Short Term Memory in High Functioning Adult Dyslexics: Isolating the Deficit

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Specimen layout for Thesis Summary and Declaration/Statements page to be included in a Thesis

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Contributions to Conferences Arising from this Thesis

Conference Talks

McDonald, E., & Macken, W, J., (2009). Failure to adapt; a fatal flaw in dyslexics verbal Short-Term Memory? BPS Cognitive Section Conference, University of Hertfordshire.

McDonald, E., & Macken, W, J., (2009). Semantic strategies the saving grace for dyslexics verbal Short-Term Memory. BPS Cognitive Section Conference, University of Hertfordshire.

McDonald, E., & Macken, W, J., (2008). Semantic Short Term Memory and Dyslexia. PsyPAG Annual Conference, Manchester University.

McDonald, E., & Macken, W, J., (2007). Memory and Dyslexia: The dots task used to assess visuo-spatial serial memory. PsyPAG Annual Conference, London South Bank University.

Conference Posters

McDonald, E., & Macken, W, J., (2008). Quantitatively different, but qualitatively identical: A comparison of verbal STM processing in dyslexic and control groups. British Dyslexia Association International Conference, Harrogate.

McDonald, E., & Macken, W, J., (2008). Intact visuo-spatial STM in dyslexia. British Dyslexia Association International Conference, Harrogate.

McDonald, E., & Macken, W, J., (2007). Dyslexics' serial STM performance: Quantitatively different but Qualitatively similar. European Society for Cognitive Psychology Conference, Marseille, France.

McDonald, E., & Macken, W, J., (2007). Adult dyslexics' visuo-spatial serial memory: Evidence of intact non-verbal encoding? The Cognitive Science Society Conference, Nashville, USA.

McDonald, E., & Macken, W, J., (2006). Survival of Auditory Recency in Adult Dyslexics: Intact Automatic Processing Despite Phonological Encoding Deficits. BPS Cognitive Section Conference, Lancaster University.

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Summary

The overall aim of this thesis was to provide a detailed characterisation of impaired and unimpaired performance in dyslexia. One of the core areas of Interest in dyslexia research has been short term memory (STM). Typically, attempts to understand the nature of dyslexic's STM deficits have attempted to localise impairments in dyslexics to one or more components of working memory model (e.g. Smith-Spark, Fisk, Fawcett & Nicolson 2003). However, inconsistent results have led to the conclusion that dyslexics have general STM deficits as they have not been localised to an area of the working memory model (Everatt, Weeks & Brooks 2007). Three subsections of the thesis looked at performance in different areas of STM. The first chapter established that performance on verbal STM tasks by dyslexics' showed a typical pattern of recall. The findings consistently demonstrated that dyslexics had quantitatively deficited performance, however qualitatively performance was equivalent to that of the control groups. The findings also suggest that dyslexics were not able to adapt strategies (e.g. passive, serial) for encoding information which would allow optimal recall on basic verbal STM tasks. The second chapter looked at memory for items with similar and different semantic characteristics, to establish the stability and use of these characteristics when encoding. Findings showed dyslexic and control groups demonstrated use of semantic encoding strategies. Dyslexic participants performed comparably to controls on those verbal STM tasks that promoted semantic encoding. The third chapter demonstrated that dyslexics did not have a deficit on a non-verbal serial recall task designed to minimize the possibility of verbal re-coding (Parmentier et al., 2006). The results again establishing that the pattern of recall interference was the same across groups. To conclude, the experiments reported in this thesis have provided convincing evidence that dyslexics' short term memory deficit is isolated to verbal short term memory which is not supported by semantic strategies.

Chapter 1: Overview of Thesis

1.1 Introduction

Developmental Dyslexia (Hereafter abbreviated to dyslexia) is a well-researched learning difficulty; however, the majority of this research has been conducted with a school age population. As more is learnt about the condition, there is a growing body of evidence from genetic and neurobiological studies to confirm that dyslexia is biological in origin and therefore cannot be "cured" by education. Therefore, children who are diagnosed with dyslexia will still have the condition as they mature into adulthood, although a positive outcome of early diagnosis should result in the deficits becoming less obvious. This is not because the condition has been eradicated, but rather that the individual has now been equipped with tools and coping strategies to mask the effects.

