findings are those of an impaired verbal memory with deficits in phonological awareness that stem from limitations in phonological coding (Hulme & Roodenrys, 1995). It has been reported that children with dyslexia are inclined to have phonological decoding deficits in processing written as well as spoken words. They struggle to pronounce nonwords and have difficulty identifying the 'odd' word in a series three or four spoken words such as *cat mat* *tap* *bat* (Hatcher & Snowling, 2006; Rack, Snowling & Olson, 1992). The dyslexic child also has difficulty with retrieval of phonological information, they frequently take longer to retrieve the verbal codes from long-term memory (McDougall & Donohoe, 2002; Wagner et al., 1993), and struggle with vocabulary acquisition (Gathercole & Baddeley, 1990; Gathercole, Willis & Baddeley, 1991). Considering the difficulty in coding and decoding of written language (or reading), working memory seems to play a crucial role. Several studies investigating differences between skilled readers and less skilled readers with the use of cognitive measures, have found that there are deficits in the working memory domains of the less skilled readers (De Jong, 1998; Passolunghi & Siegel, 2004; Swanson, 2003; Swanson, Howard, & Saez, 2006).

Investigating the specificity of working memory deficits of 10-year-old reading disabled children matched to two control groups on reading age and chronological age respectively and utilising a variety of working memory measures, De Jong (1998) identified that deficits in working memory capacity were evident in the reading disabled group and appeared to be generalised over various academic domains. This was revealed by children performing worse in complex span tasks associated with both language and numerical domains when compared to normal reading peers. Additionally, the findings revealed that the deficits observed within the working memory system of children with a reading disability, could not be explained due to deficits in processing or verbal memory span, but seem to suggest that there is a general inability to concomitantly process and store verbal information. Swanson and colleagues (2006) found that there are different working memory components that underlie difficulties experienced in different subgroups of reading disabled children. Skilled readers outperformed less skilled readers, children with comprehension difficulties outperformed children with reading disabilities and those with reading disabilities outperformed children who were poor readers in different areas of working memory, short-term memory, executive processing, phonological processing, processing speed and updating tasks. However, with all group comparisons, working memory appeared to underlie the disparity in reading performance. It was further suggested that the differences in working memory of the less skilled readers were restrained by a storage system and executive processing that was not specifically related to phonological skills or reading. Unfortunately measures of working memory appertaining to the visuospatial domain were not included in either of the above studies.

As stated earlier, a considerable body of evidence indicates that dyslexic individuals have various short-term and working memory problems (Brunswick, McCrory, Price, Frith & Frith, 1999; Griffiths & Snowling, 2002; McDougall & Donohoe, 2002; Pennington, Cardoso-Martins, Green & Lefly, 2001; Plaza, Cohen & Chevrie-Muller, 2002; Roodenrys & Stokes, 2001; Stanovich, Siegel & Gottardo, 1997), with impaired working memory being a principal feature of dyslexia (McLoughlin, Fitzgibbon & Young, 1994). The 'passive' short-term memory store of dyslexic individuals has been investigated extensively with the use of simple verbal memory span tasks revealing deficits in the phonological loop's storage capacity (Palmer, 2000; Smith-Spark, Fisk, Fawcett & Nicolson, 2003; Helland & Asbjornsen, 2004). Smith-Spark and colleagues (2003) provided evidence that impairments are apparent in dyslexics on short-term verbal memory tasks and letter updating tasks which tap problems that surround phonological loop and serial order memory. Furthermore, impairments in the articulatory rehearsal system within the phonological loop was identified in two out of three subgroups of dyslexic children, this was a result of a lack of the recency effect in a backward recall task and a serial recall task when the working memory task demands increased. These deficits are thought to present behaviourally as the misreading and misspelling of the last section of long words or numbers, or as difficulties in sequencing letters and digits together with difficulties reading and writing word endings (Helland & Asbjornsen, 2004).

Some of the most difficult memory tasks for dyslexic children are reported to be word repetition, digit repetition and sentence repetition tasks (in order of first to third most difficult task), all requiring immediate verbal memory. Word repetition presented with difficulty retrieving phonological codes and encoding the full phonological representations and planning the articulatory movements that coincide with the phonological sequence. Digit repetition required the storage function of working memory, while sentence repetition required the ability to maintain items, order information and plan articulation (Plaza et al., 2002). An explanation for the variation in the difficulty of and performance on these tasks, appears to be related to accessing phonological representations within the long-term memory store, which can be used to support memory span performance and acquisition of new vocabulary (McDougall & Donohoe, 2002). Familiar words and digits in the digit repetition and sentence repetition tasks (Plaza et al., 2002) are familiar to items stored in long term memory while the unfamiliar words in the word repetition task however do not have the familiar item representation in long-term memory. This differentiation in retrieval of information from long-term memory is thought to provide a good measure of the operation of the articulatory loop of working memory (Hulme, Maugham & Brown, 1991).

The exact source of the short-term and working memory problems is however still unclear, thus whether the deficits identified are purely verbal working memory in nature or a deficit in phonological processing remains questionable. Some further controversy arose posing the question whether the working memory deficits observed were a result of phonetic processes or working memory processes, leading to the argument over how much group variance could be attributed to impairments in phonological processes or memory processes (Gathercole, 1994; Gathercole, Willis, Emslie & Baddeley, 1991; Snowling, Chiat & Hulme, 1991).

Many reading disabilities are evidenced to have a deficient phonological processing ability as an underlying deficit (Gottardo, Stanovich & Siegel, 1996; Siegel, 1993; Snowling, 2000; Wagner et al., 1997). It is therefore not surprising that the phonological deficit has been connected to verbal short term memory impairment (Baddeley, 1986) as well as working memory impairment in children with reading disability (Swanson, 1994). Less skilled readers have been shown to be impaired in a variety of phonological awareness tasks (Gathercole &

Baddeley, 1993; Wagner et al., 1997) and that a deficit in phonological processing as well as phonological short term memory contributes to reading impairment and reading ability (Goswami & Bryant, 1990; Vellutino et al., 2004, Swanson, 2003; Swanson & Howell, 2001). Moreover, a number of deficits in working memory have been linked to deficits in phonics, the ability to recognise words (Siegel & Ryan, 1989) and difficulty in understanding written text (Swanson, 1999, 2004; Siegel & Ryan, 1989).

Investigating the contribution of working memory in comprehension, Seigneuric et al., (2000) established that when vocabulary and decoding were controlled for, verbal and numerical working memory tasks revealed unique variance in reading comprehension of normal readers, tapping working memory resources specialised for language processing. Considering then that working memory tasks are significant predictors of and contribute to reading comprehension, the deficits in working memory would result in poorer comprehension. Nation and colleagues (1999) suggested that the memory skills of children with poor reading comprehension were not related to poor generalised processing capacity or verbal short-term recall, but rather to those memory tasks that placed stress on semantic processing skills. Nation et al's. findings however, may be attributable to the specific poor reader participants. These children did not have a specific reading disability, however were 1 year below the expected level for their age in terms of their reading comprehension. Nevertheless, children with reading disabilities do present with working memory deficits related to poor processing capacity (Gottardo et al., 1996) as well as deficits in verbal short term memory (Snowling 2000), however the processing deficit in the reading disabled are due to a phonological processing deficit independent of general cognitive deficits (Gottardo et al., 1996; Siegel, 1993).

With regard to phonological processes, evidence indicates that slow articulation rate could explain the memory span differences observed between dyslexic individuals and controls (Avons & Hanna, 1995; Hulme, Roodenrys, Brown & Mercer, 1995; McDougall & Donohoe, 2002; Roodenrys & Stokes, 2001). However, impairments in encoding, learning or using phonological representations have been implicated as possible explanations for the memory span differences in phonological processing as well (Carroll & Snowling, 2004; Kramer, Knee & Delis, 2000; Tijms, 2004). In contrast to simple span tasks that require the passive storage of information in short term memory, working memory span tasks necessitate that information held in memory be concurrently stored and processed. For the successful performance of the dynamic processing demands of these tasks, the individual draws on resources from the central executive and the associated slave systems (Baddeley, 1986; Smith-Spark & Fisk, 2007).

When controlling for simple span tasks, it is possible to establish whether the deficits in working memory are due to demands of maintenance or processing of information in dyslexic individuals (Smith-Spark & Fisk, 2007). Considering some of the different span tasks that have been developed such as the computation span task (Salthouse & Babcock, 1991), reading span task (Daneman & Carpenter, 1980), and spatial span task (Shah & Miyake, 1996), the literature indicates that working memory span tasks require the use of a factor independent of tasks related to simple span performance (Conway, Kane & Engle, 2003). Baddeley (1986) in his working memory model argues that the modality free central executive controls the two slave systems responsible for the storage and processing of visuospatial and verbal information from the sensory modalities. The phonological loop holds and processes language–based verbal information while the visuospatial sketchpad stores and maintains visual and spatial information.

It is therefore argued that the role of the central executive may be an essential component to the process of reading. It has been argued that working memory functioning can be assessed very well with reading or sentence span tasks (Swanson, Mink & Bocian, 1999). These tasks require the phonological loop to process the phonological information and also involve the central executive for strategy selection in reading (Baddeley, 1990). Similarly, measures of computation and reading span seem to utilise the same limited capacity working memory system. Computation span tasks provide evidence that working memory resources such as the phonological loop and the central executive is drawn on and involved in various components of mental maths (de Rammelaere, Stuyven & Vandierendonck, 2001; Logie, Gilhholy & Wynn, 1994). Consequently, if performance in the phonological domain on simple and complex tasks is compared, the source of the deficits could possibly be determined by establishing whether the deficits in dyslexia are due to a working memory system problem in general or restricted to the phonological domain (Daneman & Mirikle, 1996). Recent research has provided support for the working memory processing deficit in dyslexia, implicating a central executive impairment in these individuals (Jeffries & Everatt, 2004; Swanson, 1999; Swanson & Saschse-Lee, 2001; Smith-Spark, Fawcett, Nicolson & Fisk, 2004) which would imply poorer performance of dyslexics on verbal and visuospatial working memory tasks.

To investigate the contribution of the phonological loop and central executive to verbal memory impairment evident in dyslexia, Smith-Spark and colleagues (2003) administered three phonological working memory tasks consisting of simple short-term memory digit and word span tasks as well as a letter updating task thought to be involved in the central executive component. The successful completion of the tasks required the participants to recall the six most recent items from a list of 6, 8, 10 and 12 consonants. If more than six items were present in a list participants had to drop the least recent items in the list and update their string of items in memory with the newer items in the list. Thereafter they were prompted to try to remember the last six items in the same order that it was initially presented. The task therefore required the articulatory rehearsal function of the phonological loop. Smith-Spark et al. (2003) uncovered deficits in verbal working memory that were consistent with previous research (Jorm, 1983) in dyslexic individuals on both digit and word span tasks. The dyslexic group in the Smith-Spark et al. study, performed significantly worse on the letter updating task, but was unaffected by the list length which did not provide much evidence that the central executive is involved but rather that the articulatory control process failed due to poor performance at the early serial positions that were compromised by an impaired phonological loop (Smith-Spark et al., 2003). The findings therefore provide evidence for a phonological impairment and less so for deficient executive functioning.

Morris and Jones (1990) using a similar task, found that the updating task was independent of memory load and that these updating tasks tend to be similar to the working memory demands found in day to day life where various pieces of information need to be managed in working memory compared to simple serial recall of one string of information. Considering that dyslexic children in a classroom environment need to cope with a variety of tasks in the learning environment, updating information is very important. Compiled with deficits in verbal memory, the lag that may appear is rather evident (Alloway & Gathercole 2006).

It is very difficult to separate phonological memory from phonological processing (Snowling, 1991) and phonological deficits on their own do not provide sufficient clarification for literacy difficulties experienced by dyslexics (Snowling, 2008). Hence, to address dyslexia deficits further and determine whether it is restricted by an impaired phonological loop it is necessary to consider performance on visuospatial tasks. The visuospatial domain was investigated by Velluntino (1979) who concluded that dyslexics were unimpaired in visuospatial tasks. As a result, investigations into this modality by dyslexia researchers have been largely ignored.

In an attempt to try and separate the phonological deficits from central executive deficits in dyslexia, researchers have shifted attention again to the visuospatial domain for some clarification. In recent research conducted by Winner, French, Seliger, Ross and Weber (2001), young dyslexic adults performed worse than non-dyslexic controls on several visuospatial tasks. Winner et al. (2001) posited that it may be reasonable to assume that the visuospatial tasks used on previous occasions may not have been challenging enough to reduce significant differences. Rose, Feldman, Jankowski and Futerweit (1999) found that cross-modal performance, the ability to match and integrate auditory and visual information, was worse in poor readers and they generally had difficulty with perceiving temporal patterns (the sequencing, grouping and pauses within a pattern of stimuli). The findings further indicated that the impairment identified was due to the task demand on working memory and not a universal visuospatial processing deficit which suggest central executive involvement (Rose et al., 1999).

It has been argued that the separable visual cache and the inner scribe could be sensitive to the passive and dynamic features of a visuospatial stimulus within the visuospatial subsystem of working memory (Logie & Pearson, 1997; Pickering, 2001; Pickering, Gathercole, Hall & Lloyd, 2001). Passive memory tasks require the short-term storage of information presented at the same time within visuospatial working memory, secondly the dynamic tasks involve the individual to recall the location and order of the stimulus presented serial order (Pickering, 2001; Pickering et al., 2001). The updating of new information in working memory requires both the storage and concurrent processing of information which entail central executive capacity (Morris & Jones, 1990).

Smith-Spark et al. (2003) did not find differences in the performance between dyslexic and non-dyslexic participants on simple visual and spatial span tasks; they did however find a central executive deficit in spatial updating for dyslexic individuals. Within the visuospatial domain, recent research has had mixed findings. A variety of spatial working memory tasks have not revealed any significant differences between dyslexic and controls (Jeffries & Everatt, 2003, 2004; Kibby, Marks, Morgan & Long, 2004). Furthermore, there may be reason to suggest that dyslexic individuals have an advantage in visuospatial processing as a consequence of their disability (Von Karolyi, Winner, Gray & Sherman, 2003). For example, Von Karolyi and colleagues (2003) discovered that dyslexic children were considerably faster in their ability to identify that a figure was impossible compared to their non-dyslexic counterparts. Deficits in visuospatial short-term and working memory function in dyslexic children has been identified in terms of difficulty with visual encoding (Palmer, 2000) abnormal processing of visual movement (Del-Guidice et al., 2000), and puzzle assembly (Poblano et al., 2000). The nature of the tasks that assess visuospatial short-term and working memory differed across all studies. The differences observed in these studies could therefore be attributed to task related issues.

On the other side of the continuum, there is evidence that deficits do exist in the visuospatial domain of dyslexic children and adults. For example, Olson and Datta (2002) reported that there are impairments on visuospatial memory tasks that require short-term storage of visual information and visual processing of information for complex patterns, while Helland and Asbjornsen, (2003) and Winner et al. (2001) reported visuospatial sketchpad impairments on the Rey-Osterreith Test. Smith-Spark and Fisk (2007) recently found that performance on both phonological and visuospatial modalities in dyslexic individuals were impaired as well as central executive functioning in addition to the storage problems in the two subsystems of working memory. The degree of the reported deficits may not be as vast and broad as the phonological working memory deficits, but it does provide grounds for further investigation into this domain. Some feel that Dyslexia is mainly a phonologically based deficit (Stanovich, 1988; Velluntino, 1979), while others argue for a domain-general deficit of impairments in executive processing skill (Swanson, 1993, 1999; Swanson & Sachse-Lee, 2001). The evidence provided however, certainly argues for a wider view of dyslexia that encompass verbal, visuospatial as well as central executive deficits (Nicolson & Fawcett, 1990; Nicolson et al., 1995; Wolf & Bowers, 1999; Smith-Spark & Fisk, 2007).

1.5 Rational for the present study

The literature presented above illustrates that dyslexia has a variety of associated working memory problems outside of the various neurological and genetic differences. In South Africa we are confronted with a lack of research in the dyslexia domain and currently the debate as in other parts of the world rages on whether dyslexia actually exists. The major concern however revolves around those children and parents who face the difficult road of reading disability and coping in the classroom environment. The emotional effects of dyslexia are important to consider as much as the deficits associated with the disorder. Although the teacher is there to teach and facilitate learning, consideration of the pupils' emotional state should not be disregarded. Dyslexic children entering the school system are often only identified once they start struggling with reading, writing and spelling in the classroom. It is therefore imperative to try and find a way to identify those children who are likely to have a problem before they start the process of learning and subsequently failing to read, write and spell. Many dyslexic children experience emotional trauma, low self esteem, and tendencies to resort to disruptive behaviour and clowning in order to mask their learning problems (Fawcett, 2006). The early screening of dyslexia and working memory ability for the identification of potential problems would certainly aid in the provision of early intervention not only on an educational level for the child but emotionally as well.

Focussing then on the relationship between deficits in working memory and dyslexia, the present study aimed to establish whether it would be possible to use a working memory assessment as a screening tool for working memory impairments in the South African population. In addition, using a screening tool for Dyslexia utilised in the United Kingdom to establish whether children are 'at-risk' for dyslexia, the present research evaluate its effectiveness in the South African context. The study more specifically aimed to establish whether there is a relationship between working memory and dyslexia. The study examined this relationship with the use of a computerised working memory measure; the Automated Working Memory Assessment (AWMA) in order to evaluate differences between dyslexic and non-dyslexic children's working memory ability.

CHAPTER 2

METHOD

The method of the present study is discussed below. The aim and hypotheses are presented first, starting with the design, sample, instruments, procedure, ethical considerations, threats to validity, and data analysis.

2.1 AIM AND HYPOTHESES

The purpose of the present study was to investigate differences in working memory between children with dyslexia and a matched group without dyslexia.

Two specific hypotheses were generated to investigate the relationship between working memory and dyslexia:

1) Dyslexic children will show significant differences in their verbal short-term and verbal working memory when compared to non-dyslexic children.
2) There will be significant differences between dyslexic and non-dyslexic children in their visuospatial short-term and visuospatial working memory.

2.2 RESEARCH DESIGN

Due to the fact that an existing variable was used to define the groups, no random assignment was employed and direct causal relationships could not be investigated as a product of manipulation of the independent variable. For this reason the study utilised a correlational quasi-experimental design as there was no manipulation of the independent variable. Instead, working memory ability was assessed and compared in two groups. The present study considered the relationship between two variables, the independent variable dyslexia (dyslexic/non-dyslexic) and the dependent variable working memory (working memory scores of the two groups).

2.3 SAMPLE

The sample was a non-probability, convenience sample and consisted of 8 children attending a private remedial school or facility (dyslexia group), and 8 children from a mainstream private school (non-dyslexic group). The choice of using participants at a private school or facility was motivated for the following reasons: firstly, difficulty with accessibility, since there are few government remedial schools and secondly, to source children from a similar socio-economic group. A sample selected from this group would optimise the probability of obtaining a cohort receiving the same standard of education.

The parents and children were invited to participate in the research. A written informed consent form (see Appendix A) was obtained from parents after written and verbal explanation, in the form of an explanatory statement, of the purpose and requirements of the study was provided (see Appendix B). Written assent was obtained from the participating children after verbally explaining the requirements and reason for the assessment (see Appendix C).

2.3.1 EXPERIMENTAL GROUP

The size of the experimental group was very small due to the difficulty in finding diagnosed dyslexic children in the specific age group (6 – 9 years). Consequently the experimental group consisted of only 8 children with diagnosed dyslexia. The children were diagnosed through psychological and educational evaluations at the remedial facility or through a private psychologist. These children were between the ages of 72 and 113 months (M =95.87, SD =7.07) and received remedial education at a private remedial school or facility in the Johannesburg area. One child had co-morbid ADD and Petit Mal Epilepsy, and a second co-morbid ADHD. Both children were receiving treatment and were on medication for these conditions.

2.3.2 CONTROL GROUP

The control group comprised 8 children, matched to the experimental group in terms of age, gender, education level and home language. These children had no officially diagnosed learning, speech, language or auditory difficulties. All participants in the control group received main stream schooling at a private school in the Johannesburg area. In an attempt to match participants on the same socio-economic level, participants were sourced as far as possible from the same or similar geographic location as the experimental group.

2.3.3 AGE OF PARTICIPANTS

Participants were matched as far as possible on age. The means and standard deviations as well as age range of participants in the two groups are presented in the table below.

Table 1:

Mean age of participant in months, standard deviations, age range and language distribution for all groups.

	Age range in months	*Mean*	*Standard deviation*	*P-value*	*Afrikaans*	*English*
Dyslexic	87 – 106	95.87	7.07		4 (50 %)	4 (50 %)
Non-dyslexic	87 – 113	97.12	7.79	0.742	1 (87.5 %)	7 (12.5 %)

Afrikaans participants were bilingual, they either attended an English school or attended English classes as a subject if at an Afrikaans school. They were able to understand, write and speak English.

2.3.4 DISTRIBUTION OF HOME LANGUAGE

Although every effort was made to match the two groups on home language, it was not entirely possible. There was as a result uneven distribution of home language in the two groups.

The Afrikaans children had sufficient proficiency in English to have the test administered in English. For one child (due to anxiety levels) the test was administered in English and if the child was unsure of what was required, the instructions were repeated in Afrikaans. Table 1 shows the distribution of home language for both groups.

2.3.5 Distribution of Gender in sample

There was an uneven distribution of sexes in the overall sample, the sample comprised more female than male participants, which is atypical as the prevalence of dyslexia has been shown to be approximately a 2:1 male to female ratio (Miles, Haslum & Wheeler 1998). However, the present sample ratio was probably a result of the small sample size, with a male to female ratio of 1:2. The nature of the matching paradigm meant that the sexes between groups would be the same.

2.3.6 Ethnicity of participants of all groups

All participants in the groups were Caucasian.

2.3.7 Education level of participants

The level of education ranged between Grade 1 and Grade 3, and dyslexic and non-dyslexic subjects were matched on this variable.