As discussed by Snowling (2004) the diagnosis of dyslexia is far from perfect and many who have the condition are not diagnosed until later in life. Given the strong biological evidence for the origins of dyslexia, it is important to profile the cognitive characteristics of an adult population with a diagnosis of dyslexia to identify the core deficits. As part of this profiling, gaining an understanding of the effects of dyslexia on Short-Term Memory (STM) is an important element. Successful use of STM has been identified as an integral part of the processes used to develop skills such as learning, reading, reasoning, and comprehension (e.g., De Jong, 1998; Gathercole & Baddeley, 1993; Jorm, 1983; Perfetti, 1985; Siegel & Ryan, 1989).

Short Term Memory deficits have been described by McLoughlin, Fitzgibbon and Young (1994) 'the most significant and pervasive problem dyslexics experience'(p.17). This is because STM is used to temporarily store information resulting in key skills development. STM is involved in the selection, initiation, and termination of information-processing functions such as encoding, storing, and retrieving data (e.g., Atkinson & Shiffrin, 1968; Baddeley, 1986; Baddeley & Hitch, 1974; Nairne, 1988; Neath, 2000). McLoughlin, et al. (1994) identified a "specific memory failure" as one of the major defining characteristics of dyslexia; this thesis focused on distinguishing impaired and intact elements of STM in dyslexic adults.

Typically, attempts to understand the nature of STM deficits in dyslexia are framed in terms of the multi-component working memory model (Baddeley & Hitch 1974; Revised Baddeley, 1986, 2001). The multi-component working memory model (WM) breaks STM into four distinct areas; phonological loop, visuo-spatial sketchpad, episodic buffer and central executive (Baddeley 2001) and a large amount of the literature on dyslexia and STM has attempted to localise impairments in dyslexics to one or more of these WM areas (Smith-Spark, Fisk, Fawcett, & Nicolson, 2003). This has lead to the majority of studies using classic working memory tests, such as digit span to examine the difficulties dyslexics have with STM. However, inconsistent results have lead to the conclusion that dyslexics have general STM deficits, as it has not been possible to localise the effects to any single component of the WM (Everatt, Weeks, & Brooks, 2007). The dominance of the WM model in the theoretical understand of dyslexics deficits has translated in to the methodologies used e.g. span tasks (Savage, Lavers & Pillay, 2007). This in turn limits any conclusion that can be drawn from investigations.

The overall aim of this thesis was to provide a detailed characterisation of impaired and unimpaired STM performance in dyslexia, which goes beyond that provided by the WMM and its associated tasks. This was completed by examining the role of processes such as auditory perceptual organisation, speech planning and output, nonverbal spatial processing and the susceptibility of these processes to interference from irrelevant tasks and sounds. This thesis gives a more comprehensive explanation of dyslexics' STM deficits, free from the constraints of the current dominant working memory model (WM). Three experimental chapters of the thesis looked at different STM tasks and performance on them.

1.2 The structure of the thesis

Chapters 2 and 3 constituted a review of the literature relevant to the course of study undertaken. **Chapter 2** addressed the definition of dyslexia. Section 2.1 detailed the range of symptoms; followed by a review of the literature on the biological underpinnings (2.2). Section 2.3 then outlined the specific group who are the focus of the experimental chapters. This included a profile of the participant group who took part in the experimental series (Section 2.3.1). **Chapter 3** summarised the main theoretical perspectives on dyslexia; Phonological, Cerebella/Automaticity and Magnocellular. **Chapter 4** then specifically examined the dyslexia and STM literature. **Chapter 5** examined key verbal short-term memory phenomena, comparing dyslexic and control groups' performance on serial recall tasks. This included examination of the pattern of recall in both groups for both the visual and auditory presentation of items. The verbal series of experiments then compared the effect of irrelevant sound on serial recall in both the dyslexic and the control group. Chapter 5 also investigated the effects of manual and articulatory suppression on the performance of serial recall. **Chapter 6** investigated the role of semantic processing in STM. Words were used as the TBR items to explore the effects of using semantic strategies to enhance recall. The experiments included words from defined semantic categories (Marsh, Hughes, & Jones, 2009) as the basis of the tasks. Dyslexics were reportedly more heavily reliant on semantic encoding strategies (Snowling, 2000) and the experiments were designed to explore the stability and use of these characteristics. **Chapter 7** contrasted non-verbal serial recall, and considered whether any deficit was specific to the verbal component. Participants completed a visuo-spatial serial recall task that had been designed to minimise the possibility of verbal re-coding (Parmentier & Andrés, 2006). The dyslexic group performance was compared to the control group across the three experiments within this chapter, establishing whether the pattern of recall interference was comparable across groups. **Chapter 8** summarised the main findings of the empirical chapters, relating the results to the theoretical underpinnings. Implications, limitations and the potential future directions for research into this area are also considered.

Chapter 2: Overview of Dyslexia

2.1 Dyslexia: A definition and symptomology

Dyslexia is reported to affect 10-15% of school age children (the British Dyslexia Association /Dyslexia Action website 2009) and 2.64% of students in higher education (in 2005/06 Higher Education Statistics Agency) in the UK, making dyslexia one of the most prevalent learning disabilities in the UK. Dyslexia has been found in similar percentages of populations across the globe, in different cultures and languages (Stevenson, Stigler, Lucker, Lee, Hsu, & Kitamura, 1982; Yamada, Banks, 1994; Grigorenko, 2001; Glezerman, 1983 cited in Grigorenko, 2001). In a review of the cross-cultural research, Grigorenko (2001) concluded that "the existence of dyslexia is recognised across many cultures and continents. ...a consistent pattern in specific dyslexia, which does not depend on any one writing system or geographic location." (p96).

The first substantial publication on dyslexia[1] appeared in 1917 by James Hinshelwood. His book reviewed the topic and formalised his observations from his 20 years examining congenital word-blindness. It also includes reports of both developmental and acquired dyslexia, initially included in medical journals. Morgan (1986) reported a case study "first... found in medical literature" (p. 41; Hinshelwood, 1917), of a patient Percy (14

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[1] The term Dyslexia was introduced 1887 by Berlin for a mild reading impairment resulting from head injury. Word-Blindness was introduced by Kussmaul in 1877 and later given the prefix congenital by Morgen in 1896 to differentiate from the acquired condition originally reported (cited in Hinshelwood, 1917).

year old male) who "has always been a bright and intelligent boy, quick at games, and in no way inferior to others of his age." (p. 1378). Morgan reported that his schoolmaster of some years was of the opinion that he could be the "smartest lad in the school" (p. 1378) if it were not for his inability to learn to read and spell, despite constant application by Percy and receiving 7 years of schooling/tuition. This is typical of a description of the condition and is still consistent with the current basis for a diagnosis of dyslexia. A diagnosis was based upon a person performing to two standard deviations below their reading and spelling level, as predicted by their IQ (Snowling, 2000).

Although dyslexia is a widely recognised disability, there is often debate about its definition and diagnosis. In a review of research conducted about dyslexia in adults for the National Research and Development Centre for adult literacy and numeracy, over 28 differing definitions were identified (Rice & Brooks, 2004). The current definition adopted by the International Dyslexia Association (Website 2008) is:

> Dyslexia is a specific learning disability that is neurological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge.

This definition incorporates the core features that most include, such as reading accuracy, deficit and cognitive impairment. This has stayed constant and there has been little advancement from the inherently weak 'definition by exclusion' as discussed by Vellutino (1979, in Snowling, 2004). Vellutino's

(1979) definition was "severely impaired readers who have at least average or above average intelligence, who sustain no sensory acuity problems, gross brain damage, or pronounced emotional or social disorders, and whose learning difficulties are not due to inadequate instruction or socioeconomic disadvantage" (p. 321)

The phonological deficit theory is the dominant account of dyslexia (Fowler, 1991; Snowling & Hulme, 1994). The main body of research accepts that dyslexics have a core phonological deficit and this is reflected by the fact it is included in the IDA's definition. However, alternative theories of dyslexia such as Cerebella/Automaticity theory (Nicolson & Fawcett, 1990) and Magnocellular theory (Stein, 2001) incorporated a wider range of symptoms (e.g. Automaticity; Movement / Magnocellular; Visual and Auditory fine processing). These additional symptoms are sometimes included in the definition of dyslexia, which results in the definition changing according to the author's subscription to a theory.

Increasingly, dyslexia is being considered on a continuum with other learning difficulties to account for the variation in symptoms. Examining where dyslexia lies on this continuum (in relation to dyspraxia and ADHD, for example) help to explain the motor movement and visual/auditory fine processing symptoms proposed by the other theories. The continuum explanations have the potential to move the definition away from exclusion by developing our understanding of the variables involved, such as the phonological skills that differentiate dyslexia from other learning difficulties (Snowling, 2008).