2.4 Instruments

2.4.1 Biographical Questionnaire

The biographical questionnaire (see Appendix D) was constructed by the researcher in order to obtain relevant background information, as well as whether the child has had any previous educational and psychological assessments. The information was needed to ascertain how the dyslexic children were diagnosed and whether the non-dyslexic children had any other learning or reading difficulties that may influence the results of the assessments. The information was also used in the matching of the dyslexic children to non-dyslexic children.

2.4.2 Working memory assessment

The Automated Working Memory Assessment (AWMA) is fully computerised and assesses working memory skills utilising a computer software programme. The administration of the assessment takes approximately 60 to 80 minutes and is suitable to assess children who are aged between 4 and 11 years (Alloway, Gathercole, & Pickering, 2004) and consists of 12 subtests. The AWMA assesses short-term as well as working memory. Short-term memory refers to the ability to store information for brief periods of time, while working memory refers to the capacity to hold and manipulate information in the mind for short periods of time. The short-term and working memory tests are separated into two sets, those of the verbal and visuospatial type, allowing for four aspects of memory to be assessed with three measures each. The AWMA was standardised in England and has not been used extensively in South Africa, however, given the nature of the tasks it was not anticipated that there would be any foreseeable problems with the use of this measure on school children in the private sector.

The AWMA consists of the following subsections:

Verbal Short-term Memory. To assess verbal short-term memory, three measures were administered. These included the digit recall, word recall and nonword recall tasks. In the <u>digit recall</u> task a sequence of spoken digits are presented to the child, beginning with 1 number and increasing to a maximum of 9 numbers. The child is instructed to remember each sequence of digits in the correct order. For example a 4 digit sequence of **'9138'** must be recalled as "9138" for the sequence to be given a correct score.

In the <u>word recall</u> task a series of spoken words are presented to the child, beginning with 1 word and increasing to a maximum series of 7 words. The child has to recall each sequence of spoken words as they were presented in the correct order. For example a 3 word sequence such as **'lot palm tell'** must be recalled as **"lot palm tell"** for the child to receive a correct score.

In the nonword recall task the child is provided with a sequence of spoken nonwords (nonsense words) beginning with 1 nonword and increasing to a maximum of 6 nonwords. The child has to correctly recall the serial order of each sequence of nonwords. For example a 3 word sequence of **'leet mip dort'** must be recalled as **"leet mip dort"** for the child to receive a correct score. Test-retest reliability for UK children aged 4.5 to 11.5 years is .85 for digit recall, .76 for word recall, and .64 for the nonword recall tasks (Alloway et al., 2004).

Visuospatial Short-term Memory. Three measures to assess the visuospatial short-term memory component were administered; the dot matrix, mazes memory and block recall tasks. In the dot matrix task a 4x 4 matrix is presented on the screen, the child is shown the position of a red dot in one of the squares. The child has to recollect the position(s) of each dot by touching the correct square on the computer screen. For example if the position of the dot was in square 7 and 15, the child must touch square 7 and 15 in the same order when prompted to recall the dot's position for a correct score to be given. The trials started with 1 dot being presented moving up to a sequence of 9 dots. Every dot is presented in its position on the computer screen for 2 seconds. The order of each sequence was random and none of the positions of the dots were repeated more than once within each trial.

In the mazes memory task a maze with a red pathway is shown to the child. The path which represents the way out remains there for 3 seconds, the child is then asked to trace with their finger the same path they were shown when provided with a blank maze on the computer screen. The task begins with small mazes and increases to larger mazes. A correct score is given if the child is able to trace the route on the blank maze exactly as it was in the test maze.

In the block recall task the child is shown a tray of blocks that are being touched (tapped) in a specific order. The child is asked to repeat the exact series that were tapped in the correct order by touching the computer screen on an image of the blocks. The trials start with 1 block moving up to a sequence of 9 blocks. Therefore if blocks 1, 6 and 4 were touched (tapped) the child must reproduce the sequence on the image by touching (tapping) blocks 1, 6 and 4 in that same order. Each block was touched (tapped) at a rate of one block per second.

Test-retest reliability for UK children aged 4.5 to 11.5 years is .83 for the dot matrix task, .81 for the mazes memory task, and .83 for the block recall task (Alloway et al., 2004) with British children.

Verbal Working Memory. Three measures were administered, these included the listening recall, counting recall and backward digit recall tasks. In the listening recall task a series of spoken sentences are presented to the child, who then has to state whether each sentence is 'true' or 'false'. At the end of each trial the child is asked to recall what the last word of each sentence was in the order that it was presented. For example if two sentences are presented **'Chairs lay eggs'** and **'Bananas have teeth'** the child should respond 'false' to each sentence in this instance and then after the sequence recall the words **'"eggs"** and **"teeth"** in that order. The trials starts with only one sentence and increases to 6 sentences with a correct score given for the 'true' or 'false' response (a precision score) and for the words recalled in the correct order.

In the counting recall task a visual display of red circles and blue triangles are presented on the computer screen. The child is asked to count the number of circles out loud while tapping each circle as it is being counted. The child is then required to recollect the total number of circles for each display of circles and triangles that were presented. Therefore if two sets of circles and triangles were shown, the first with 4 circles and the second with 7 circles, the child needs to recall '4 and 7' in that order for a correct response. The task begins with 1 set of circles and triangles and increases to 7 sets. Each visual display is kept on the screen until the child indicates that they finished counting the circles.

In the backward digit recall task a series of spoken digits are presented to the child, who then has to remember the digits in the reverse order. The task begins with two numbers and increases to 7 numbers. For a sequence of 4 digits **'6, 1, 7, 3'** the recall should be **"3, 7, 1, 6"**, a correct score will only be given if the digits were recalled in the correct backwards order.

Test-retest reliability for UK children aged 4.5 to 11.5 years for the respective tasks are .81 for listening recall, .79 for counting recall, and .64 for backward digit recall (Alloway et al., 2004).

Visuospatial Working Memory. Three measures for visuospatial working memory were administered; these included the odd one out, Mr X and spatial span tasks. In the odd one out task the child views a row of three boxes each containing a shape. The child is required to point to the shape that is the 'odd-one-out'. At the end of every trial, the child is asked to recall the correct order and point to the correct location in the boxes on the screen of where the odd shape was located. For example if the odd-one-out shape was in box 1 in the first set and box 2 in the next set, the child will point to box 1 and then 2 when the blank boxes appear. The task begins with 1 set of shapes and increases to 7 sets of shapes. A correct score is awarded for identifying each odd shape and correctly recalling the position of each odd shape in sequence.

In the Mr X task the child views a picture of two Mister X figures holding a red ball, one with a blue hat and the other with a yellow hat. The child is asked to identify if the Mister X with the blue hat is holding the ball in the same or different hand as the Mister X with the yellow hat. The Mister X with the blue hat is rotated to present the ball on one of 8 locations. After each trial the child is asked to remember the location of each ball in the correct order by pointing to the position of the ball on a picture showing 8 compass points. The task begins with 1 set of Mr X's and increases to 7 sets of Mr X's. A correct score is given for correctly identifying whether the ball is held in the same or different hand and for the correct recollection if the position of the ball in sequence.

In the spatial span task a picture of two shapes is shown to the child on the computer screen. The shape on the right is displayed with a red dot above it. The child's task is to correctly identify whether the shape with the red dot is the same or different to the shape without the red dot. The shape with the red dot is rotated to display the red dot in 1 of 3 locations. At the end of each trial the location of each red dot must be recalled in the correct order by pointing to the position of the dot on a picture showing three compass points. A correct score is given for correctly identifying whether the shape with the red dot is the same or different to the shape on the left and for the correct recollection if the position of the red dot in sequence.

Test-retest reliability is .81 for the odd one out task, .77 for the Mr X task, and .82 for the spatial span task for UK children aged 4.5 to 11.5 years (Alloway et al., 2004).

2.4.3 Dyslexia Screening Assessment

The Dyslexia Screening Test – Junior (DST-J) is designed to screen for and identify children who may be at risk of developing dyslexia. The administration of the test takes approximately 30 to 40 minutes and is suitable for children aged between 6.6 and 11.5 years (Fawcett & Nicolson, 2004). The DST-J consists of 12 subtests each tapping into various aspects of dyslexia. The DST-J is not a diagnostic tool and was used in this study as a control to mainly screen for children in the control group who may present with reading difficulties that may influence results and to have a measure of the degree of dyslexia present in the dyslexic group.

The DST-J has not been used extensively in the South African population and there is no published literature on its use in South Africa. Therefore it was used as an experimental measure in the present study. The DST-J shows very good reliability and validity with British children, with test–retest reliability for the various clusters of subtests ranging between satisfactory (0.7 and above) for bead threading, postural stability and semantic fluency, good to very good (0.8, to 0.88) for verbal fluency, backwards digit span, rapid naming, and phonemic segmentation, and excellent for tests of attainment (reading, spelling, nonsense passage reading and writing) which was above 0.9 (0.91 - 0.99).

The DST-J consists of the following subtests:

Rapid Naming. In the rapid naming test the child is given an A4 sized card and asked to name a series of line drawings under timed conditions. The aim of this task is to measure how long the child takes to name all the pictures. There is evidence that suggests dyslexic children on average tend to take longer naming familiar pictures when compared with non-dyslexic children (Denckla & Rudel, 1976; Wolf & Bowers, 1999).

Bead threading. The bead threading task requires the child to thread as many beads as he or she can in 30 seconds. It involves fine motor skill and assesses hand-eye co-ordination and manipulative skill. Dyslexic children often have a mild degree of clumsiness or motor skill deficits (Fawcett & Nicolson, 1995).

One minute reading. In the one minute reading task developed by Fawcett and Nicolson (2004) to measure the speed as well as the accuracy of reading, the child is asked to read a passage under timed conditions. This demands that the child produce a speeded as well as accurate performance which is difficult and problematic even for successful dyslexic individuals.

Postural Stability. This test has been specifically developed to provide an accurate index of balance ability following the discovery in dyslexic children of abnormalities in the cerebellum, shown to be closely involved in motor skill, balance, and eye movement control

(Nicolson et al., 1995). The child's balance is assessed by giving a controlled push to the back while blindfolded.

Phonemic Segmentation and Rhyme. Phonemic segmentation assesses the ability of the child to segment words into their basic sounds and manipulating those sounds. The rhyming test assesses phonological ability. Dyslexic children have been shown to have difficulties with phonological coding and with the ability to detect rhymes (Gathercole et al., 1991; Goswami, 1999)

Two minute spelling. The two minute spelling test involves speed of writing as well as accuracy of the spelling. The child is asked to spell a certain amount of words within two minutes. Dyslexic children often struggle with speed of writing and their spelling, which is often worse than their reading (Fawcett & Nicolson, 2004).

Backwards digit span. A series of spoken digits are presented to the child. The child is then asked to repeat the sequence in backward order. Forward digit span tasks seem to be a task that dyslexic individuals struggle with normally, backward digit span has been shown to be even more sensitive to dyslexia (Miles, 1983, as cited in Fawcett & Nicolson, 2004).

Nonsense passage reading. In the nonsense passage reading task the child is asked to read a passage out loud that has nonsense word mixed into the sentences of real words. Dyslexic individuals often have difficulty reading words that they are not familiar with even though they may score within average standards on other tests of reading. Problems reading nonsense words indicate that there may be difficulties in orthographic analysis skills (Fawcett & Nicolson, 2004; Gathercole et al., 1991).

One minute writing. The child is asked to copy a passage (length is age dependant) as neatly and accurately as possible in one minute. Dyslexic children tend to write slowly and have difficulty completing their work in time. The test therefore examines the speed and accuracy of copying a short passage without having to give too much thought to spelling to give an accurate estimate of speed of writing (Fawcett & Nicolson, 2004).

Verbal fluency. This test assesses the verbal fluency of the child, he or she is required to think of as many words in a minute that start with the letter S. the implications for dyslexic children is that there is evidence that suggest that dyslexic children perform poorly on verbal fluency but well on semantic fluency (Frith, Landerl & Frith, 1995).

Semantic fluency. This test is similar to that of verbal fluency, but instead of thinking about letters, they think of words. The child is asked to think of as many animals as they can in a minute. Dyslexic children tend to perform much better on the semantic task than the verbal task (Fawcett & Nicolson, 2004).

Vocabulary. The vocabulary test was designed to assess receptive vocabulary in a multi choice format, with some words included to check reasoning ability. The child is given three pages with rows (1 to 16) of four pictures each. There are 16 words to match with the correct picture. The child is given the word and has to circle the correct picture (Fawcett & Nicolson, 2004).

2.5 PROCEDURE

Once clearance was obtained from the Human Research Ethics Committee of the university (Non-Medical, Protocol Number: H070612) (see Appendix E) as well as the Graduate School, Faculty of Humanities, participants were contacted and times were arranged with the schools, remedial facilities or parents.

Testing for the control group took place at a mainstream private school in the Johannesburg area, and testing of the dyslexic participants (experimental group) took place in a quiet room either at the private remedial school, the remedial facility or in cases where the parent felt that the child would be more comfortable at home. Letters were sent out to the parents of the children informing them of the study and inquiring whether they would be willing to have their children participate or alternatively (given the circumstances) they were contacted directly by the researcher after the teacher had spoken with the parents about the study and they had given their permission to be contacted. An envelope with the consent form (Appendix A), subject information sheet (Appendix B) and biographical questionnaire (Appendix D) was sent or given to those parents who indicated that they would like to have their children participate in the study. The parents were asked to complete the biographical questionnaire and consent form and return it to the researcher.

Each child was assessed individually in a quiet area of the school, remedial facility or home environment in two sessions lasting up to 120 minutes in total. Before commencing with the assessments the child was given an explanation of what the testing was about and asked to complete an assent form by writing their name on the form (see Appendix C). It was stressed that they may stop the assessment at any time if they would like to have a break or did not understand what was required of them. The DST-J was administered first following the standardised instructions for both the practice trials and the main test in the predetermined order of subtest 1 to 12. The child's responses were recorded and scored on the scoring sheets that accompanied the DST-J. Administration took approximately 30 to 40 minutes after which a short break was given before commencing with the AWMA assessment.

A laptop computer with a screen resolution set at 800 x 600 pixels was used to present all tests of the AWMA. Instructions were automated and were followed by practice trials. Scoring of the AWMA was fully automated and the testing sequence pre-set. The researcher recorded the child's responses using the left and right arrow keys on the keyboard. The right arrow key (→) recorded a correct response and the left arrow key (←) an incorrect response; the scores were automatically recorded and calculated by the program. Administration took approximately 60 to 80 minutes.

2.6 Ethical considerations

In keeping with appropriate research ethics, the following steps were taken to ensure that the participants in the present study were not recruited under duress or caused any harm. Permission from the participating schools and remedial facilities was obtained before contacting and inviting the parents and children to participate through a teacher or remedial therapist. The headmaster/headmistress sent out a letter to all parents with a reply slip to indicate their interest to participate in the research. A subject information sheet, consent form and biographical questionnaire were sent to the parents who were interested. As the children were minors, the parents provided voluntary informed consent on behalf of their children to participate in the study. Although parents provided consent, the children were individually asked if they were willing to participate and it was verbally explained that they were under no obligation to take part in the assessments, if the children agreed they were asked to write their name on the assent form indicating their willingness to continue. It was made clear to the children that they may stop at any time if they did not want to continue with the assessment or if they changed their mind about taking part in the study.

It was made known to the parents that participation in this study was completely voluntary and that they were under no obligation to have their children participate. If they chose to allow their children to participate or decline to participate in this research project, their relationship with the school or remedial facility would not be affected. In the event that a memory related problem or deficit was observed during the assessments, the child and the parents would be referred to the school psychologist for further assessment.

Furthermore, no findings that could identify any individual participant would be published or made known to anyone. Only the combined results of all participants would be reported. The raw data collected will be stored for 5 years in a secure place and will contain no personal information as per University regulations. Electronic data would be kept on a password protected computer should other researchers wish to verify the findings (as per HPCSA regulations). Only the researcher involved in this study will have access to the data and know the identities of participants.

2.7 Threats to validity and data analysis

The final sample of the study was very small in nature which is likely to affect statistical validity with regard to the types of analyses that could be carried out. Due to the fact that a convenient, non-random sampling method was utilised in a group of individuals from a certain socio-economic status, external validity was possibly negatively affected. The ‘privileged’ small sample able to afford a high level of education and/or remedial help for their children, may not accurately reflect the nature and context of the general school-aged child in their foundation years of education. Thus, the results may not be generalisable to other groups.

Once data collection was completed, it was necessary to assess the distributions of the data and whether the data was suitable for parametric analysis or not. Assessment of normality was done using histograms (see Appendix F), measures of central tendency and Shapiro-Wilk Tests of Normality. In all analyses equality of variance checks were carried out.

To identify whether the ages of participants in the two groups differed significantly between the two groups, an independent samples t-test was utilised. Pearson’s Chi square was used to consider ratio of home language dispersion. The Dyslexia quotient obtained for the DST-J was subjected to an independent samples t-test to check whether true differences between groups were analysed using both a parametric and non-parametric equivalent. An independent samples t-test comprised the parametric analysis and the Wilcoxin Rank-Sum test the non-parametric analysis. It has been noted however that a disadvantage of non-parametric tests are that they may have lower power in comparison to the parametric equivalent, potentially leading to more Type II Errors (Howell, 2002), thus effect sizes should also be calculated.

To facilitate further understanding of the quantitative data, content analysis of the reports generated for the assessments were carried out. The purpose was to see if certain themes were present with regard to the tasks the participants found difficult in the AWMA and DST-J respectively.

CHAPTER 3

RESULTS

3.1 INTRODUCTION

The study investigated the differences in working memory of dyslexic and non-dyslexic children, utilising a new computer-based working memory assessment measure (Automated Working Memory Assessment – AWMA) to investigate two hypotheses. The first hypothesis was that differences would be observed in verbal short term memory and verbal working memory in dyslexic individuals when compared to non-dyslexic matched controls. The second hypothesis was that there would be significant differences between the experimental and control groups in terms of their visuospatial short term memory and visuospatial working memory.

As discussed in chapter 2, two measures were utilised, the first a dyslexia screening test and the second a working memory assessment. The dyslexia screening test is a measure that indicates the ‘at risk’ status of a child for dyslexia. The measure was administered to both the diagnosed dyslexic cohort as well as the non-dyslexic controls. The Dyslexia Screening Test – Junior (DST-J) consists of 12 subtests each administered individually. Each subtest was scored and the raw scores used for analyses. The computerised working memory assessment includes 12 subtests, each administered individually and divided into 4 composite categories (3 subtests in each category), which is the overall Verbal Short Term Memory score, Verbal Working Memory score, Visuospatial Short Term Memory score and Visuospatial Working Memory score. Performance was measured for the AWMA measures in terms of raw scores for each subtest and composite scores, higher scores being indicative of better performance. For the DST-J higher scores on the Rapid Naming and Postural Stability subtests indicated poorer performance, however high scores on the remaining subtests indicated better performance.

Inferential and descriptive statistical techniques as well as frequency analysis were performed on all variables to assess the suitability of the data for parametric analysis, followed by appropriate statistical techniques designed to address the research question and hypotheses of the study using SPSS version 17. The data for the independent variable – dyslexia – consisted of dichotomous nominal data, Group (Dyslexic/Non-dyslexic) and the DST-J met a ratio scale of measure. The dependent variable - Working Memory data met an interval scale of measure. Independent samples t-tests were calculated to determine if there were significant differences between the experimental and control groups in terms of dyslexia and working memory. Effect sizes were calculated to assess the degree of difference observed. Correlational analysis was performed to examine the relationship between working memory (AWMA) and the dyslexia screening subtests (DST-J) for both groups. Lastly, content analysis was utilised to identify whether any themes with regard to task difficulty could be identified from the reports for the measures.

3.2 NORMALITY

To utilise parametric techniques it is necessary to meet a number of assumptions, namely that data for dependent variable(s) should be at least an interval scale of measure, sampling should be independent and random, homogeneity of variance should be present and the distribution should be reasonably normal (Howell, 2002). Although a convenience sample was used and thus was not independent and random, the order of the measures was alternated for each subject to eliminate possible effects due to the order of presentation.

Due to the small sample size (16) it was unlikely that normality of distribution would be achieved. Normality of the data was therefore assessed with the use of histograms, measures of central tendency and Shapiro-Wilk Tests of Normality. It is important to check for normality of distribution as there is firstly an important link between distributions and probabilities (Howell, 2002), if information is known about the distribution of events, something may be known of the probability of one of these events' likelihood to occur. Secondly, most of the statistical techniques have had an assumption of a normally distributed population in their origin (Howell, 2002).

Examination of the histograms (see Appendix F) for all 12 subscales of the AWMA as well as the 4 composite scores of the non-dyslexic group, revealed generally normally distributed raw scores when considering the superimposed normal curve. The only subtests that were slightly positively skewed, on visual inspection, were the data for Block Recall. The data for the Listening Recall, Dot Matrix, and Mazes Memory subtest were slightly negatively skewed. For the dyslexic group, distribution of raw scores were generally normal, with the exception of the Digit Recall and Counting Recall subtests and the Verbal Working Memory and Visuospatial Sort Term Memory composite scores being slightly positively skewed. The Nonword Recall and Backwards Digit Span subtests appeared slightly negatively skewed.

The 12 subtests of the DST-J revealed normal distribution of data for the non-dyslexic group. Examination of the histograms (see Appendix F) revealed that the Dyslexia quotient was positively skewed, which was expected as most of the participants for the non-dyslexic group received a 0.00 score as a ‘not at risk’ status, also the Semantic Fluency subtest was slightly positively skewed. The Rhyming, Phonemic segmentation, Two Minute Spelling, and Vocabulary subtests were slightly negatively skewed.

For the dyslexic group, examination of the histograms (see Appendix F) for the DST-J indicated that the Rapid Naming, Bead threading, One Minute Reading, and Nonsense Reading subtests were slightly positively skewed. The Semantic Fluency, Two Minute Spelling and Vocabulary subtests appeared slightly negatively skewed. The remaining subtests were relatively normally distributed. Table 2 below provides the measures of central tendency for the AWMA subtests and composite scores as well as the DST-J subtests, for both the experimental and control groups.

Table 2:
Simple descriptive statistics for the AWMA and DST-J by group.