2.2 Genetic and neurobiological Influences

Physiological and genetic markers of dyslexia have been investigated for many years (e.g., Kussmaul,1877, as cited in Hinshelwood 1895; 1917). These investigations have historically been case studies that have looked at family heredity and post-mortem examinations. Research has continued in this area and has built upon these early pioneering works. Longitudinal studies of twins of have produced strong evidence that dyslexia is a genetic condition (Olson, 2008). Genetic factors accounted for 50% of the variance in Olson and Byrne's (2005) sample of twins. Studies such as Pennington and Gilger (1996) reported that the heritability rate of dyslexia was between 23% and 65% in children of dyslexic parents, and 40% of siblings of a dyslexic child are also diagnosed. Four candidate genes have been located within three linked regions; DYX1C1 on chromosome 15 (Rosen' et al., 2007), ROBO1 on chromosome 3 (Hannula-Jouppi, et al., 2005) and KIAA0319 (Cope et al., 2005) and DCDC2 (Schumacher et al., 2006) on chromosome 6. All of these areas have also been linked with brain development (Paracchini, Scerri, & Monaco, 2007). Although this research is not yet at the stage to permit genetic testing for dyslexia, the data on heritability is informing Individual Educational Plans for children with a familial risk of dyslexia.

Post-mortem examinations have historically investigated structural differences in dyslexic's brains (e.g. Galaburda & Kemper, 1979; Galaburda et al., 1985, 1994). The cerebellum, corpus callosum, posterior cortex of the left hemisphere and magnocellular systems are key regions of interest for structural differences. However, methodological issues have prevented strong conclusions being drawn (Beaton, 2004).

Recently, the increasing use of new technologies such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) have allowed the study of living participants, reducing some methodological problems. Although not universally accepted, three regions have been frequently associated with structural abnormalities (Kronbichler et al., 2008; Eckert, 2004): the inferior frontal gyrus (e.g., Brown et al., 2001; Eckert et al., 2003), the superior temporal and temporoparietal cortex (e.g., Brambati et al., 2004; Brown et al., 2001; Leonard et al., 2001) and the cerebellum (e.g., Brambati et al., 2004; Brown et al., 2001; Eckert et al., 2003; Rae et al., 2002).

Diffusion tensor magnetic resonance imaging tractography (DT-MRI) has offered new insight into the intricate structure and connectivity of white matter (e.g. Richards et al., 2008). It has also given rise to renewed interest in explanations of dyslexia as a disconnection syndrome (e.g. Richards et al., 2008).

However, the majority of neurological studies have examined the functional differences in dyslexics. In a Meta-analysis of Functional Neuroimaging Studies of dyslexia, the authors concluded that:

> "The likelihood for controls to show more task-related activity compared to dyslexics was greatest in left hemisphere posterior ventral, inferior parietal/ temporal, and inferior frontal cortices, as well as the right fusiform, postcentral, and superior temporal gyri. The highest ALE (activation likelihood estimate[2]) values and greatest convergence among studies for this comparison was found in left extrastriate cortex (inferior temporal gyrus) in BA 37. ... The Dyslexics > Controls meta-analysis revealed a right hemisphere overactivation by dyslexics in the right thalamus, and a less robust finding in the anterior aspect of the right insula. We found no

[2] Emma McDonald added

evidence for hyperactivation in left frontal cortex in adult dyslexia, nor for cerebellar differences." (p. 255, Maisog, Einbinder, Flowers, Turkeltaub, & Eden 2008)

Temporal discrepancies have been consistently found in dyslexic's patterns of brain activation using Magnetoencephalography (MEG) and Electroencephalograph (EEG) (c.f. Lyytinen et al.,2004). A full review of the literature is beyond the scope of this thesis. However, there is a growing robust body of evidence for dyslexia being a lifelong condition with biological markers (Shaywitz, Morris, & Shaywitz, 2008; Vellutino, Fletcher, Snowling, & Scanlon, 2004).

2.3 Dyslexia in adults that continue in education (High-functioning)

Chapters 5 through 7 of this thesis examined the short-term memory characteristics of dyslexics whom have continued in education to university. This population of dyslexics have been described as 'compensated' or 'high-functioning' dyslexics (Kemp, Parrila, & Kirby, 2009). Compensated dyslexics were originally defined by Lefly and Pennington (1991) as adults who were diagnosed as dyslexic in childhood but now perform within normal literacy range. Although many dyslexics in higher education may not meet these criteria of having been compensated, Kemp et al. (2009) argued that they can be considered 'high-functioning' as they achieve the same learning outcomes. Therefore, it is important to consider the differences in the characteristics of this population compared to the children who are more frequently the focus of research.