	Dyslexic (N=8)						Non-dyslexic (N=8)					
Variable	*Mean*	*Median*	*Std.Dev*	*Variance*	*Minimum*	*Maximum*	*Mean*	*Median*	*Std.Dev*	*Variance*	*Minimum*	*Maximum*
AWMA												
Digit Recall	**100.25**	**98**	**11.88**	**141.07**	**86**	**126**	113.5	113	17.45	304.57	90	146
Word Recall	**121.5**	**122.5**	**12.76**	**162.86**	**106**	**138**	130.5	130.5	6.05	36.57	120	140
Nonword Recall	**114.25**	**115.5**	**17.25**	**297.64**	**85**	**133**	133.63	133	3.25	10.55	127	137
VSTM comp	**115.13**	**115.5**	**15.5**	**240.41**	**90**	**141**	132.38	132	7.84	61.41	120	147
Listening recall	**106**	**104.5**	**19.87**	**394.86**	**76**	**139**	106.75	108.5	19.43	377.36	71	127
Counting recall	**97.38**	**92**	**13.93**	**193.98**	**81**	**126**	115.13	115.5	14.71	216.41	95	136
Backwards digit span	**99.88**	**104**	**13.08**	**170.98**	**81**	**116**	105.75	106.5	9.2	84.79	92	118
VWM comp	**101.38**	**100**	**12.57**	**157.98**	**86**	**116**	111.25	111	9.78	95.64	95	125
Dot Matrix	**99.63**	**99.5**	**11.52**	**132.55**	**77**	**115**	123.5	125	11.1	123.14	105	137
Mazes memory	**120**	**119**	**12.4**	**153.71**	**101**	**137**	123.5	125	13.77	189.55	94	137
Block Recall	**97.63**	**97**	**16.67**	**277.98**	**77**	**133**	119	118	14.99	224.57	101	146
VSSTM comp	**107.38**	**103**	**13.34**	**177.98**	**94**	**135**	124.75	125.5	7.29	53.07	115	135
Odd-one-out	**98.63**	**98**	**9.1**	**82.84**	**87**	**116**	122.25	123.5	16.15	260.78	98	146
Mr X	**94.75**	**92**	**13.38**	**179.07**	**70**	**111**	109.63	114.5	21.1	445.12	78	139
Spatial Span	**102**	**102**	**19.57**	**382.86**	**64**	**129**	115.75	115	11.55	113.36	100	133
VSWM comp	**98.25**	**100**	**14.25**	**203.07**	**77**	**124**	119.63	118.5	8.77	76.84	106	132
DST-J												
Dyslexia quotient	**1.03**	**1**	**0.44**	**0.19**	**0.4**	**1.7**	0.03	0.00	0.05	0.002	0.0	0.1
Rapid Naming	**50.38**	**36**	**36.78**	**1353.13**	**29**	**140**	32.5	32	3.89	15.14	27	38
Bead Threading	**7.13**	**7**	**0.99**	**0.98**	**6**	**9**	7.13	7.5	1.64	2.7	5	9
One Min Reading	**7.25**	**4.5**	**6.63**	**43.93**	**1**	**20**	41.63	56	25.3	639.98	8	70
Posture	**2.88**	**3**	**1.46**	**2.13**	**1**	**5**	1.38	1.5	1.41	1.98	0	4
Phonemic Segmentation	**8**	**7.5**	**2.39**	**5.71**	**5**	**12**	9.38	10.5	2.33	5.4	6	12
Rhyming	**6.25**	**7**	**1.9**	**3.64**	**4**	**8**	7.25	7	0.71	0.5	6	8
Two min Spelling	**5**	**5**	**2.33**	**5.43**	**2**	**8**	7.25	8	1.49	2.2	4	8
Backwards Digit Span	**3.88**	**4**	**1.25**	**1.55**	**2**	**6**	3.88	4	1.25	1.55	2	6
Nonsense reading	**17.13**	**13.75**	**12.72**	**161.77**	**5**	**38**	42.5	51	15.67	245.43	12	58
One min Writing	**7.13**	**6.5**	**3.18**	**10.13**	**3**	**11**	12.75	12.5	3.69	13.64	7	19
Verbal fluency	**7.25**	**7.5**	**3.1**	**9.64**	**3**	**12**	11.5	11	2.83	8	7	16
Semantic fluency	**16.25**	**17**	**3.35**	**13.36**	**11**	**23**	17.25	17	2.71	7.36	15	23
Vocabulary	**12.12**	**12.5**	**1.36**	**1.84**	**10**	**14**	13	13	1.07	1.14	11	14

The measures of central tendency indicated acceptable normality of the data for the subtests. However, a more stringent analysis was required; therefore normality was further assessed using Shapiro-Wilk Test of Normality. Table 3 shows the ***D*** statistic and significance levels obtained. It can be assumed that normality is achieved when the obtained significance level is smaller than 0.05 (Coakes & Steed, 2001).

Table 3:
Shapiro-Wilk Test for Normality for AWMA and DST-J subtests and composite construct scores.

	Dyslexic		Non-dyslexic	
	Statistic (D)	***P-Value***	***Statistic (D)***	***P-Value***
AWMA				
Digit Recall	**.86**	**p > 0.05**	.94	p > 0.05
Word Recall	**.90**	**p > 0.05**	.96	p > 0.05
Nonword Recall	**.93**	**p > 0.05**	.83	p > 0.05
VSTM comp	**.99**	**p > 0.05**	.95	p > 0.05
Listening recall	**.97**	**p > 0.05**	.92	p > 0.05
Counting recall	**.89**	**p > 0.05**	.96	p > 0.05
Backwards digit span	**.91**	**p > 0.05**	.96	p > 0.05
VWM comp	**.86**	**p > 0.05**	.99	p > 0.05
Dot Matrix	**.93**	**p > 0.05**	.95	p > 0.05
Mazes memory	**.93**	**p > 0.05**	.86	p > 0.05
Block Recall	**.87**	**p > 0.05**	.94	p > 0.05
VSSTM comp	**.86**	**p > 0.05**	.92	p > 0.05
Odd-one-out	**.96**	**p > 0.05**	.99	p > 0.05
Mr X	**.91**	**p > 0.05**	.96	p > 0.05
Spatial Span	**.95**	**p > 0.05**	.90	p > 0.05
VSWM comp	**.93**	**p > 0.05**	.95	p > 0.05
DST-J				
Dyslexia quotient	**.57**	**p > 0.05**	.97	p < 0.001
Rapid Naming	**.58**	**p > 0.05**	.96	p < 0.001
Bead Threading	**.87**	**p > 0.05**	.89	p > 0.05
One Min Reading	**.80**	**p < 0.05**	.80	p > 0.05
Posture	**.93**	**p > 0.05**	.86	p > 0.05
Phonemic Segmentation	**.92**	**p > 0.05**	.84	p > 0.05
Rhyming	**.75**	**p > 0.05**	.83	p < 0.05
Two min Spelling	**.90**	**p < 0.001**	.60	p > 0.05
Backwards Digit Span	**.96**	**p > 0.05**	.96	p > 0.05
Nonsense reading	**.84**	**p > 0.05**	.83	p > 0.05
One min Writing	**.90**	**p > 0.05**	.99	p > 0.05
Verbal fluency	**.97**	**p > 0.05**	.97	p > 0.05
Semantic fluency	**.94**	**p < 0.05**	.80	p > 0.05
Vocabulary	**.93**	**p > 0.05**	.86	p > 0.05

The results of the Shapiro-Wilk test in Table 3 indicate that all the subtests and composite scores for the AWMA could be considered normally distributed for both dyslexic and non-dyslexic groups. Although Non-Word Recall for the non-dyslexic group appears to be negatively skewed when examining the histograms (see Appendix F), results fall just short of being regarded as non-normal in the Shapiro-Wilk test. The Shapiro-Wilk results for the dyslexic group indicate that normality may be assumed for the AWMA, however examining the histograms (see Appendix F) Digit recall appears to be slightly positively skewed.

The Shapiro-Wilk results for the DST-J revealed that for the dyslexic group, the subtests One Minute Reading, Two Minute Spelling and Semantic Fluency are not normally distributed. The non-dyslexic group presented with a non-normal distribution for the Dyslexia quotient, Rapid Naming and Rhyming subtests. However, after examining the data, the reason for the non-normal distribution is due to the manner in which the quotient on the DST-J is calculated, with a score of 0.00 – 0.5 being 'not at risk' for dyslexia). Two participants of the eight non-dyslexic participants had scores of 0.1 while the remaining six had scores of 0.00 (see Appendix F for the histograms).

Homogeneity of variance was established with Levene's test for equality of variance, it was established that equality of variances may be assumed for all variables except for the Word Recall and Non-word Recall subtests. Equality of variance was established at $p < 0.01$.

Howell (2002) points out that an advantage of the nonparametric technique is that it does not rely on very stringent and restrictive assumptions concerning the shape of the distribution of the sample data. One of the major disadvantages attributed to nonparametric tests however is their apparent lower power relative to the parametric equivalent; therefore nonparametric tests may lead to more Type II Errors (Howell 2002). Howell (2002) further states that it is generally very difficult to know whether the nonparametric test would have greater or less power compared to corresponding parametric tests. Using both parametric and nonparametric tests, would thus provide a means of verification of the results. However, despite the normality, and the small sample size in the current study, it was ultimately decided that the parametric statistical technique (which is more stringent) would be utilised (although the non-parametric analyses may be viewed in Appendix G) as both the parametric and non-parametric analyses produced the same final results. Effect sizes were also calculated to further control for Type II errors.

3.3 Demographic findings

As mentioned in the Method section, 16 individuals participated in the present study. In an attempt to control for confounding variables, the 8 dyslexic children were matched to 8 non-dyslexic children. Every effort was made to match participants in terms of age, gender, ethnicity, home language and education level. The two groups were compared on some of these demographic variables.

3.3.1 Age and Home language of participants

Using a two tailed independent samples t-test, no significant difference, $t(14) = 0.74$, $p > 0.05$, was obtained for age of participants between dyslexic (M = 95.87, SD = 7.07) and non-dyslexic groups (M = 97.12, SD = 7.79). No significant difference was found between the Afrikaans: English home language ratio for both groups using Pearson's chi square (p = 0.106), although two cells had lower than expected numbers.

3.4 Dyslexia Screening Test for Juniors (DST-J), quotient scores for Dyslexic and Non-dyslexic children.

All participants were assessed on the DST-J, even though the non-dyslexic children had no reported learning or reading difficulties and the dyslexic children had been diagnosed with Dyslexia by an educational or clinical psychologist. A Dyslexia quotient was obtained indicating whether the child is at risk for dyslexia. Each test score was allocated to one of five normed categories or 'at risk indices' (calculated by the computer software provided), ranging from poor performance for the relevant age (bottom 4% indicating a strong risk for dyslexia), well below average (bottom 5-11%), below average performance (bottom 12-22%), midrange performance (23-77%) and above average performance (top 22%). The Dyslexia quotient is the 'at risk index' derived at by working out the numbers of 'at risk indices', an At Risk Quotient (ARQ) of 1.2

indicates that the child has a strong risk for Dyslexia, an ARQ of 0.9 – 1.1 indicates risk and an ARQ of 0.6 – 0.8 indicates mild risk, anything between 0.0 and 0.5 indicated that the child is not at risk. A two sample independent t-test was used to investigate group differences between the dyslexia quotients of the two groups.

Analysis of the dyslexia quotient obtained revealed that, as expected, with this screening measure the dyslexic group (M = 1.03, SD = 0.44) scored significantly higher on the DST-J ($t(14) = -6.44$, $p < 0.001$) to the non-dyslexic group (M = 0.025, SD = 0.05). Thus, the non-dyslexic group did not present with any difficulties the measure was sensitive to, while the dyslexic group's deficits were readily identified.

3.5 Working Memory differences between dyslexic and non-dyslexic groups

An independent samples t-test was conducted (as well as the Wilcoxin Rank-Sum Tests, results available in Appendix G) to test the hypothesis that there would be a significant difference in working memory performance between dyslexic and non-dyslexic children in their foundation years (grade 1 and 2). The present study examined the differences between scores obtained on the AWMA in children diagnosed with dyslexia and matched controls with no known learning disability.

Levene's test for equality of variance was performed on the data and indicated that for most variables equality of variance between groups may be assumed, however variances were not equal for Word Recall and Non-word Recall. Therefore, for the latter 2 variables the Welch-Satterthwaite adjustment was used. Equality of variance was established at $p > 0.01$.

The parametric analyses of the data are presented in Table 4 demonstrating t-values and Cohen's ***d*** when each subtest on the AWMA is compared across the two groups.

Table 4:

Independent samples t-test comparisons between dyslexic and non-dyslexic groups, and effect sizes.

Subtest	***t-value***	***Cohen's d***
Digit Recall	1.78	0.94
Word Recall	1.8	0.96
Nonword Recall	3.12 *	1.65
VSTM comp	2.81 *	1.49
Listening recall	0.08	0.4
Counting recall	2.48 *	1.31
Backwards digit span	1.04	0.55
VWM comp	1.75	0.93
Dot Matrix	4.22 **	2.24
Mazes memory	0.48	0.25
Block Recall	2.7 *	1.43
VSSTM comp	2.23 **	1.71
Odd-one-out	3.61 **	1.91
Mr X	1.68	0.89
Spatial Span	1.71	0.91
VSWM comp	3.61 **	1.92

Note: * = $p < 0.05$; ** = $p < 0.01$

Two tailed, independent samples t-tests revealed that there was a significant difference between the dyslexic and non-dyslexic groups on the Non-word recall task ($t(14) = 3.12$, $p < .05$), Verbal short term memory composite scores ($t(14) = 2.81$, $p < .05$), Counting recall task ($t(14) = 2.48$, $p < .05$) and Block recall task ($t(14) = 2.69$, $p < .05$) with $\alpha = 0.05$.

Further, there were significant differences between the two groups on the Dot matrix ($t(14) = 4.22$, $p < .01$), Visuospatial short term memory composite score ($t(14) = 2.23$, $p < .01$), Odd-one-out ($t(14) = 3.61$, $p < .01$), and Visuospatial working memory composite score ($t(14) = 3.61$, $p < .01$) with $\alpha = 0.01$. In all cases the dyslexic group performed at a lower level than the non-dyslexic cohort (means and standard deviations are presented in Table 2).

No significant statistical differences were found between the Digit recall task, Word recall task, Listening recall task, Backwards Digit span task, Verbal working memory composite score, Mazes memory task, Mr X task, and Spatial span task.

Significant differences were obtained between the two groups on at least one measure for each of the four constructs assessed by the AWMA. Considering that both the parametric and nonparametric tests identified the same statistically significant differences on the AWMA measure between the dyslexic cohort and non-dyslexic cohort, the sample size may not have influenced the results as much as may have been expected.

3.6 Effect sizes

The practical significance of calculating effect sizes is that effect size measurements provide the researcher with the relative magnitude of the experimental effect, while statistical tests offer information about the likelihood that the experimental results differ from chance (Thalheimer & Cook, 2002). As such, effect sizes were calculated to establish the relative magnitude of the statistical differences observed. Cohen's delta (***d***) was utilised to calculate the effect sizes of the obtained results. Cohen (1992) suggested three levels of ***d***, an effect size of 0.2 is small, 0.5 is medium, and 0.8 is large. Power was set at $\alpha = 0.01$

Large effect sizes (above 0.8) were found for the difference between dyslexic and non-dyslexic cohorts on the Nonword Recall subtest ($d = 1.65$), Verbal Short Term Memory composite score ($d = 1.49$), Counting Recall subtest ($d = 1.31$), Dot Matrix subtest ($d = 2.24$), Block Recall subtest ($d = 1.43$), Visuospatial Short Term Memory composite score ($d = 1.71$), Odd One Out subtest ($d = 1.91$), Visuospatial Working Memory composite score ($d = 1.92$). These large effect sizes suggest that the results obtained are sufficiently deviant to suggest that there are practical or meaningful short-term memory and working memory differences between non-dyslexic and dyslexic children.

3.7 Correlational relationships between AWMA and DST-J subtests.

In order to assess to what extent the AWMA memory subtests were related to the subtests of the DST-J, these variables were correlated for the dyslexic and non-dyslexic cohorts. A series of parametric Pearson's Correlation Coefficients (*r*) was utilised. A Spearman's Correlation was also conducted as the nonparametric equivalent and since both analyses yielded very similar significant relationships, only the Pearson's results are reported to avoid repetition (the nonparametric Spearman's correlational analyses appear in Appendix G).

Table 5 presents the correlations between the verbal subtests of the AWMA and all subtests of the DST-J for both groups, while Table 6 presents the relationships for the visuospatial subtests and all subtests of the DST-J for the dyslexic and non-dyslexic groups. For all analyses significance was determined at $\alpha = 0.05$.

Table 5:

Pearson's Correlation Coefficients for Verbal AWMA subtests and DST-J subtests for non-dyslexic and dyslexic participants.

	DST-J Subtests												
AWMA Subtests	Rapid Naming	Bead Threading	One Min Reading	Posture	Phonemic Segmentation	Rhyming	Two min Spelling	Backwards Digit Span	Nonsense reading	One min Writing	Verbal fluency	Semantic fluency	Vocabulary
Digit Recall	-.19	-.14	.28	.15	.18	-.14	.56	.81*	.40	-.55	.72*	.18	.26
Word Recall	.41	.08	-.65	.35	-.69	-.67	-.71*	.45	-.75*	-.24	-.12	-.36	-.18
Nonword Recall	.04	.12	-.53	.16	-.51	-.45	-.36	-.01	-.54	-.31	.04	.27	-.62
VSTM comp	-.06	-.07	-.03	.28	-.13	-.41	.22	.87**	.05	-.62	.64	.11	.09
Listening recall	-.85**	.45	.82*	.16	.76*	.39	.29	.13	.65	.42	.41	.60	.74*
Counting recall	-.02	-.42	.45	.40	.31	.24	.74*	.39	.567	-.64	.37	.65	.13
Backwards digit span	-.84**	-.05	-.42	.44	.23	-.03	-.10	.27	-.42	-.18	-.31	-.26	-.32
VWM comp	-.36	.11	.79*	.57	.72*	.47	.64	.437	.71*	-.11	.42	.78*	.56
Digit Recall	**.32**	**-.37**	**-.30**	**.45**	**-.10**	**.27**	**.16**	**.23**	**-.22**	**.03**	**-.48**	**-.26**	**-.52**
Word Recall	**-.03**	**.27**	**.44**	**-.27**	**.45**	**.43**	**.36**	**-.02**	**.54**	**.11**	**.20**	**-.26**	**.02**
Nonword Recall	**-.21**	**.15**	**.55**	**-.06**	**.44**	**.82***	**-.046**	**-.11**	**.50**	**.16**	**.19**	**-.02**	**-.04**
VSTM comp	**-.01**	**.03**	**.30**	**.03**	**.31**	**.62**	**.15**	**.01**	**.33**	**.12**	**-.01**	**-.18**	**-.19**
Listening recall	**.16**	**-.35**	**-.01**	**.12**	**.24**	**.46**	**.21**	**.35**	**.06**	**.15**	**-.15**	**-.05**	**-.09**
Counting recall	**-.26**	**-.18**	**-.22**	**.56**	**-.28**	**.17**	**-.53**	**.10**	**-.42**	**.01**	**-.03**	**.70**	**.05**
Backwards digit span	**.41**	**-.02**	**.36**	**.06**	**.64**	**.48**	**.03**	**.76***	**.35**	**.13**	**.24**	**.17**	**.29**
VWM comp	**.17**	**-.31**	**.04**	**.35**	**.30**	**.57**	**-.09**	**.61**	**-.00**	**.14**	**-.01**	**.35**	**.09**

* $p < 0.05$
** $p < 0.01$

Bold font denotes dyslexic group
Normal font denotes non-dyslexic group

The results presented in Table 5, indicate that there seems to be a wider pattern of relationship between the subtests for the verbal subtests of the AWMA and the subtests of the DST-J of the non-dyslexic group, with markedly fewer relationships for the dyslexic cohort.

3.7.1 Non-dyslexic group

A strong negative relationship exists between Listening Recall and Rapid Naming (r = - 0.85; $p < 0.01$), Backwards Digit Span on the AWMA and Rapid Naming (r = - 0.84; $p < 0.01$) on the DST-J. Statistically significant negative relationships were observed for Word Recall and Two Minute Spelling (r = - 0.71; $p < 0.05$), and Word Recall and Nonsense Reading (r = - 0.75; $p < 0.05$). This suggests that good performance on the AWMA subtests is associated with poorer performance on the DST-J subtests and implies that different skills are being drawn on in these tasks.

Verbal Short Term Memory and Backwards Digit Span (DST-J) presented with a very strong positive relationship ($r = 0.87$; $p < 0.01$). A statistically significant positive relationship was observed for Listening Recall (AWMA) and One Minute Reading (DST-J) ($r = 0.82$; $p < 0.05$), Verbal Working Memory (AWMA) and One Minute Reading (DST-J) ($r = 0.79$; $p < 0.05$) and Listening Recall (AWMA) and Phonemic Segmentation (DST-J) ($r = 0.76$; $p < 0.05$). Furthermore, Verbal Working Memory (AWMA) and Phonemic Segmentation (DST-J)($r = 0.72$; $p < 0.05$), Digit Recall (AWMA) and Backwards Digit Span (DST-J) ($r = 0.81$; $p < 0.05$), as well as Counting Recall (AWMA) and Two Minute Spelling (DST-J) ($r = 0.74$; $p < 0.05$) were positively related. Positive relationships existed for Verbal Working Memory (AWMA) and Nonsense Reading (DST-J) ($r = 0.71$; $p < 0.05$), Digit Recall (AWMA) and Verbal Fluency (DST-J) ($r = 0.72$; $p < 0.05$), Verbal Working Memory (AWMA) and Semantic Fluency (DST-J) ($r = 0.78$; $p < 0.05$), and lastly Listening Recall (AWMA) and Vocabulary (DST-J) ($r = 0.74$; $p < 0.05$).The positive relationships would suggest there is overlap in the processing skills used in these tasks.

3.7.2 Dyslexic group

Fewer statistically significant relationships were observed for the dyslexic group and none were similar to the non-dyslexic group. Statistically significant relationships were observed between Nonword Recall (AWMA) and Rhyming (DST-J) ($r = 0.82$; $p < 0.05$), in addition to Backwards Digit Span (AWMA) and Backwards Digit Span (DST-J) ($r = 0.76$; $p < 0.05$).

The results presented in Table 6, indicate that as with the verbal subtests of the AWMA, there seems to be a wider pattern of relationship between the subtests for the visuospatial subtests of the AWMA and the subtests of the DST-J of the non-dyslexic group, with only two significant relationships for the dyslexic cohort.

Table 6:

Pearson's Correlation Coefficients for Visuospatial AWMA subtests and DST-J subtests for non-dyslexic and dyslexic participants.

	DST-J Subtests												
AWMA Subtests	Rapid Naming	Bead Threading	One Min Reading	Posture	Phonemic Segmentation	Rhyming	Two min Spelling	Backwards Digit Span	Nonsense reading	One min Writing	Verbal fluency	Semantic fluency	Vocabulary
Dot Matrix	.12	.21	.40	.51	.38	.00	.70	.65	.55	-.28	.63	.49	.54
Mazes memory	-.66	.61	.05	-.14	.07	-.31	.05	.09	.08	.11	.63	.47	.03
Block Recall	.26	.18	.27	.90**	.25	.01	.41	.67	.27	-.35	.37	.63	.37
VSSTM comp	-.08	.46	.24	.29	.34	-.07	.61	.53	.38	-.14	.72*	.48	.26
Odd-one-out	-.01	.38	.10	-.03	.41	.37	.20	.04	.04	.39	.03	-.10	-.11
Mr X	.81*	-.45	-.63	.29	-.73*	-.57	-.18	.35	-.47	-.71*	-.10	-.28	-.34
Spatial Span	-.57	.45	.58	.40	.45	-.13	.54	.68	.62	-.18	.92**	.77*	.69
VSWM comp	.47	.10	-.30	.44	-.22	-.40	.22	.73*	-.16	-.50	.42	.03	-.11
Dot Matrix	**-.72***	**.49**	**.21**	**.35**	**.18**	**.44**	**.41**	**-.55**	**.26**	**.75***	**.21**	**.53**	**.13**
Mazes memory	**-.12**	**.13**	**-.04**	**.41**	**.23**	**.25**	**.26**	**.49**	**-.01**	**.29**	**.23**	**.68**	**.35**
Block Recall	**.20**	**.15**	**-.22**	**.62**	**-.07**	**.12**	**.22**	**.29**	**-.16**	**.06**	**-.19**	**.10**	**-.31**
VSSTM comp	**-.20**	**.30**	**-.06**	**.61**	**.11**	**.31**	**.35**	**.15**	**-.01**	**.41**	**.06**	**.51**	**.03**
Odd-one-out	**-.32**	**-.06**	**-.11**	**.78***	**.01**	**.62**	**.05**	**-.04**	**-.14**	**.54**	**-.16**	**.55**	**-.16**
Mr X	**-.02**	**.11**	**.28**	**.27**	**.17**	**.65**	**-.35**	**.38**	**.12**	**-.27**	**.19**	**.29**	**-.05**
Spatial Span	**-.72***	**.07**	**.03**	**.17**	**-.11**	**.46**	**.17**	**-.59**	**.05**	**.33**	**-.02**	**.24**	**-.12**
VSWM comp	**-.51**	**.08**	**.10**	**.41**	**.00**	**.68**	**-.03**	**-.20**	**.04**	**.22**	**.02**	**.40**	**-.14**

* = $p < 0.05$
** = $p < 0.01$

Bold font denotes dyslexic group
Normal font denotes non-dyslexic group

3.7.3 Non-Dyslexic

Block Recall and Posture presented with a statistically significant positive relationship ($r = 0.90$; $p < 0.01$), as did Spatial Span (AWMA) and Verbal Fluency (DST-J) ($r = 0.92$; $p < 0.01$). A statistically significant correlation was observed between Mr X (AWMA) and Rapid Naming (DST-J) ($r = 0.81$; $p < 0.05$), and also for Visuospatial Working Memory (AWMA) and Backwards Digit Span (DST-J) ($r = 0.73$; $p < 0.05$). Visuospatial Short Term Memory (AWMA) and Verbal Fluency (DST-J) ($r = 0.72$; $p < 0.05$), in addition to Spatial Span (AWMA) and Semantic Fluency (DST-J) ($r = 0.77$; $p < 0.05$) revealed a statistically significant positive relationship. A statistically significant negative relationship was observed between the Mr X (AWMA) and one Phonemic Segmentation tasks (DST-J) ($r = - 0.73$; $p < 0.05$), and Mr X (AWMA) and One Minute Writing tasks (DST-J) ($r = - 0.71$; $p < 0.05$).

3.7.4 Dyslexic

Two significantly positive relationships were identified, the first between Dot Matrix (AWMA) and One Minute Writing (DST-J) ($r = 0.75$; $p < 0.05$) and the second between the Odd One Out (AWMA) and Posture tasks (DST-J) ($r = 0.78$; $p < 0.05$). Statistically significant negative relationships existed for Dot Matrix (AWMA) and Rapid Naming (DST-J) ($r = - 0.72$; $p < 0.05$), and lastly Spatial Span (AWMA) and Rapid Naming (DST-J) had a significant negative relationship ($r = - 0.72$; $p < 0.05$).

3.8 Content Analysis

Thematic content analysis of the DST-J reports for the dyslexic cohort, revealed that they had below average scores on six subscales in varying degrees of consistency. These subscales (presented in Table 7) were identified as needing attention with remediation.

Table 7:

Subtest Difficulties experienced by the dyslexic group for the DST-J.

Subtests of DST-J	**Number**
One minute reading	7
Rhyme	3
Two minute spelling	6
Nonsense passage reading	5
One minute Writing	4
Verbal Fluency	3

Considering the subscales identified, two additional themes were identified, weak literacy skills and weak phonological skills.

Table 8:

Themes identified from the reports for the dyslexic cohort for the DST-J.

Specific difficulty	**Number**
Weak Literacy	8
Weak phonological skill	5

Weak literacy skills refer to below average performance on the one minute reading, and two minute spelling. Poor performance in rhyming and verbal fluency was indicative of weak phonological skills. These themes suggest that the dyslexic cohort struggled with tasks of phonetic ability and difficulty in learning to read, write and spell.

3.9 Conclusion

This section has explored the differences and correlations between variables. Statistically significant differences between the experimental and control groups were identified and significant relationships between the two measures for both groups were investigated. The overall task difficulty of the AWMA and the DST-J was reported in terms of the dyslexic and non-dyslexic groups. The findings that emerged for the dyslexic group in this study are consistent with what has been observed in some prior studies (e.g. Boada & Pennington, 2006; Brunswick et al., 1999; McDougall & Donohoe, 2002; Pennington et al., 2001; Plaza et al., 2002; Roodenrys & Stokes, 2001), however provides further insight into children of this particular age group within South Africa. Interpretation of the findings presented in this chapter, and with cognisance of the literature presented in the introductory chapter, will be presented in the next chapter.

CHAPTER 4

DISCUSSION

Research has identified working memory differences in both the verbal and visuospatial domains of dyslexic individuals relative to non-dyslexic controls (Brunswick et al., 1999; Daneman & Mirikle, 1996; Helland & Asbjornsen, 2003; McDougall & Donohoe, 2002; Olson & Datta, 2002; Plaza et al., 2002; Roodenrys & Stokes, 2001; Smith-Spark & Fisk, 2007; Smith-Spark et al., 2003; Winner et al., 2001). The importance of research within the South African population with regard to dyslexia is focussed around early identification of these individuals in order to provide intervention at the academic as well as psychological level. The screening for dyslexia without a written component would therefore be useful especially before formal education begins.

The main aim of the present study therefore was to compare the working memory of dyslexic and non-dyslexic children in the South African population. To do this, the study endeavoured to evaluate the working memory performance of children with dyslexia by comparing their performance to a carefully matched non-dyslexic control group. More specifically, working and short term memory of the verbal and visuospatial type were examined with the use of a new computerised measure, the Automated Working Memory Assessment (AWMA) developed by Alloway, Gathercole and Pickering (2006). To this end, the relationship between working memory and dyslexia was explored by considering two hypotheses. Firstly, dyslexic children would present with significant differences in verbal short-term and verbal working memory when compared to non-dyslexic children, and secondly, visuospatial short-term and visuospatial working memory will be significantly different in dyslexic children compared to non-dyslexic children.

One may recall from chapter three, that the AWMA consists of 12 subscales assessing four aspects of memory. Two domains are assessed, namely verbal and visuospatial. Within these domains, the AWMA assesses both the short-term memory construct and the working memory construct. As stated previously in chapter one, in the verbal memory domain, the short-term memory construct consists of tasks that require only the short-term storage of verbal information in the phonological store of the phonological loop, while the working memory construct consists of tasks that require storage, processing and manipulation of verbal information with the help of the articulatory rehearsal system in the phonological loop. The visuospatial memory domain too consists of both the short-term construct, responsible for short-term storage of visuospatial information in the inner scribe and visuo-spatial cache, and the working memory construct responsible for the storage, processing and manipulation of visuospatial information in the visuospatial sketchpad (Baddeley, 1986).

In this chapter a general overview of the sample will be provided first. This will be followed by a discussion of the differences observed between dyslexic and non-dyslexic groups on the verbal short-term memory and working memory tasks. The relationship between the verbal tasks and the DST-J tasks will be considered next. The visuospatial short-term memory and working memory tasks will then be examined following the same sequence as with the verbal memory discussion.

As discussed in chapter two, the size of the experimental group was constrained by the limited number of available diagnosed dyslexic children in the specified age group. Of the total number of participants, only eight had been diagnosed as dyslexic individuals and eight were carefully matched controls with no known learning or reading difficulties. It was necessary to establish equivalence between the dyslexic and control sample on as many variables as possible to ensure that the results obtained were due to actual differences between the groups, reducing chances of a Type I error, and not due to confounding variables that may lead to an increase in the chance of making a Type II error. Thus, the participants were matched as far as possible on age, home language, gender, ethnicity and education. No significant differences were found between the dyslexic and control groups ($p > 0.05$) in terms of age. Uneven distribution of home language existed between the groups, with the dyslexic group consisting of four Afrikaans and four English speaking participants while the non-dyslexic group consisted of one Afrikaans and seven English speaking participants. Gender was unevenly distributed for the overall sample, and is atypical to the prevalence of dyslexia reported in the literature, the typical male to female ratio being 2:1 for dyslexic individuals (Miles et al., 1998). The present sample comprised more female than male participants, with a male to female ratio of 1:2. Education level ranged between Grade 1 and Grade 3, and all participants were Caucasian.

Consequently, with the general outline of the sample in mind the results obtained for the verbal short term memory, verbal working memory, visuospatial short-term memory, as well as visuospatial working memory tasks and composite scores within the framework of Baddeley's working memory model are discussed.

4.1 VERBAL SHORT TERM MEMORY AND WORKING MEMORY TEST PERFORMANCE

Researchers have found that in terms of cognitive abilities, children with reading disabilities and specifically Dyslexia show deficits in a variety of short-term memory and working memory tasks (Brunswick et al., 1999; McDougall & Donohoe, 2002; Palmer, 2000; Pennington et al., 2001; Plaza et al., 2002; Stanovich et al., 1997; Roodenrys & Stokes, 2001; Smith-Spark et al., 2003; Smith-Spark & Fisk, 2007; Snowling, 2008; Swanson 1994). These difficulties impact their reading acquisition, reading ability, text comprehension and classroom functioning (Alloway & Gathercole, 2006). While the verbal short-term and working memory's role has been extensively investigated, the visuospatial domain has been largely neglected until recently (e.g. Smith-Spark et al., 2003, 2007). The findings of the current study found both verbal and visuospatial memory differences in the present sample of dyslexic children. A better understanding of the contributions of these differences may aid the identification of these children at an earlier age if the differences are consistently established within dyslexic children and understood.

In order to provide more clarity in this regard, each component of short-term and working memory was examined separately. Verbal short-term memory specializes in the temporary storage of verbal information and verbal working memory is involved with the maintenance, processing and retrieval of verbal information. The AWMA tasks used to assess the short-term memory construct were Digit Recall, Word Recall and Nonword Recall, while the working memory construct was assessed with the Listening Recall, Counting Recall and Digit Recall tasks.

The group differences in verbal short term and working memory between the dyslexic and non-dyslexic groups in the present study were analysed using an independent samples t-test.

The dyslexic and non-dyslexic groups differed significantly from each other on several of the verbal subscales. The first hypothesis of the present study was therefore only partly upheld. The mean scores of the dyslexic group were overall lower than that of the control group. In terms of specific test differences, the scores of the dyslexic group were significantly lower than that of the control group on the Nonword Recall subtest ($t(14) = 3.12$, $p < .05$), the Verbal Short Term memory Composite score ($t(14) = 2.81$, $p < .05$), and the Counting recall subtest ($t(14) = 2.48$, $p < .05$) of the AWMA. Thus, indicating that the dyslexic groups' functioning was significantly different to controls on some tasks of short-term and working memory.

Overall Verbal short term memory differences assessed by simple span tasks such as Word Recall, Digit recall, and Pseudoword/Nonword recall have been shown to be present in dyslexic individuals when compared to normal controls (Helland & Asbjornsen, 2004; Palmer, 2000; Rose et al., 1999; Smith-Spark & Fisk, 2007; Smith-Spark et al., 2003). The verbal short-term memory composite score of the dyslexic group was significantly poorer than that of the Controls. The dyslexic group performed worse than the control group on all measures for verbal short term memory, the combined scores of the Word Recall, Digit Recall and Nonword Recall tasks, may reflect the significant difference obtained for the verbal short term memory composite score. Yet, when the verbal short term memory scores were separated out, differences were only found to exist on the Nonword Recall task. These findings can be reconciled in terms of regular words that can be recognised directly and the individual does not have to employ phonological processes, while with irregular nonwords' phonetic structure is unfamiliar and require an unfamiliar spoken response utilising their phonetic processing skill (Stanovich et al., 1997).

The differences between the groups on the Nonword Recall subtest are supported by the findings of Boada and Pennington (2006) who considered as part of a larger study, the relationship between implicit phonological representation and Nonword repetition in 11 – 13 year old dyslexic twin pairs. Similarly to the present findings with regard to Nonword recall, Boada and Pennington found that the dyslexic group scored worse than the chronological age twin pairs and reading age matched controls on the measure of Nonword repetition. The two measures are essentially the same task with the only difference between the present study and Boada and Pennington's study relating to the scoring of the two tasks, which was slightly more lenient in the present study compared to that of Boada and Pennington (2006). The nonwords recalled by the participants in the present study merely had to be repeated and sound as similar as possible to the word provided, while the Nonword repetition task in Boada and Pennington's study was scored in terms of the total number of correct phonemes pronounced correctly for a four-syllable word. Although these tasks differed slightly in scoring, the core differences were still acknowledged. It is evident that the Nonword/Pseudoword repetition or recall task is a skill that dyslexic children experience difficulty with relative to non-dyslexic children (Brunswick et al., 1999; Gathercole & Baddeley, 1990; Rack et al., 1992; Roodenrys & Stokes, 2001). Difficulty with this skill suggests that there is a problem within the phonological store of the phonological loop in terms of the phonological trace left by increased rapid decay in dyslexic individuals for coding, segmenting and identifying phonological information (Gathercole & Baddeley, 1990; Pennington et al., 2001).

The findings with regard to verbal working memory only revealed significant differences between the two groups on the Counting Recall task, which requires the maintenance and reproduction of digits while counting. The above findings have built on the results from Siegel and Ryan (1989) in terms of counting span tasks where reading disabled children performed worse than normal achieving children. Furthermore, the present findings are supported by De Jong's (1998) research. De Jong assessed deficits in working memory of 10-year old reading disabled children matched to two control groups on reading age and chronological age. His findings suggested that those children, who have a reading disability, may present with a general working memory deficit. These deficits could be due to the deficits in complex span tasks that do not reflect specific tasks tapping either the language or numerical domain. Furthermore, specifically with regard to the Counting Span task, which is methodologically similar to the Counting Recall task with the only exception being that the present studies' task was computerised, de Jong's findings revealed that the reading disabled group performed worse than controls. Overall verbal working memory differences were not present in the current studies' sample, although differences in overall verbal working memory have been identified elsewhere (Jefferies & Everatt, 2004; Kibby et al., 2004; Smith-Spark & Fisk, 2007).

According to Baddeley's (1986) working memory model, the differences observed thus far reflect poorer abilities within the phonological loop of the dyslexic group, these differences varying from possible storage problems, capacity problems, phonological coding problems and processing problems. Considering these differences and exploring the findings further, the memory constructs employed for the AWMA and DST-J tasks were investigated by considering the relationships between the subscales of the two measures.

A Pearson's correlation analysis aimed to establish whether dyslexic and non-dyslexic participants utilised similar memory constructs to access and process information. This analysis formed part of further examination of the group differences observed between the two groups on the AWMA. To this end the relationship between the AWMA and the DST-J subscales were investigated.

In terms of relationships between the verbal subtests of the AWMA and the DST-J, the control group presented with considerably more significant correlations between the two measures. The DST-J utilises a variety of measures to assess the Dyslexia 'at risk status' of children, these measures include for example assessments of short-term memory, working memory, reading ability, phoneme awareness, semantic knowledge, motor control and balance. If tasks that tap specific skill within short term or working memory are positively related, it would suggest that the same skills are utilised to successfully complete a given task. With regard to the verbal subscales of the AWMA, the control group appeared to utilize the same memory construct with a variety of the DST-J subscales, suggested by the positive correlations. Also, the negative correlations would indicate that as the memory construct is utilized for a specific task, performance of the other decreases. Thus, if words are required to be stored in short term memory for recall (Word Recall – AWMA), the constructs employed for timed spelling (DST-J) and nonsense reading (DST-J) were not actively engaged. The same can be seen for rapid naming (DST-J) and listening recall (AWMA), and rapid naming (DST-J) and backwards digit span (AWMA). The latter two correlations are a prime example where both visual recognition and a verbal response was engaged in the rapid naming task compared to auditory input and verbal response required by the listening recall (AWMA) and backwards digit span (AWMA) response.

Positive correlations in terms of the use of the phonological loop were identified between verbal short term memory composite score (AWMA) and backwards digit span (DST-J) and similarly correlations between digit recall (AWMA) and the backwards digit span (DST-J) as well as verbal fluency (DST-J) tasks. These tasks are consistent with accessing the phonological store of the Phonological loop, requiring storage of the verbal information. For backwards digit span the articulatory rehearsal system is activated to rehearse and maintain the initial information in the phonological store in order to repeat the sequence backwards. The verbal fluency task is dependent on accessing long term memory to retrieve known words that begin with a specific sound/letter/phoneme and place them in the short-term phonological store.

In terms of the verbal working memory tasks, the listening recall task (AWMA) was significantly correlated with one minute reading (DST-J), phonemic segmentation (DST-J), and vocabulary (DST-J). Listening recall is a complex working memory measure utilising auditory input that requires comprehension and maintenance of information and a subsequent verbal response. Phonemic segmentation assesses the ability to split words into their constituent sounds and a sensitive measure of phonological decoding and recoding ability, while the Vocabulary task evaluates receptive vocabulary by associating a word with a picture. Similarly counting recall (AWMA) and two minute spelling (DST-J) were significantly correlated, with counting recall storing and rehearsing digits and two minute spelling storing, rehearsing and decoding words. In all tasks the phonological loop's storage component for storage of information and phonological coding is utilised, and secondly the articulatory rehearsal system for the maintenance of the phonological trace in the phonological store, both contributing to comprehension of verbal input (Daneman & Merikle, 1996).

The findings that verbal working memory composite score (AWMA) is significantly correlated with the one minute reading (DST-J), phonemic segmentation (DST-J), nonsense reading (DST-J), and semantic fluency (DST-J) tasks, suggests that all four of the DST-J tasks utilise verbal working memory which engages with both the phonological storage and articulatory rehearsal systems of the phonological loop. Thus the significant relations between the short-term or working memory tasks and the DST-J tasks provide an indication that the control group accessed the similar memory construct for these tasks which require either verbal storage, verbal processing or phonetic decoding, comprehension and in many tasks a combination of the phonological loops' storage and processing abilities.

The dyslexic group presented with only two statistically significant correlations and both were positive. This in itself is interesting as it suggests that very few of the tasks employed the same constructs. The statistically significant correlation between backwards digit span (AWMA) and backwards digit span (DST-J) occurred understandably because these are the same tasks and suggests that the dyslexic group drew on the same skills for both subtests. The significant correlation between nonword reading (AWMA) and the rhyming subtest (DST-J) was very interesting. The phonological deficit in dyslexia is often assessed with the use of nonword reading tasks or rhyming (Griffiths & Snowling, 2002; Rack et al., 1992), and these tasks are helpful in detecting phonological processing and phonological awareness respectively. Dyslexic children have difficulty recognizing nonwords (these are all words that do not exist), furthermore, it has been shown that dyslexic individuals have difficulty with rhyming, or identifying rhyming words (Gathercole et al., 1991; Ramus, 2003; Ramus, Pidgeon, et al., 2003). Sensitivity to phonological awareness and the ability to decode phonological information has repeatedly been demonstrated with nonword repetition tasks with dyslexics consistently performing worse than controls (Gathercole et al., 1991; Ramus, 2003; Ramus, Pidgeon, et al., 2003; Snowling 2008). The findings thus indicate that both rhyming and nonword recall seem to tap the same skills responsible for identifying new words or nonwords and breaking them up in their phonemic segments.

The verbal short-term and working memory differences observed thus far, suggest that phonological decoding skills and the articulatory rehearsal system may be implicated in this sample. Secondly, considering subtype classification, the findings are consistent with the phonological subtype of dyslexia that has difficulty decoding nonwords.

Qualitative analysis of the reports revealed that consistent with the quantitative findings, the dyslexic cohort performed worse on many of the subtests of the AWMA. However, more than two of the dyslexic children performed better than their matched controls on the digit recall, word-recall, listening recall, mazes memory, Mr. X, and spatial span subtest, although not statistically significantly different. For the DST-J, it appears that the scores of the one minute reading, rhyme, two minute spelling, nonsense reading, and one minute writing subtests were identified as problematic in at least half of the dyslexic children. This suggests that this particular group presented with difficulties predominantly in the phonological domain according to the

DST-J assessment. Further analysis of the DST-J reports yielded consistently that weak literacy and weak phonological skill were the underlying problems in this particular sample. These findings appear to be consistent with previous findings in dyslexic samples, as most dyslexic individuals present with a phonological deficit (Palmer, 2000; Smith-Spark et al., 2003; Smith-Spark & Fisk, 2007; Stanovich et al., 1997).

4.2 Visuospatial Short Term Memory and Working Memory test performance

In terms of visuospatial short term and working memory group difference between the dyslexic and non-dyslexic groups, the present study analysed these differences using an independent samples t-test.

The dyslexic and non-dyslexic group differed significantly from each other on several of the visuospatial subscales. Thus, the second hypothesis of the present study was partly upheld. The non-dyslexic group's t-results were generally higher when compared to the t-results of the dyslexic group as with the verbal tests. Furthermore, the mean scores of the dyslexic group were significantly poorer to that of the control group. With regard to specific test differences, the scores of the dyslexic group was significantly poorer to that of the control group on the Dot Matrix subtest ($t(14) = 2.23$, $p < .01$), the Block Recall subtest ($t(14) = 2.69$, $p < .05$), the Visuospatial Short Term memory Composite score ($t(14) = 3.61$, $p < .01$), the Odd One Out subtest ($t(14) = 3.61$, $p < .01$) and the Visuospatial Working memory Composite score ($t(14) = 4.22$, $p < .01$) of the AWMA.

Consistent with the findings of Smith-Spark and Fisk (2007), who found differences in the Corsi block span measure of dyslexic adults when compared to the controls, the present study found significant visuospatial differences on the Block Recall task which is very similar to the Corsi block task between dyslexic and non-dyslexic groups. The composite score differences for visuospatial short-term memory and working memory supports findings from Helland and Asbjornsen (2003), Olson and Datta (2002), and Smith-Spark and Fisk (2007). Winner and colleagues (2001) found that dyslexic adults performed significantly worse than controls on a range of visuospatial tasks that assess similar components of Visuospatial short-term and working memory to the Odd One Out, Block recall and Dot Matrix subtests of the AWMA. Although Smith-Spark and Fisk (2003) and Winner et al. (2001) found visuospatial differences in adult dyslexics, Del Giudice and colleagues (2000) and Poblano et al. (2000) found evidence for a visuospatial deficit in dyslexic children. The present findings therefore provide valuable insight into the differences that exist for dyslexic children in this domain. Consequently, these results contribute to the findings of Poblano et al. (2000) who suggested that visuospatial working memory alterations may result in both auditory and visuospatial deficits in dyslexic children and to that of Del Giudice et al. (2000), who found a child who had significant visuospatial deficits.

The present findings were further contradictory to those of Jeffries and Everatt (2003; 2004), and Kibby et al. (2004), who found no significant differences in visuospatial tasks of dyslexic children when compared to controls. Von Karolyi (2001) and Von Karolyi and colleagues (2003) have suggested that dyslexics have global visuospatial strengths in terms of the speed at which they recognise impossible figures. This may not be in contradiction to the present findings as the tasks in the present study required focussing on specific aspects of the visuospatial stimuli that were not timed and not a global figure recognition task. However, dyslexic participants were outperformed by the controls when they had to match specific figures (Von Karolyi, 2001; Von Karolyi et al., 2003) which is consistent with the present findings. Reconciling the different findings is not easy as the differences may be due to developmental, co-morbitity or task issues. Also, most of the literature does not distinguish between dyslexic subtypes which could reflect the predominantly phonological deficit and ignored the visuospatial deficit.

Considering then that although the literature has been divided, it has been suggested that the visuospatial differences observed previously, may be related to domain general deficits in executive processing skills of the central executive and not merely contained to a verbal or visuospatial domain specific impairment (Nicolson & Fawcett, 1990; Nicolson et al., 1995; Palmer, 2000; Smith-Spark & Fisk, 2007; Swanson, 1993, 1999; Swanson & Sachse-Lee, 2001; Wolf & Bowers, 1999). There is evidence that the executive processing of the central executive provides a unique contribution to reading comprehension and word recognition (Swanson, 1999; Palmer, 2000). However the findings of the current study could not dissociate whether the differences observed were purely a result of domain specific differences or more domain general differences with aspects of the central executive being affected or even whether there may have been differences in attention that could be attributed to the observed differences.

Further examination of the group differences observed for the scores of the AWMA was conducted to investigate whether similar memory constructs are utilized to access and process information for visuospatial tasks. To this end the relationship between the AWMA and the DST-J subscales for dyslexic and control groups were investigated.

In terms of the visuospatial subtests of the AWMA and the DST-J, the findings revealed that the control group presented with considerably more significant correlations than the dyslexic group between the two measures, as with the verbal subtests. Negative correlations were found between the Mr X (AWMA) and Phonemic segmentation tasks, and Mr. X (AWMA) and one minute writing (DST-J) tasks. The Mr. X task requires visuospatial manipulation of information with a visuospatial response, while the phonemic segmentation and one minute reading tasks require verbal or written input and a verbal or written response, thus accounting for the negative correlation.

A significant positive correlation was observed between block recall (AWMA) and posture (DST-J). The block recall task measures visuospatial short term memory, thus accessing the visual cache for storage of visual and spatial information. The relation between the block recall task and the posture task, which was designed to provide a measure of balance to detect cerebellar abnormalities, is unexpected. It could possibly be related to the motor skill and control of eye movements, which is also associated with cerebellar sensitivity, required in the block recall task by following the hand and finger tapping the blocks and subsequently pointing to the blocks (Stoodley et al., 2006).

Interestingly, MR. X (AWMA) and rapid naming (DST-J) was significantly correlated and spatial span (AWMA) was significantly related to verbal fluency (DST-J) and semantic fluency (DST-J). The MR. X and Spatial span tasks both require the storage of visual and spatial information in terms of the visual representation and location of the objects in the visual cache and maintenance, rehearsal and retrieval of the decaying information by the inner scribe. Verbal and semantic fluency are tasks associated with verbal information, as such the correlations observed between visuospatial working memory tasks and these verbal tasks may be due to the children visually representing the words in mind by associating the words with pictures or symbolically visualising the words they retrieve from long term memory. Similarly the significant relationship between the visuospatial short-term memory composite score (AWMA) and verbal fluency (DST-J), and the visuospatial working memory composite score (AWMA) and backwards digit span (DST-J) could be due to mentally creating a visuospatial representation of the words and digits.

None of the significant correlations observed for the control group were observed for the dyslexic group, again suggesting that the dyslexic group utilises different components of memory for the tasks compared to their matched controls. The dot matrix (AWMA) task and the rapid naming (DST-J) task, as well as the spatial span (AWMA) task and the rapid naming (DST-J) task was negatively correlated. Positive correlations existed between the dot matrix (AWMA) task and one minute writing (DST-J), and odd one out (AWMA) and posture (DST-J). These correlations are consistent with what the tasks require at the cognitive level, separating the visual input and output of information from verbal output of information. The positive correlation between the dot matrix (AWMA) task and one minute writing (DST-J) task could be due to the one minute writing task requiring merely copying the sentence or paragraphing as quickly as possible. The dyslexic children may simply tap their visuospatial store by copying the words as pictures instead of processing the sentence through their verbal store while writing.

Poor posture has been implicated as one of the main indicators of being at risk for dyslexia due to abnormalities in the cerebellum (Nicolson at al., 1995; Stoodley et al., 2005; Stoodley et al., 2006). The cerebellum affects reading in a variety of ways; it is involved in the control of various motor movement, which includes control of eye movements, visuospatial attention and peripheral vision, all of which are important for reading and letter recognition and for maintaining good posture (Fawcett et al., 1996; Stein & Walsh, 1997). For this reason, it was interesting to see that the odd one out task which requires the participant to point to the odd picture and thereafter remembering where the odd picture was and pointing to its location in empty boxes, was positively related to posture as assessed by the Posture task on the DST-J. It supports the notion that there would be impairment in the cerebellum that affects eye movement and motor control as posited by Nicolson et al. (1995), Fawcett et al. (1996), Stoodley et al. (2005), and Stoodley et al. (2006). Although Stoodley and colleagues (2005, 2006) established that dyslexic adults and children tend to perform worse than controls on measures of balance, speed and accuracy of pointing tasks, differences for the pointing tasks were only obtained when speed and accuracy were combined. There has been mixed support for the cerebellar hypothesis with Heim et al. (2008) and Ramus, Rosen, et al. (2003) who found no differences on a variety of cerebellar tasks that included balance, finger tapping, bead threading, finger to thumb movements, and rhythm imitation.

The results indicating visuospatial short-term and working memory differences between dyslexics and controls, implies that the cognitive difficulties experienced by dyslexic individuals are not exclusively due to verbal storage or processing deficits. Both visuospatial storage systems and visuospatial maintenance and rehearsal systems affect dyslexics' performance on tasks that require the storage and maintenance of visual and spatial information. Thus, although there may be difficulties associated with the phonological decoding and processing of written text, the ability to store the visual written information would be affected by the differences within visuospatial short-term and working memory.

4.3 Limitations of the Study

Despite the value these findings may have within the South African context, a number of limitations were noted. These limitations relate to both the sample and instruments used.

Firstly, the sample utilized in the study was decidedly problematic. The small sample size and the method of sampling may have threatened the validity of the findings as a small sample size reduces the power of the statistical tests. In the attempt to include only children from a similar socio-economic background, convenience sampling and the matching paradigm resulted in the sample being obtained from a private mainstream school and private remedial schools/facilities in the Johannesburg area. Thus, the findings may only be generalised to pupils attending urban private schools. Further, in terms of the dyslexic group, no subtypes were specified in their diagnosis as provided in the Biographical questionnaire. Hence the findings may not be generalised to specific subtypes, but only to Dyslexia in general within this socio-economic group. This could possibly have been controlled for by asking the parents to specify which subtype of Dyslexia their child had. Co-morbid ADD, ADHD and epilepsy in two of the dyslexic children, could have influenced the findings. These children however have been receiving treatment for the co-morbid disorders. However, it is not clear to what degree the cognitive abilities of the children were affected.

Secondly, the cultural fairness of the instruments may be questioned. Limitations in this regard in general would be that both measures were in English and although all participants could speak, understand and write English, those who were bilingual could possibly have been at an added disadvantage even though they were matched to bilingual controls. Specifically for the AWMA, the test instructions are given in British English and the accent may have influenced the children's understanding, or it may have resulted in a cognitive distraction from the task being explained. Furthermore, not being able to access the individual scores for each completed task, lead to loss of data that could have provided further insight into where the differences started to occur, i.e. at a specific level of difficulty, or the number of errors made. With regard to the DST-J, some of the terminology and vocabulary used, South African children have not been exposed to, whereas British children have more exposure to terminology used in their culture.

4.4 Future Directions

In South Africa working memory differences in dyslexic children have largely been unexplored, and children who do present with reading difficulty in their early years of schooling do not always get the remedial intervention they require. This in turn provides the foundation for these children who go unidentified or unaided to develop problems with academic achievement which in turns leads to low self-esteem and acting out behaviourally.

The most useful aspect of this research is the basis it provides for future research within this area in the South African context. The findings provides a general view of dyslexic deficits in a limited sample, which presents the possibility to explore working memory deficits in not only the private setting but in government school settings as well. Other possibilities include identifying specific subtypes of dyslexia and considering which differences in working memory could be associated with the specific subtypes that exist. Further research in this area, specifically with children in their foundation years of schooling, could provide valuable information on how creative ways of intervention for dyslexic children could be implemented bearing in mind working with their specific working memory difficulty.

4.5 Conclusion

In conclusion, the aim of the study was to investigate whether there was a significant difference between the short-term and working memory performance of children with dyslexia and a matched control group. Short-term memory and working memory ability of the children were assessed using the AWMA. The results of the study have identified significant discrepancies in the performance on selected tasks tapping verbal short-term memory, verbal working memory, visuospatial short-term memory, and visuospatial working memory between the dyslexic and control groups. It was also established that the two groups utilise different memory constructs to complete a task when the subtests of the AWMA and the DST-J were correlated, suggesting that dyslexic children may utilise different skills to compensate for their difficulty in specific tasks. The main finding is that working memory and short-term memory difficulties are present in children diagnosed with dyslexia. Thus, utilising measures to assess working memory and developing strategies to implement learning support programmes to address the working memory difficulties would certainly benefit these children.

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APPENDIX

APPENDIX A: CONSENT FORM

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

School of Human and Community Development

Private Bag 3, Wits 2050, Johannesburg, South Africa

Tel: (011) 717-4500 Fax: (011) 717-4559

Email: 018lucy@muse.wits.ac.za

Consent Form

"Working Memory: A Comparison between Dyslexic and Non-Dyslexic Children"

*NOTE: **This consent form will remain with the University of the Witwatersrand researcher for their records***

I agree to take part in the University of the Witwatersrand research project specified above. I have had the project explained to me, and I have read the Subject Information Sheet that I will keep for my records. I understand that agreeing to take part means that I am willing to:

- **Agree to have my child assessed by the researcher**
- **Agree to have my child complete the Automated Working Memory Assessment relating to their Short term and working memory functioning.**
- **Agree to have my child complete the Dyslexia Screening Test – Junior which screens for indications of dyslexia.**
- **Agree to complete the Biographical Questionnaire that records information about my own and my child's demographic and biographic details.**
- **I agree to have the data collected used for further research that may be published provided that all information that could identify me be coded and kept confidential with restricted access to the researcher.**

I understand that data collected will be kept in secure restricted storage and accessible to the researcher, Maatje Scheepers.

I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party.

I understand that any data that the researcher extracts from the questionnaires and assessments for use in reports or published findings will not, under any circumstances, contain names or identifying characteristics.

I understand that my child's participation is voluntary, that I can choose that my child not participate in part of or the entire project and that I can withdraw my child at any stage of the project without being penalised or disadvantaged in any way.

Participant's name ……………………………………………………………………

Signature …………………………… **Date ………………………………..**

APPENDIX B: SUBJECT INFORMATION SHEET

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

School of Human and Community Development

Private Bag 3, Wits 2050,Johannesburg, South Africa

Tel: (011) 717-4500 Fax: (011) 717-4559

Email: 018lucy@muse.wits.ac.za

Subject Information Sheet

"Working Memory: A comparison between Dyslexic and Non-dyslexic Children"

Dear Parent
My name is Maatje Scheepers and I am conducting a research project with Dr. Kate Cockcroft as my supervisor in the Department of Psychology at the University of the Witwatersrand towards a Masters in Research Psychology.

The aim of this study is to determine what differences and relationships exist in the working memory of individuals who have dyslexia and who do not have dyslexia. The 'normal' functioning of working memory is essential given the amount of information processing required in the classroom setting. The present study will focus specifically on the relationship between working memory and dyslexia as a learning and reading impairment in children. The data generated from this will provide further insight into the underlying deficits in working memory of individuals with dyslexia and provide valuable information with regard to the effectiveness of the Automated Working Memory Assessment (AWMA) as a screening tool for working memory impairments in the South African population. This data will help researchers understand the various underlying deficits that exist on a working memory level in learning disabled populations and aid in the development of an intervention programme for these individuals.

I would like to invite your child to participate in the study. Participation will involve the completion of three assessments/questionnaires, the first assessing the working memory components of the children (the Automated Working Memory Assessment, (AWMA)), the second screening for dyslexia in order to have a baseline for both groups (the Dyslexia Screening Test - Junior), and the third, a Biographical Questionnaire, to be completed by parents in order to collect demographic information for matching purposes. The AWMA is a computerised assessment administered by the researcher and the trained research assistants. The other two assessments are administered and scored by the researcher or the trained research assistants and the Biographical Questionnaire is completed by the child's parent(s)/guardian.

The completion of the two assessments will take a maximum of 120 minutes of the child's time. Assessment will take place at a time negotiated with the parents and the school. This will be conducted at the school in a quiet environment across two separate sessions to reduce fatigue in the children. The Biographical Questionnaire will take approximately 15 minutes to complete and may be returned to the researcher in a sealed envelope that will be provided. I will be using the results of these assessments for my research project.

No findings that could identify any individual participant will be published, only those findings of the combined results of all participants will be used. The data collected from you and your child will be stored by the University in a secure place and will contain no personal information or identifying information. Only

I will have access to the data and identities of the data and this will be destroyed as soon as the data has been captured.

A report of the study other than the thesis may be disseminated to interested parties, or published in a professional journal, but individual participants will not be identifiable in such a report.

Participation in this study is completely voluntary and you are under no obligation to consent to have your child participate. If you choose to have your child participate or decline to participate in this research project, your relationship with the school will not be affected. If you agree to participate, you may withdraw at any time without prejudice. The data collected may be used for other purposes (i.e. further study) but will remain confidential and no individual participant will be identifiable in the publication of any findings that result from further use of the data. If the researcher finds any result from the assessment that is of concern for any individual child, the child will be referred to the school psychologist for further assessment and guidance.

A general feedback session will be held at the school after completion of the research project to give feedback of the overall findings of the study. Written feedback for both assessments will be provided for each child and given to the parents. These reports are part of a research project and the assessment measures used are under investigation as well. Thus the feedback given should not be used as an educational or scholastic assessment of your child. Should you find after completion of the assessments that you would like to discuss anything relevant to the study or the contents of the questionnaires/assessments further, please feel free to contact us.

If you would like to contact the **researchers** about any aspect of this study, please contact the Chief Investigator:	If you have a **complaint** concerning the manner in which this research **(project number: H070612)** is being conducted, please contact:
Prof. Kate Cockcroft **Tel: 011 717 4511** **E-mail: kate.cockcroft@wits.ac.za** **Ms. Maatje Scheepers** **Tel: 011 795 1596** **Fax: 086 607 7971** **E-mail: maatjecj@gmail.com**	Human Ethics Officer Human Research Ethics Committee (HREC) Tel: 011 717 1234

Kind Regards

Maatje Scheepers

APPENDIX C: ASSENT FORM-CHILDREN

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

School of Human and Community Development

Private Bag 3, Wits 2050, Johannesburg, South Africa

Tel: (011) 717-4500 Fax: (011) 717-4559

Email: 018lucy@muse.wits.ac.za

Assent Form - children

"Working Memory: A comparison between Dyslexic and Non-dyslexic Children"

Date: …………………

This is to confirm that I (the researcher) have explained the process of assessment and what is required of the child to them, also that I have explained that they are allowed to stop me at any time if they do not want to participate further, are tired, do not understand what they have to do, or would like to have a break without any consequences. The following statement is what would be told to the child:

"I would like to do an assessment with you, this assessment is like an exercise to see how well you remember things. It doesn't matter if you get the answers wrong, just do your best. If you want to stop you can tell me and we will stop. If you are tired and would like a break, you can tell me and we will have a break. If you don't understand something in the exercise you are welcome to ask me. Is it alright if I do this assessment with you, would you help me?"

I …………………………………………………………….agree to participate.
Name of child

………………………………
Maatje Scheepers

………………………………
Child's name

APPENDIX D: BIOGRAPHICAL QUESTIONNAIRE

Biographical Questionnaire

This questionnaire is intended to collect information for matching purposes only. All information will be kept strictly confidential. Only the researcher will have access to this data.)

1. Name of parent/guardian …………………………………………………………………

2. Name of child ……………………………………………………………………….

3. Date of birth (child) ……………………………………………………………………

4. Gender of child

Male	Female

5. Population group

Black	Coloured	Indian	White	Other

6. Home language ………………………………………………………………………..

7. Has your child had psychological/educational evaluations?

Yes	No

8. Has your child been diagnosed with a learning or reading disorder?

Yes	No

9. If you answered **<u>yes</u>** to number **8** above, please state what learning or reading disorder i.e. dyslexia

………………………………………………………………………………………...

10. Has your child had any other therapy such as the following?

Speech Therapy	Occupational Therapy	Physio	Remedial lessons	Other

If **Other** please specify………………………………………………………………..

11. Has your child repeated a year at school?

Yes	No

APPENDIX E: ETHICAL CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Scheepers

CLEARANCE CERTIFICATE **PROTOCOL NUMBER H070612**

PROJECT Working Memory: A comparison between dyslexic and non-dyslexic children

INVESTIGATORS Miss M Scheepers

DEPARTMENT School of Human and Community Development/Psychology

DATE CONSIDERED 07.06.15

DECISION OF THE COMMITTEE* Approved unconditionally

NOTE:

This ethical clearance is valid for 2 years and may be renewed upon application

DATE 07.07.18 **CHAIRPERSON** ....
(Professor M Vorster)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : Dr K Cockroft
School of Human and Community Development

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

This ethical clearance will expire on 1 February 2009

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix F: Histograms of Normality Plots for AWMA and DST-J

Histograms of normality for Non-dyslexic cohort

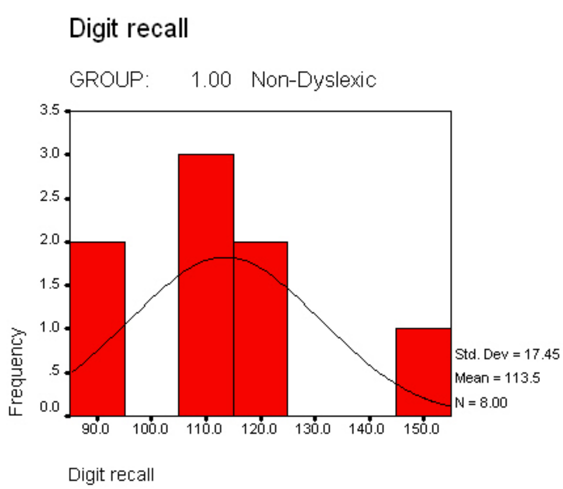


Figure 3: Digit Recall (AWMA)

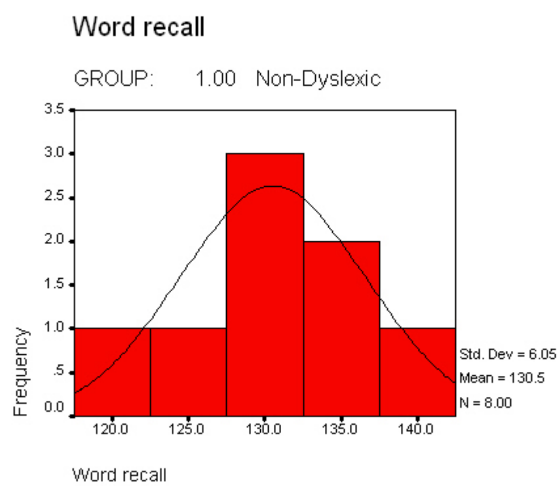


Figure 4: Word Recall (AWMA)

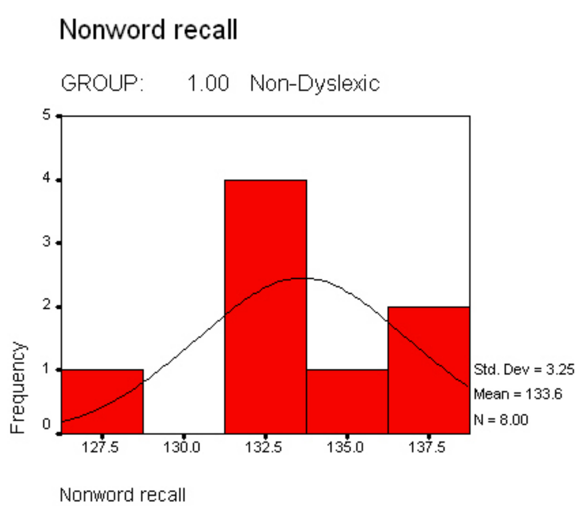


Figure 5: Nonword Recall (AWMA)

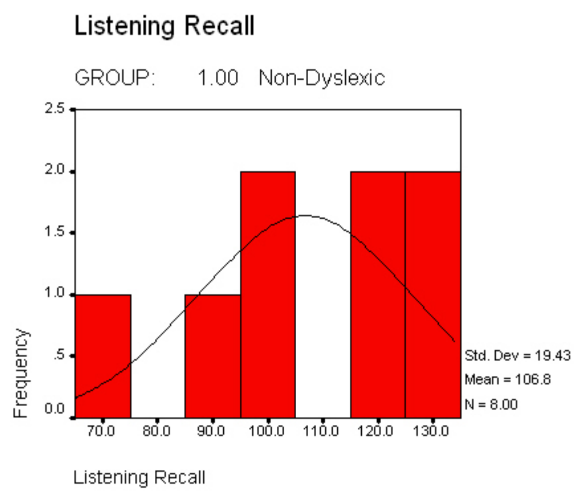


Figure 6: Listening Recall (AWMA)

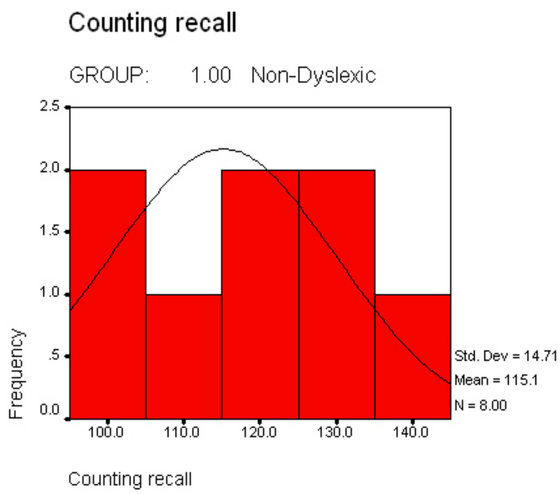


Figure 7: Counting Recall (AWMA)

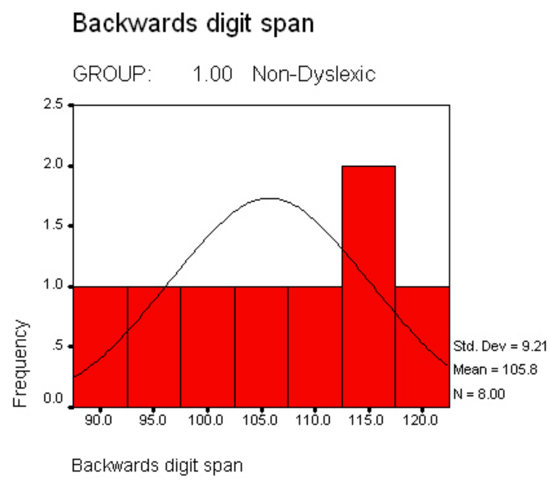


Figure 8: Backwards Digit Span (AWMA)

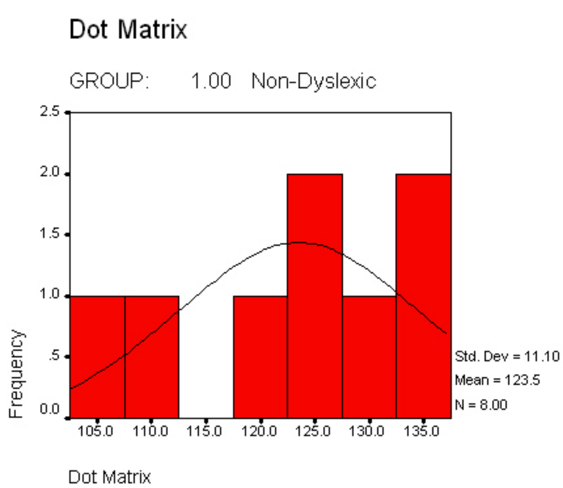


Figure 9: Dot Matrix (AWMA)

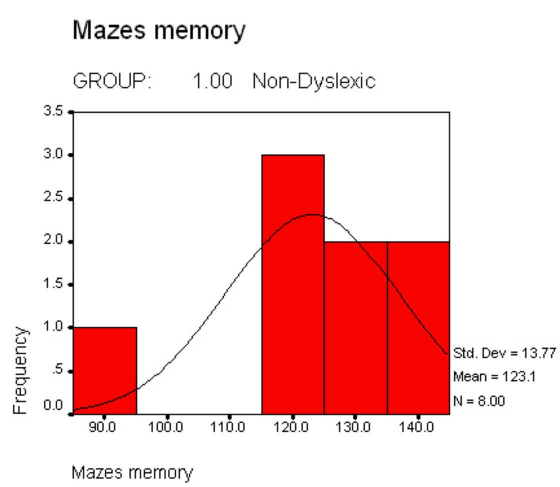


Figure 10: Mazes Memory (AWMA)

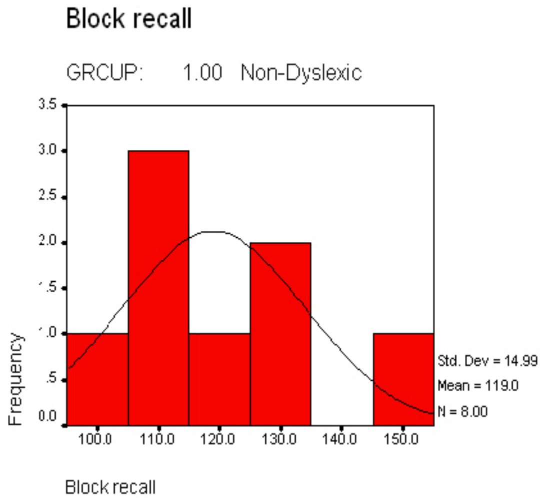


Figure 11: Block Recall (AWMA)

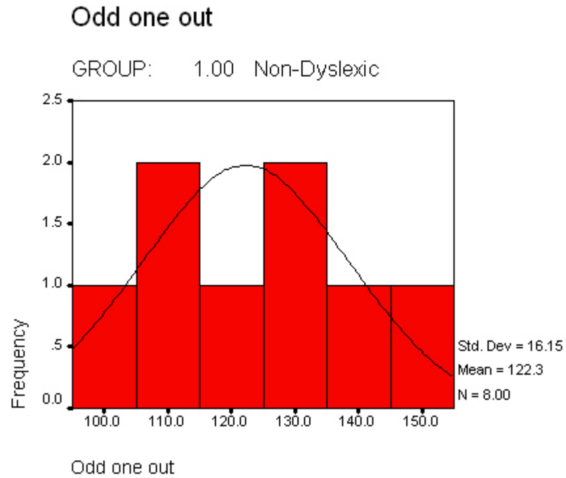


Figure 12: Odd One Out (AWMA)

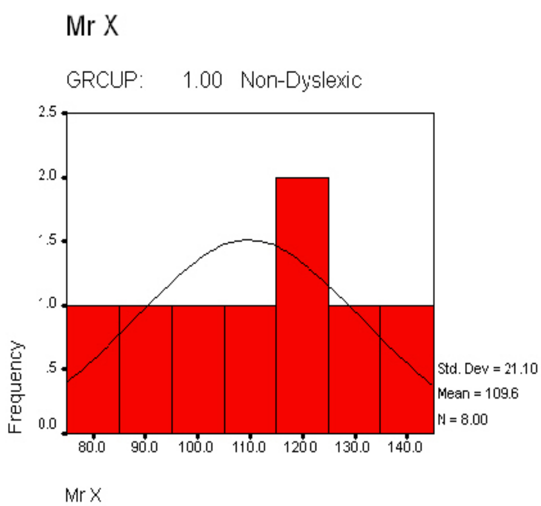


Figure 13: Mr X (AWMA)

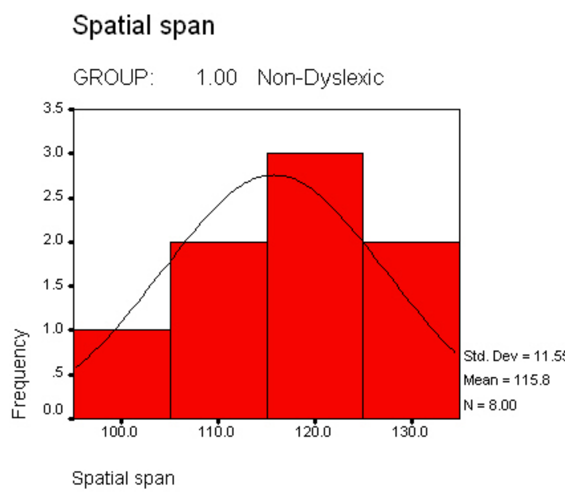
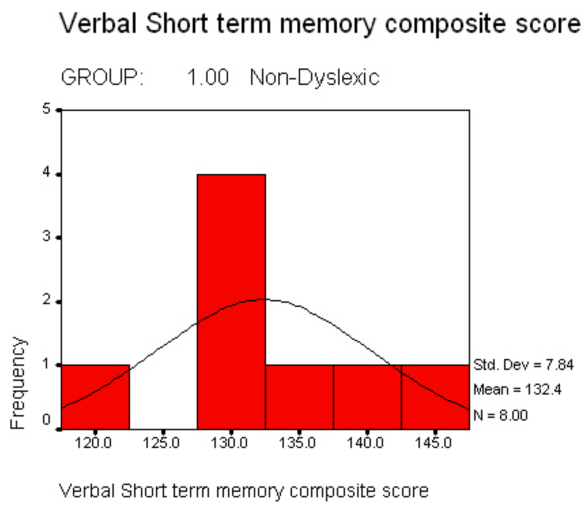


Figure 14: Spatial Span (AWMA)



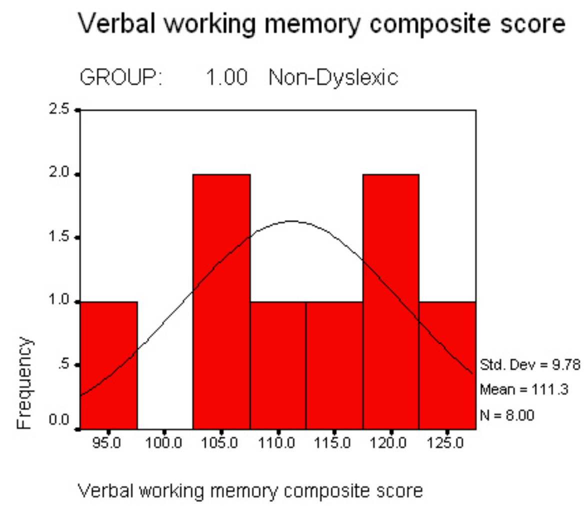
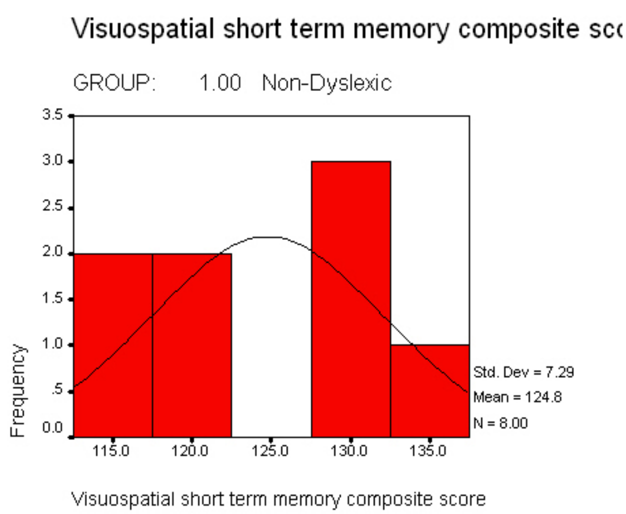


Figure 15: Verbal Short Term Memory (AWMA) Figure 16: Verbal Working Memory (AWMA)



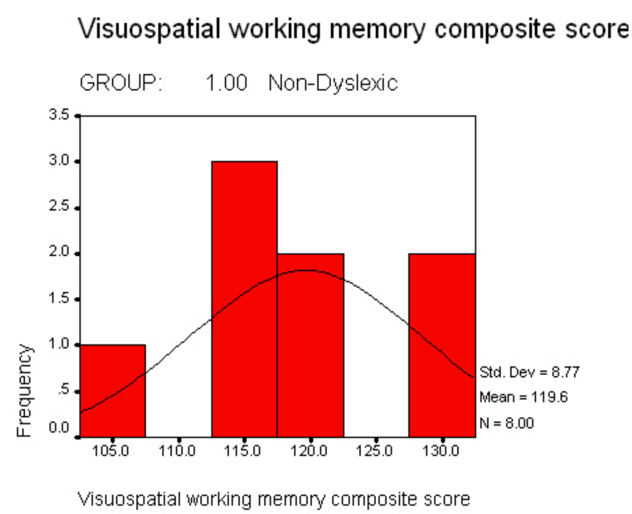


Figure 17: Visuospatial Short Term Memory (AWMA) Figure 18: Visuospatial Working Memory (AWMA)

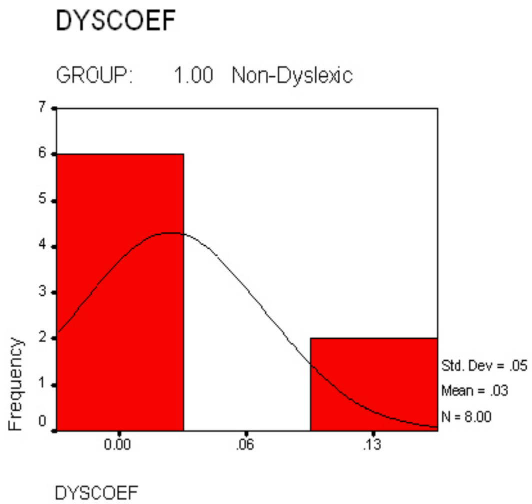


Figure 19: Dyslexia Quotient (DST-J)

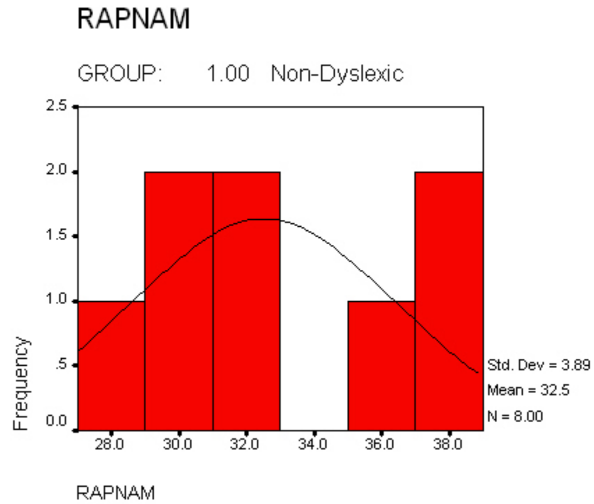


Figure 20: Rapid Naming (DST-J)

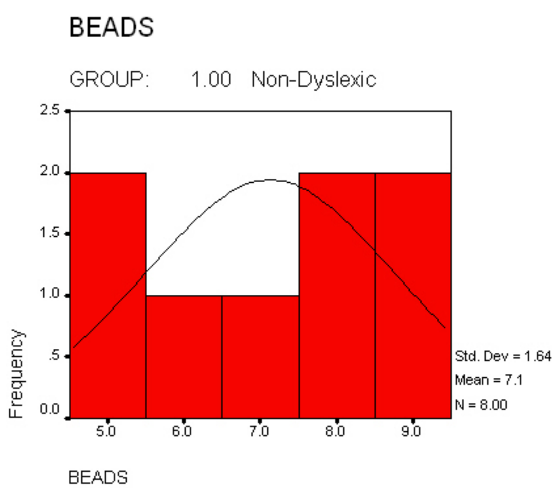


Figure 21: Bead Threading (DST-J)

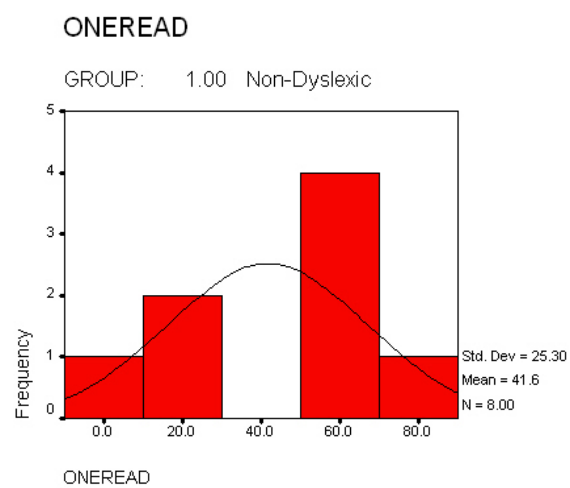


Figure 22: One Minute Reading (DST-J)

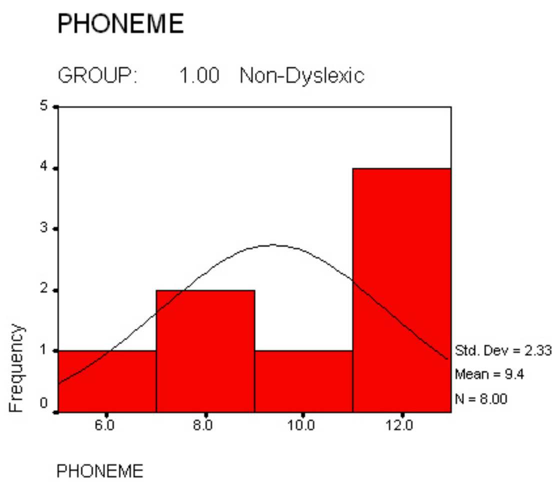


Figure 23: Phonemic Segmentation (DST-J)

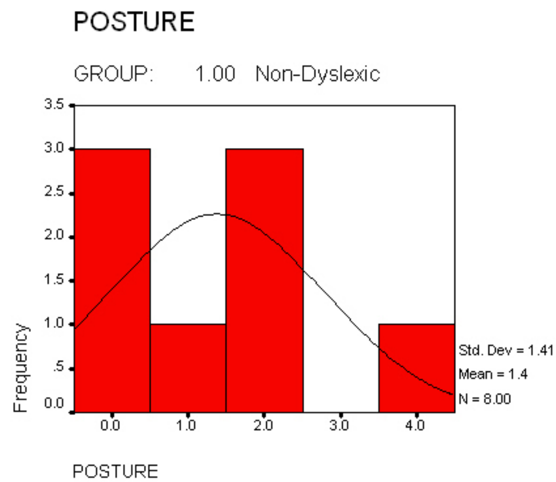


Figure 24: Postural Stability (DST-J)

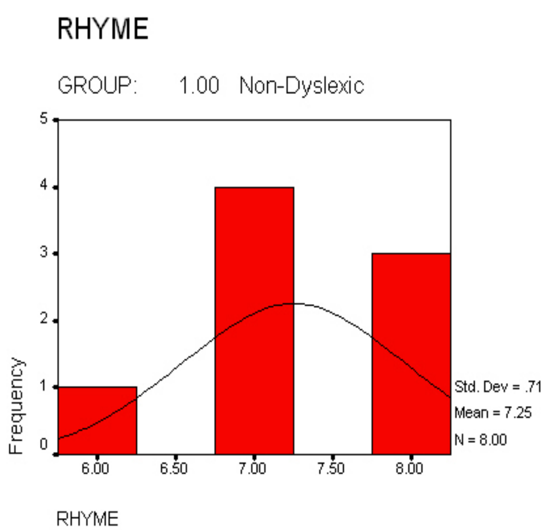


Figure 25: Rhyming (DST-J)

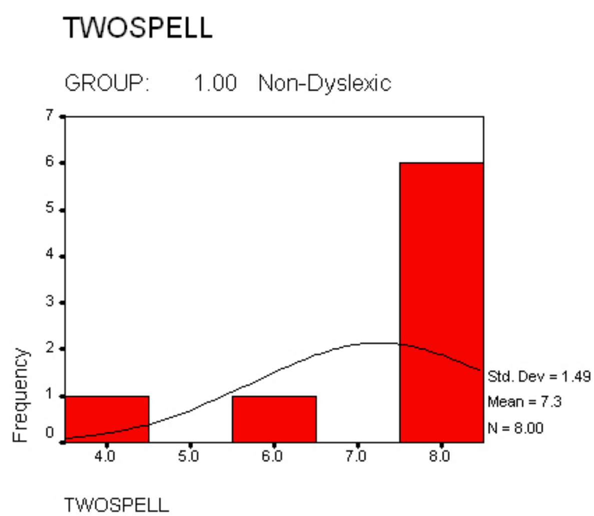


Figure 26: Two Minute Spelling (DST-J)

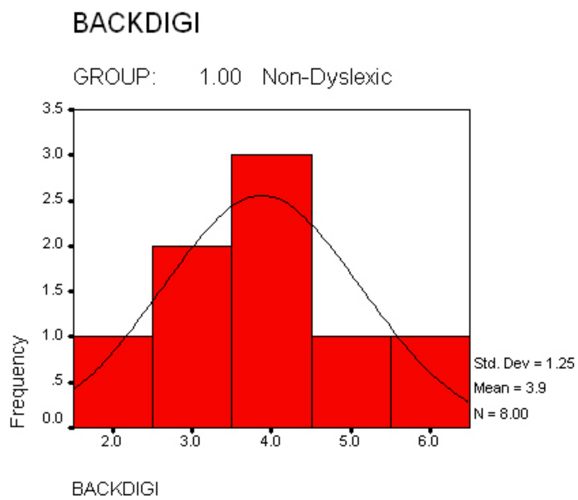


Figure 27: Backward Digit Span (DST-J)

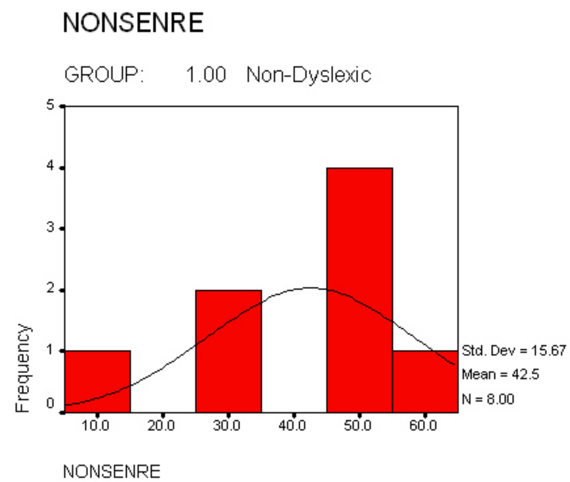


Figure 28: Nonsense Reading (DST-J)

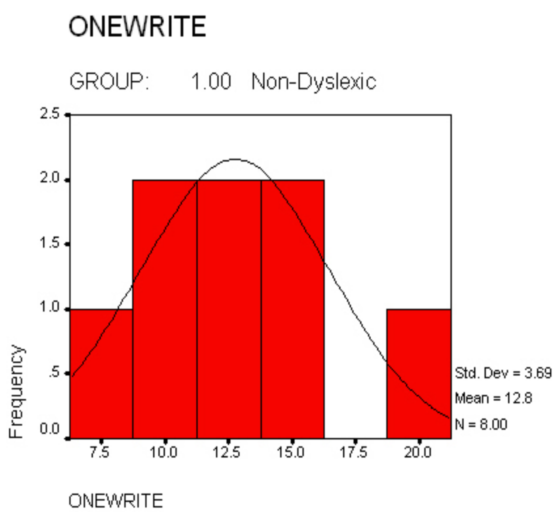


Figure 29: One Minute Writing (DST-J)

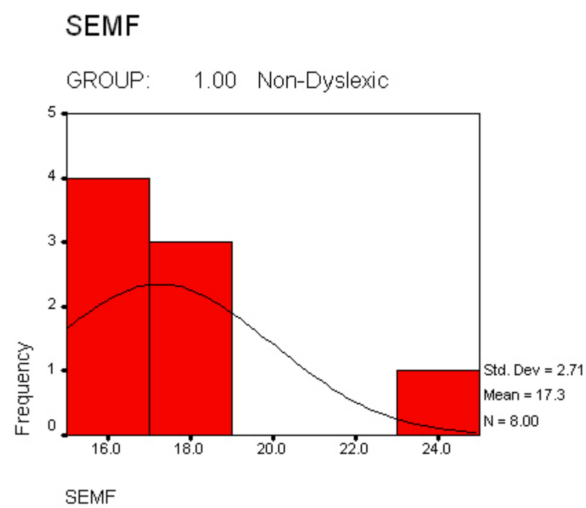
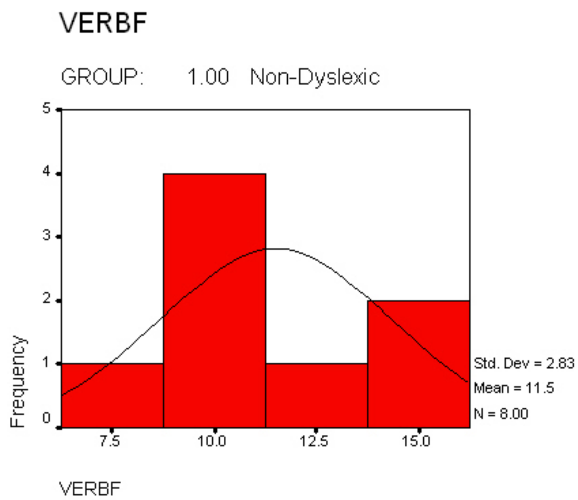


Figure 30: Semantic Fluency (DST-J)



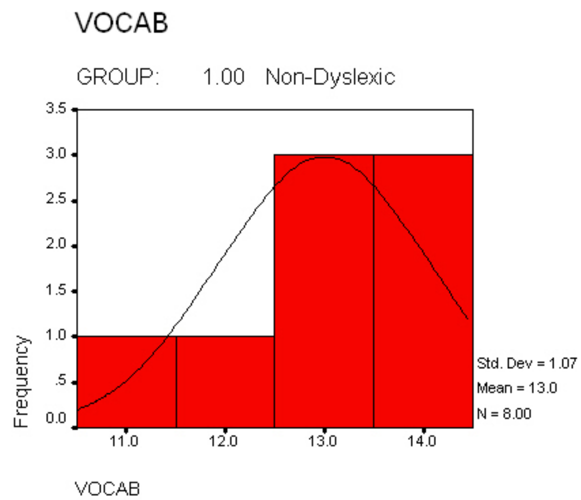


Figure 31: Verbal Fluency (DST-J)

Figure 32: Vocabulary (DST-J)

Histograms of normality for Dyslexic cohort

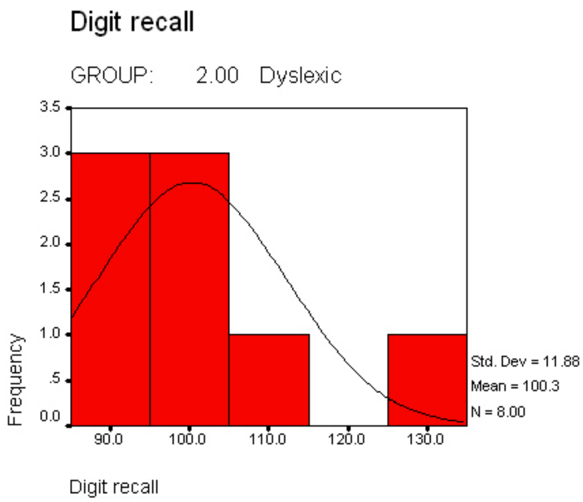


Figure 33: Digit Recall (AWMA)

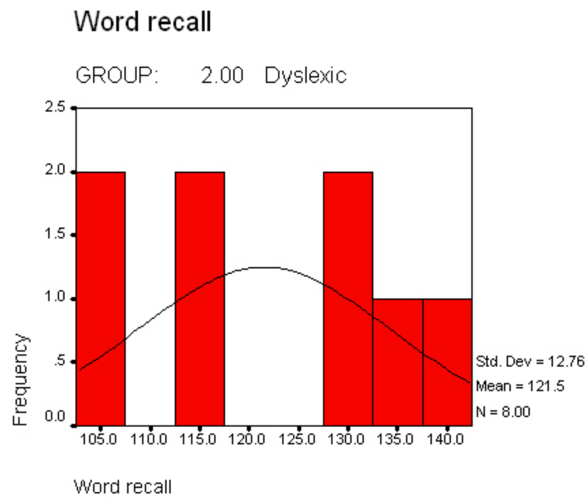


Figure 34: Word Recall (AWMA)

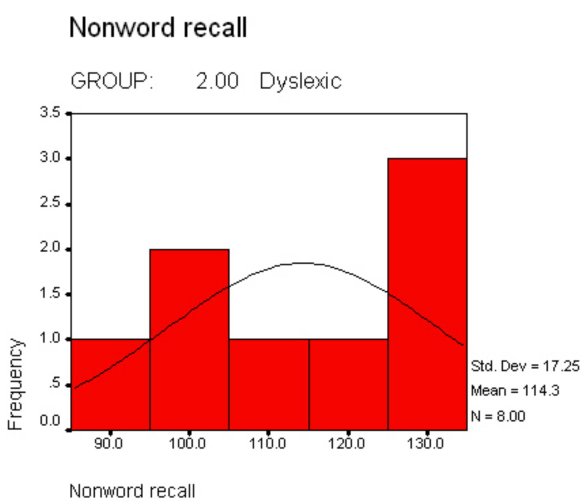


Figure 35: Nonword Recall (AWMA)

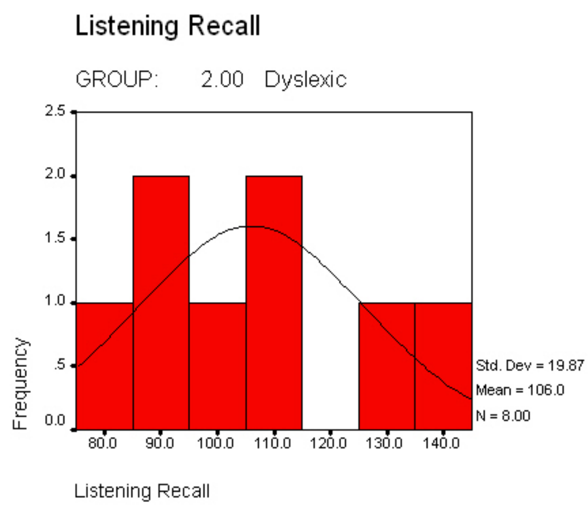


Figure 36: Listening Recall (AWMA)

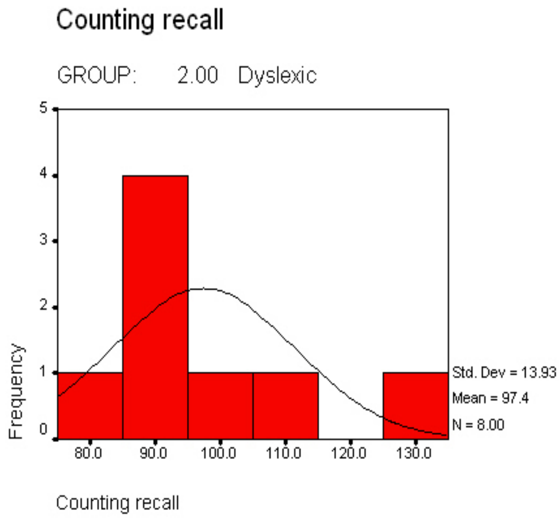


Figure 37: Counting Recall (AWMA)

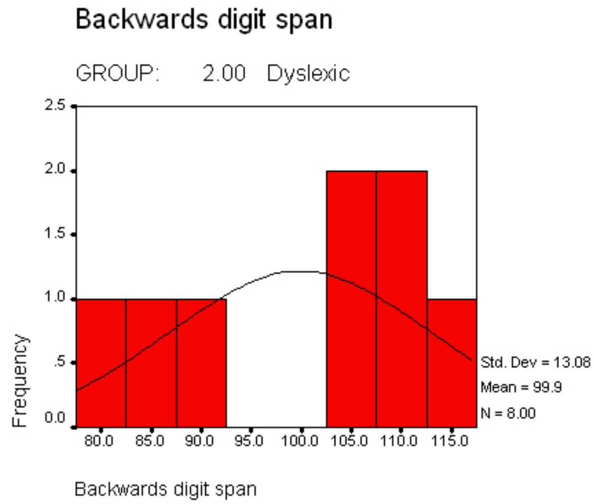


Figure 38: Backwards Digit Span (AWMA)

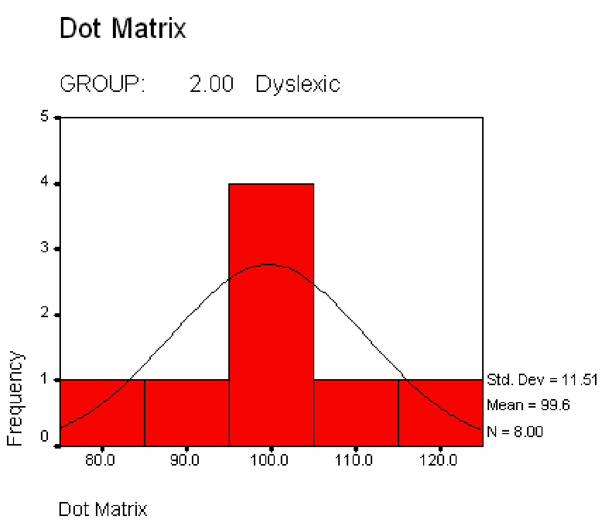


Figure 39: Dot Matrix (AWMA)

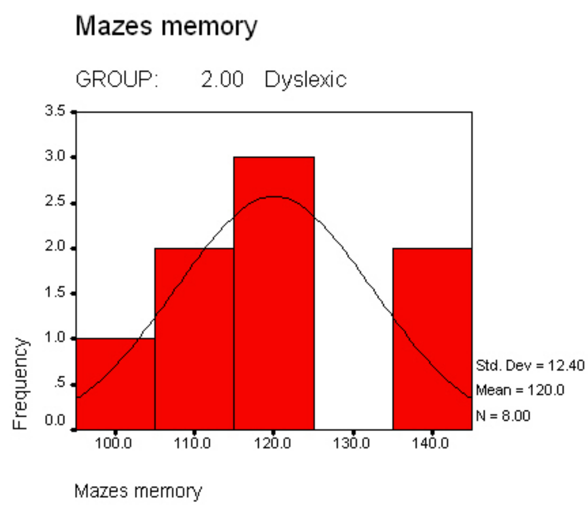


Figure 40: Mazes Memory (AWMA)

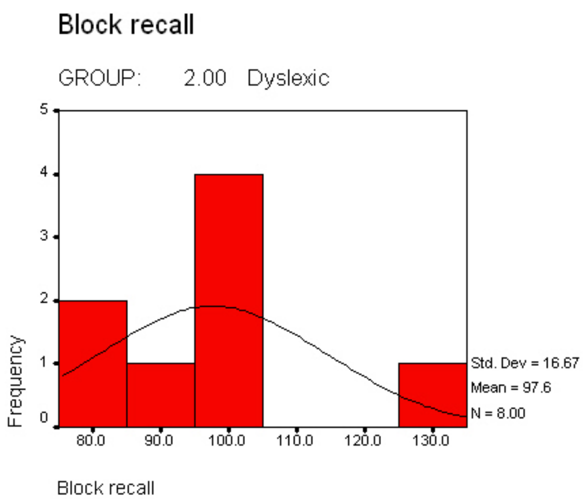


Figure 41: Block Recall (AWMA)

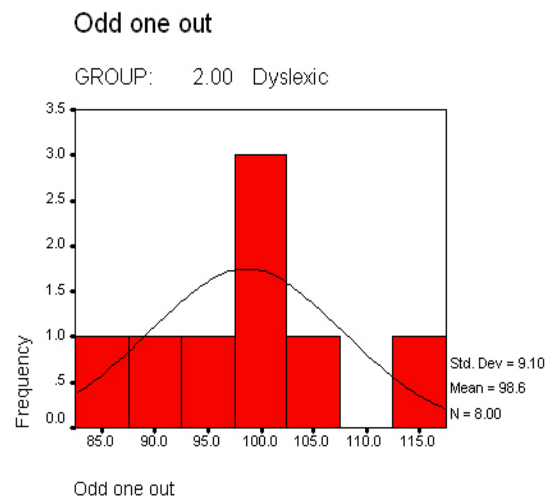


Figure 42: Odd One Out (AWMA)

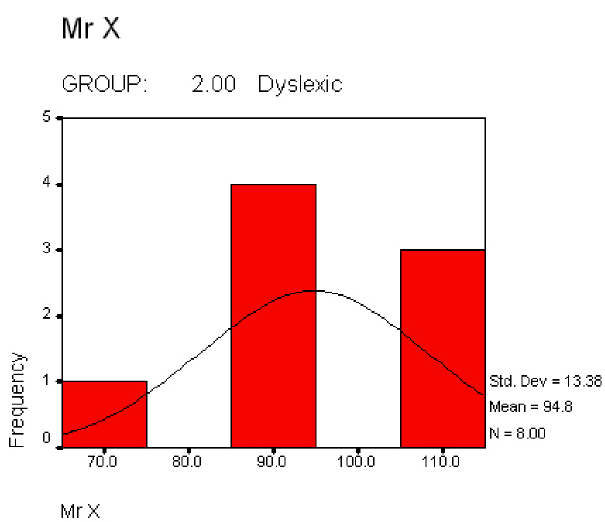


Figure 43: Mr X (AWMA)

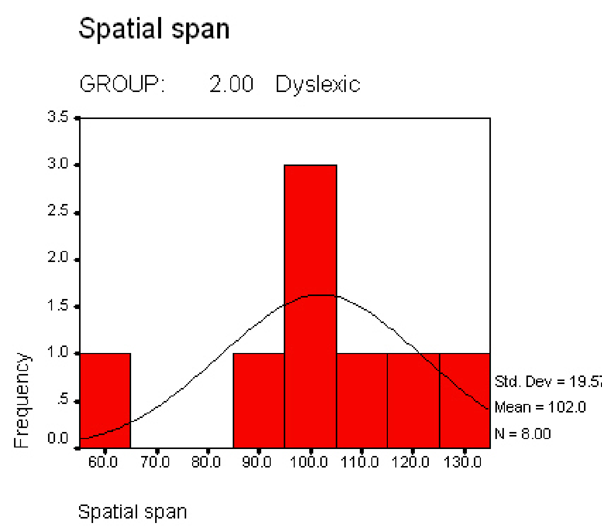


Figure 44: Spatial Span (AWMA)

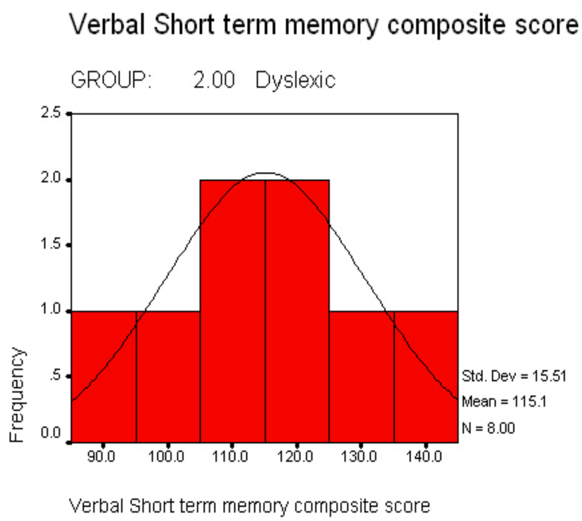


Figure 45: Verbal Short Term Memory (AWMA)

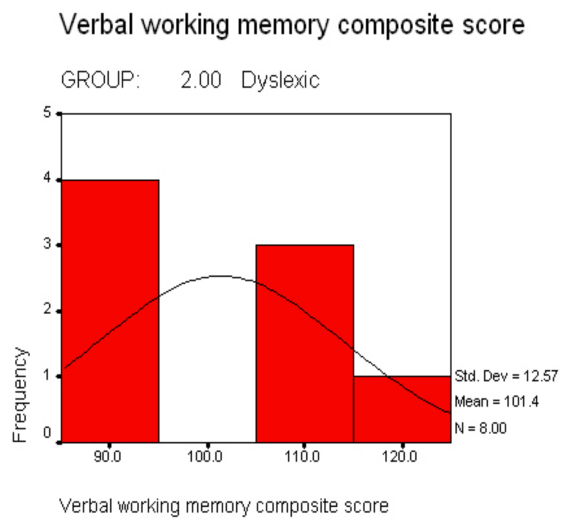


Figure 46: Verbal Working Memory (AWMA)

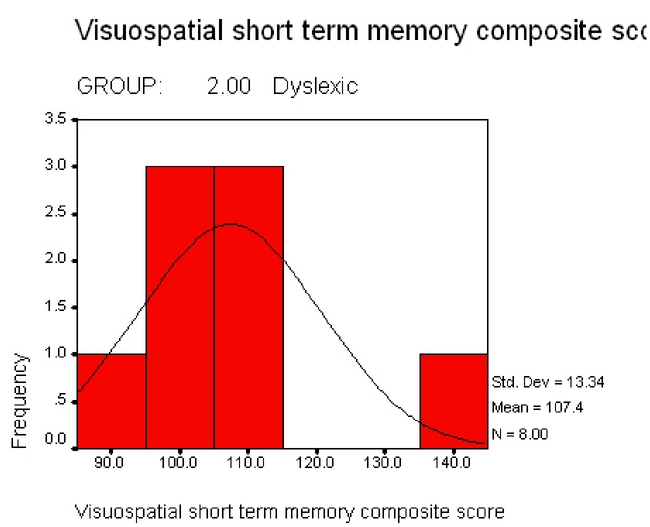


Figure 47: Visuospatial Short Term Memory (AWMA)

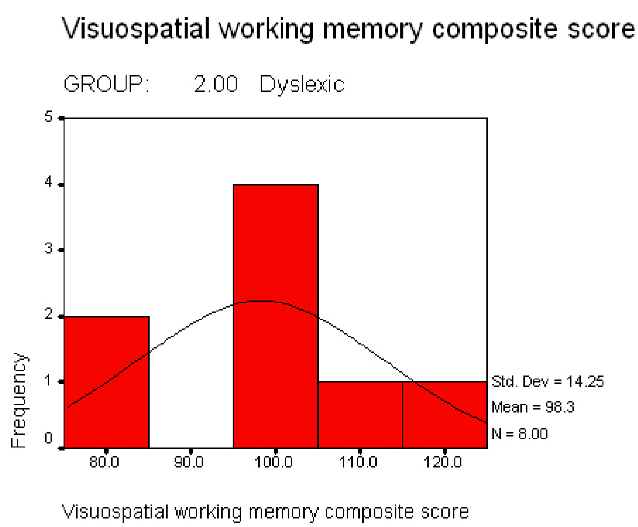


Figure 48: Visuospatial Working Memory (AWMA)

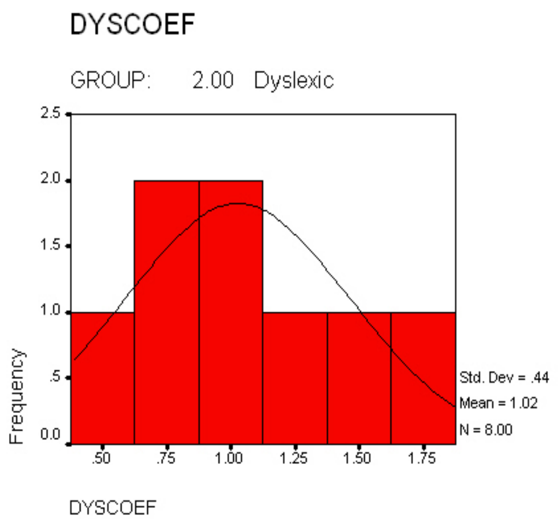


Figure 49: Dyslexia Quotient (DST-J)

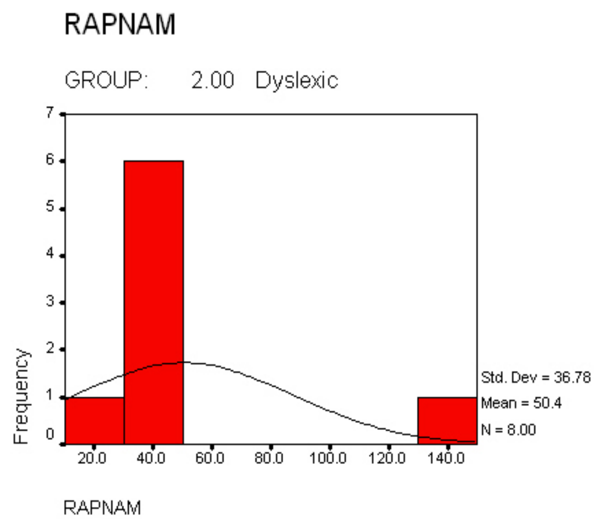


Figure 50: Rapid Naming (DST-J)

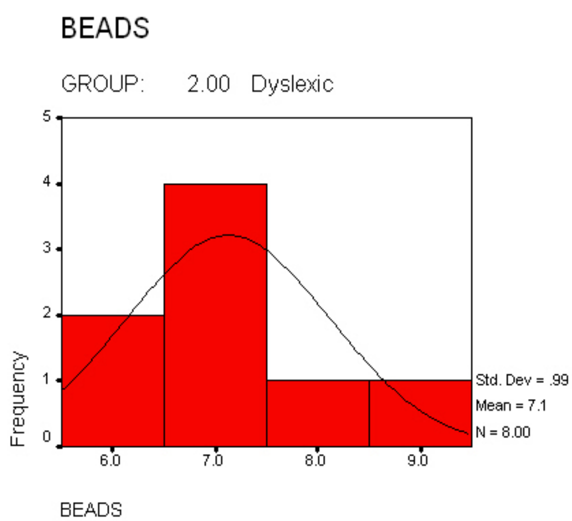


Figure 51: Bead Threading (DST-J)

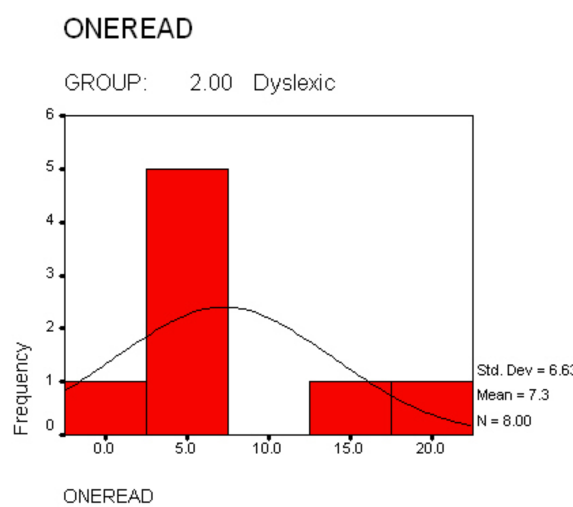
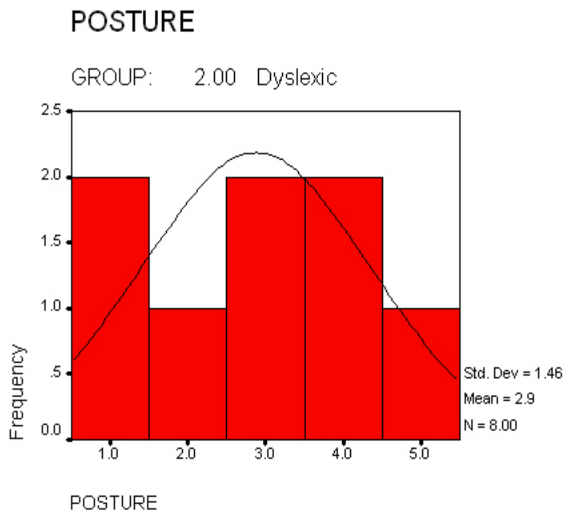


Figure 52: One Minute Reading (DST-J)



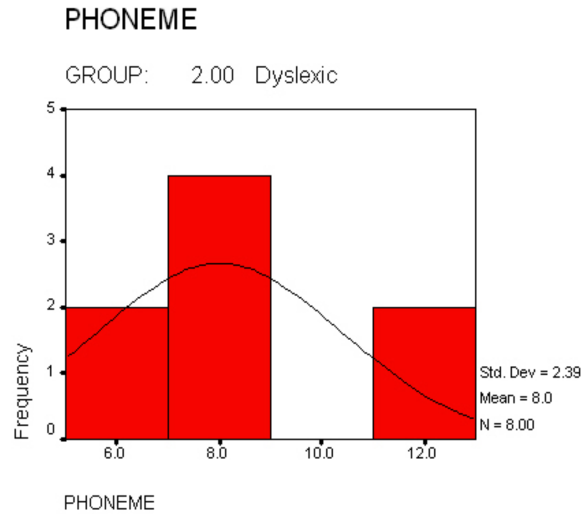
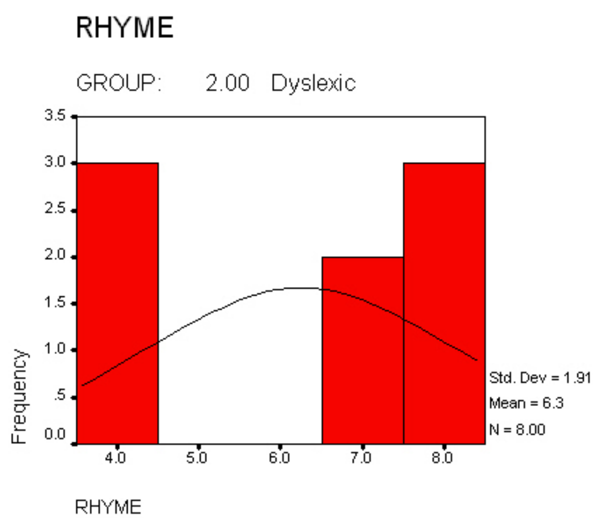


Figure 53: Phonemic Segmentation (DST-J)

Figure 54: Postural Stability (DST-J)



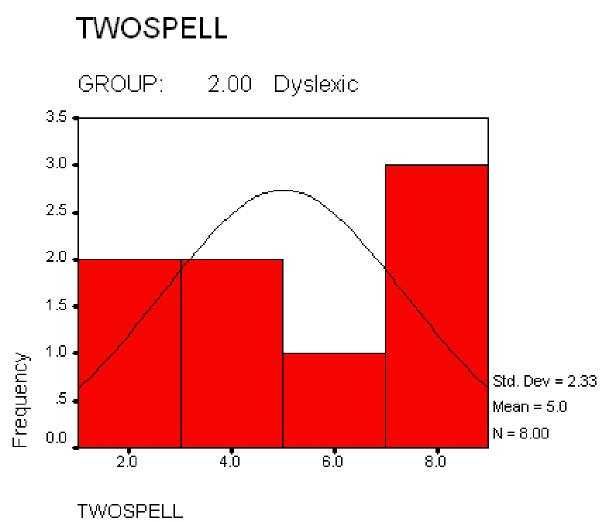


Figure 55: Rhyming (DST-J)

Figure 56: Two Minute Spelling (DST-J)

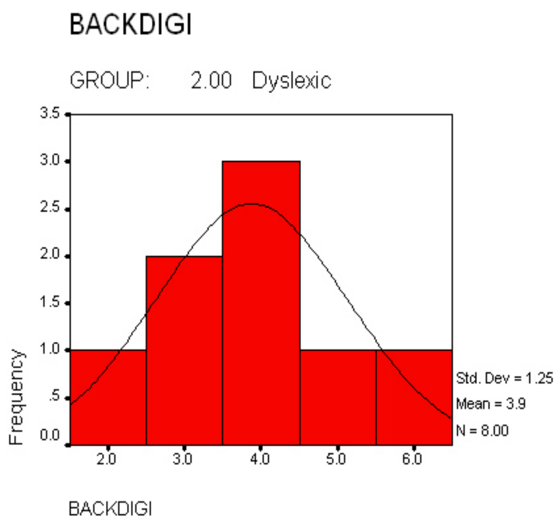


Figure 57: Backward Digit Span (DST-J)

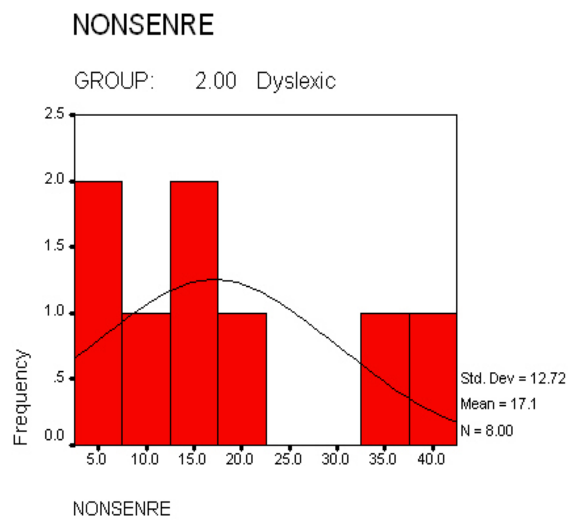


Figure 58: Nonsense Reading (DST-J)

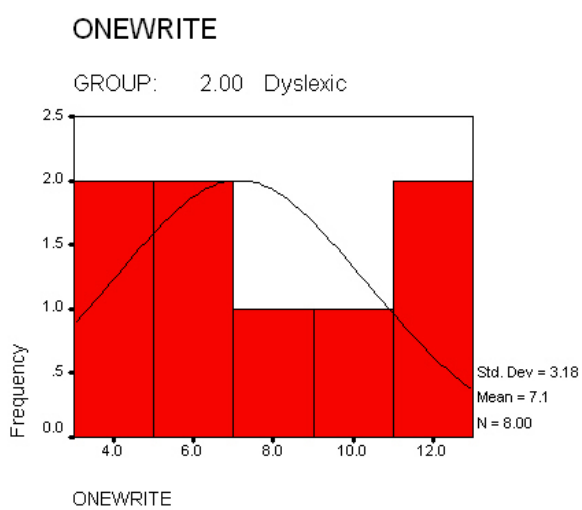


Figure 59: One Minute Writing (DST-J)

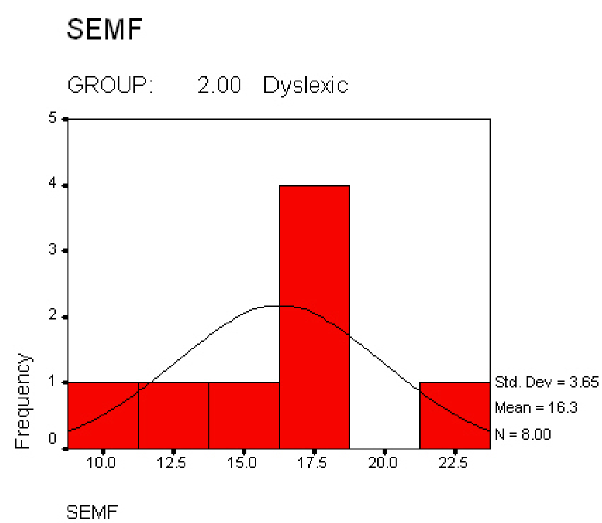


Figure 60: Semantic Fluency (DST-J

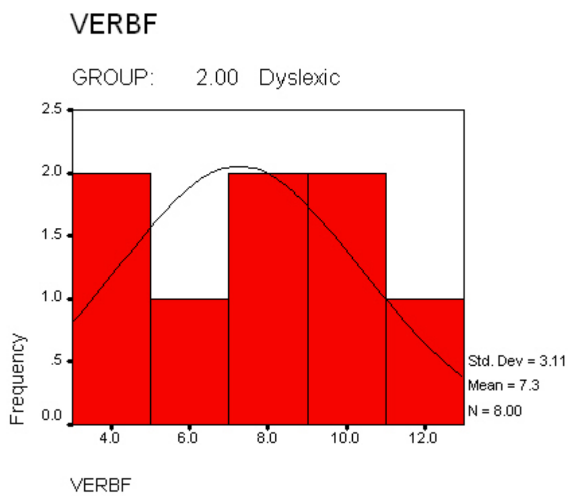


Figure 61: Verbal Fluency (DST-J)

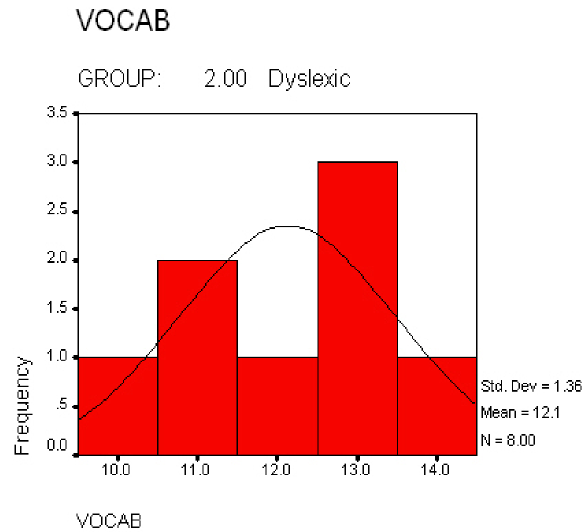


Figure 62: Vocabulary (DST-J)

APPENDIX G: NON-PARAMETRIC ANALYSIS

Table 9: Wilcoxon Rank-Sum test z-scores, p-value and effect sizes for AWMA group differences for dyslexic and non-dyslexic children.

	Wilcoxon W (Z)	***Cohen's d***
Digit Recall	1.477	0.78
Word Recall	1.480	0.78
Nonword Recall	2.698**	1.43
VSTM comp	2.417*	1.28
Listening recall	0.053	0.03
Counting recall	2.266*	1.2
Backwards digit span	0.999	0.53
VWM comp	1.578	0.84
Dot Matrix	2.998**	1.59
Mazes memory	0.743	0.39
Block Recall	2.530*	1.34
VSSTM comp	2.579**	1.37
Odd-one-out	2.739**	1.45
Mr X	1.526	0.81
Spatial Span	1.581	0.84
VSWM comp	2.688**	1.42

Note: * = $p < 0.05$; ** = $p < 0.01$

Table 10:

Spearman's Correlation Coefficients for Verbal AWMA subtests and DST-J subtests for non-dyslexic and dyslexic participants.

DSTJ Subscales

AWMA Suscales	Rapid Naming	Bead Threading	One Min Reading	Posture	Phonemic Segmentation	Rhyming	Two min Spelling	Backwards Digit Span	Nonsense reading	One min Writing	Verbal fluency	Semantic fluency	Vocabulary
Digit Recall	-.163	-.287	.327	.126	.148	.007	.659	.630	.247	-.551	.528	.378	.252
Word Recall	.327	.110	-.713*	.329	-.721*	-.779*	-.718*	.385	-.876**	-.120	.012	-.532	-.215
Nonword Recall	.353	-.046	-.620	.242	-.553	-.469	-.334	-.026	-.579	-.358	-.092	.081	-.644
VSTM comp	-.054	-.152	.061	.302	-.247	-.459	.353	.834*	-.080	-.755*	.712*	.353	.201
Listening recall	-.831*	.341	.733*	.151	.692	.439	.486	.154	.704	.228	.417	.705	.642
Counting recall	.072	-.424	.554	.300	.147	.209	.764*	.405	.528	-.667	.317	.601	.250
Backwards digit span	.814*	-.109	-.446	.551	-.172	-.065	.062	.282	-.466	-.071	-.342	-.350	-.150
VWM comp	-.443	.194	.747*	.501	.577	.365	.733*	.466	.687	-.119	.488	.801*	.726*
Digit Recall	**.733***	**-.601**	**-.618**	**.166**	**-.226**	**.064**	**.025**	**.211**	**-.349**	**-.333**	**-.578**	**-.679**	**-.596**
Word Recall	**.675**	**.186**	**.108**	**-.159**	**.327**	**.539**	**.238**	**.056**	**.419**	**-.042**	**.108**	**-.356**	**-.123**
Nonword Recall	**.361**	**.199**	**.367**	**.024**	**.382**	**.887****	**-.024**	**-.062**	**.419**	**.229**	**.252**	**-.025**	**-.006**
VSTM comp	**.539**	**.153**	**.228**	**-.085**	**.386**	**.756***	**.145**	**.000**	**.429**	**.132**	**.167**	**-.220**	**-.061**
Listening recall	**.407**	**-.447**	**-.252**	**.073**	**.133**	**.315**	**.170**	**.417**	**-.095**	**-.072**	**-.214**	**-.317**	**-.147**
Counting recall	**-.540**	**-.288**	**-.110**	**.646**	**-.247**	**-.065**	**-.335**	**.013**	**-.464**	**.245**	**-.220**	**.525**	**-.075**
Backwards digit span	**.265**	**-.096**	**.181**	**.006**	**.661**	**.475**	**.195**	**.741***	**.275**	**.169**	**.240**	**.061**	**.309**
VWM comp	**.188**	**-.278**	**.061**	**.423**	**.287**	**.638**	**-.123**	**.609**	**-.036**	**.055**	**.024**	**.161**	**.000**

* = significant at the 0.05 level

** = significant at the 0.01 level

Bold font denotes dyslexic group

Table 11:

Spearman's Correlation Coefficients for visuospatial AWMA subtests and DST-J subtests for non-dyslexic and dyslexic participants.

	DSTJ Subscales												
AWMA Suscales	Rapid Naming	Bead Threading	One Min Reading	Posture	Phonemic Segmentation	Rhyming	Two min Spelling	Backwards Digit Span	Nonsense reading	One min Writing	Verbal fluency	Semantic fluency	Vocabulary
Dot Matrix	.084	.255	.349	.601	.246	-.039	.655	.773*	.270	-.333	.610	.501	.701
Mazes memory	-.703	.736*	.134	-.127	.360	-.125	.229	.155	.205	.108	.753*	.684	.329
Block Recall	.228	.279	.169	.901**	.184	.000	.452	.687	.074	-.167	.293	.401	.551
VSSTM comp	-.187	.549	.182	.277	.445	.007	.659	.531	.222	-.096	.700	.630	.516
Odd-one-out	-.060	.449	-.277	.050	.503	.274	.312	-.049	-.135	.429	-.024	.150	-.100
Mr X	.790*	-.521	-.374	.200	-.761*	-.574	-.203	.442	-.503	-.667	-.024	-.501	-.200
Spatial Span	-.712*	.472	.531	.103	.365	-.080	.447	.528	.465	-.146	.900**	.718*	.718*
VSWM comp	.503	-.012	-.265	.551	-.307	-.469	.265	.810*	-.368	-.571	.415	.050	.150
Dot Matrix	**-.060**	**.527**	**.301**	**.476**	**.370**	**.475**	**.390**	**-.358**	**.431**	**.705**	**.132**	**.552**	**.012**
Mazes memory	**-.267**	**.239**	**.297**	**.399**	**.482**	**.287**	**.337**	**.553**	**.253**	**.315**	**.301**	**.679**	**.391**
Block Recall	**.582**	**.220**	**-.109**	**.472**	**.165**	**.096**	**.067**	**.491**	**.108**	**-.261**	**-.060**	**.037**	**-.267**
VSSTM comp	**-.247**	**.604**	**.452**	**.378**	**.424**	**.317**	**.360**	**.253**	**.443**	**.295**	**.419**	**.749***	**.346**
Odd-one-out	**-.265**	**-.058**	**.084**	**.805***	**.079**	**.507**	**-.067**	**.006**	**-.108**	**.494**	**-.096**	**.614**	**-.099**
Mr X	**.279**	**.226**	**.279**	**.239**	**.195**	**.542**	**-.160**	**.460**	**.217**	**-.273**	**.277**	**.161**	**.019**
Spatial Span	**.012**	**-.141**	**-.096**	**.244**	**-.261**	**.349**	**.000**	**-.408**	**-.120**	**.127**	**-.228**	**-.037**	**-.309**
VSWM comp	**-.074**	**.118**	**.184**	**.509**	**-.123**	**.516**	**-.261**	**-.063**	**-.024**	**.012**	**.049**	**.350**	**-.164**

* = significant at the 0.05 level

** = significant at the 0.01 level

Bold font denotes dyslexic group