Dyslexic adults (diagnosed or not) have generally developed coping strategies to deal with the dyslexia which means that they often do not demonstrate the classic symptoms (Beaton, McDougall, & Singleton,1997; Fitzgibbon, & O'Connor, 2002). Personal strategies may have been developed though extra tuition in school or individually (McLoughlin, Leather, & Stringer, 2002). Dyslexia in adults often only becomes prominent during periods of transition such as job promotion or entering higher education. This change of circumstance can lead to well established strategies becoming inadequate, meaning that the dyslexic adults will then require additional help to meet these new demands by being assessed (Kirk, McLoughlin & Reid, 2001). Such adults' reading skills are superficially comparable to those of their peers. Hanley (1997) argued that dyslexic adults feasibly have larger vocabularies to compensate for reading difficulties. Campbell and Butterworth (1985) reported a case study of a dyslexic university student, who relied upon almost entirely visual strategies to read. This meant that at a superficial level the student appeared to have normal literacy skills. This profile of superficial reading skills has been reported in further studies such as Funnell and Davison (1989), and Howard and Best (1997).

Writing and, in particular, spelling skills are often harder to mask and remain weak (Rack, 2004; Riddick, Farmer & Sterling, 1997). Horne and Singleton (1997) found that only 21% of their sample of dyslexic students performed below average on single word reading test but 40% performed below the national average on spelling, and on short passage reading comprehension 58% performed below the national average. Simmons and Singleton (2000) further examined text comprehension in a similar population using a comprehension task that is more representative of text that dyslexics would encounter in the university setting. Dyslexics' performance once again was characterised by their superficial reading ability not being impaired on literal decoding, but there was a deficit in inferential comprehension performance. Dyslexics also took significantly longer to complete the task, which is congruent with the Beaton et al. (1997) profile of a dyslexic university student. The literature examining adult dyslexic literacy skills consistently reports that when a thorough investigation is undertaken into reading ability, the underlying deficits remain.

The coping and compensatory strategies developed by undiagnosed dyslexic adults make the diagnosis more difficult (Kirk et al., 2001). This is because reading, writing and spelling performance compared between a group of dyslexics and controls would produce a difference the variance in the dyslexic group, but it would be unreliable to base a diagnosis solely on this comparison (Singleton, Horne, & Simmons, 2009). The development of reliable screening products for adult dyslexics' consistent underlying deficits, which profile general ability and WM / STM, were the basis of products such as Quick Scan (Zdzienski, 1997, as cited in Fawcett, 2001; p. 295) and Dyslexia Adult Screening Test (DAST referred to in Fawcett, 2001; p. 296). Both screening products provided an indicator of the likelihood of having the condition and whether a formal diagnosis should be sought. One of the more comprehensive of these screening tools is Study Scan which covers the majority of assessment areas in a full educational assessment:

> "the following tests: memory (auditory and visual) and coding; literacy (including reading and listening comprehension spelling and punctuation); numeracy (including reading calculations and applications); cognitive abilities (including verbal and non-verbal reasoning; as well as vocabulary);

proficiency tests (speed of reading and speed of copying; free writing" (Kirk, et al., 2001; p. 296).

The outcome of Study Scan is an automatically analysed diagnostic dyslexic report (highlighting strengths and weaknesses). Each of these screening products used STM deficits as part of the criteria for an indication of dyslexia although they do not replace the clinical judgment that is key to a formal diagnosis. Nevertheless, the screening products highlighted how STM is a cardinal impairment in the profile of dyslexic adults and that it is an ongoing deficit that cannot be resolved by internal compensatory strategies.

The empirical chapters (5-7) of this thesis were concerned with examining the short-term memory profiles of high-functioning dyslexics. As this population can be considered to have deficits due to their dyslexia rather than not engaging in activities that are problematic. Many of the core processing deficits apparent in dyslexia have been found to persist into adolescence and adulthood and although compensation (often external) is used to mediate everyday difficulties.

2.3.1 Profile of the dyslexic participant group

All dyslexic participants were current students at Cardiff University at the time of taking part in the study. All individuals included in the dyslexic groups provided a copy of their educational psychologists' report, which confirmed that they were dyslexic and had special educational needs. All reports completed during secondary school specified exam arrangements (most frequently 25% extra time), while reports written at university stated the student was eligible for the Disabled Student Allowance (DSA). The majority of reports included a WAIS-III, test, tapping into literacy skills (reading aloud, spelling and writing to dictation), phonological processing, semantic knowledge and memory.

Chapter 3: Theories of Dyslexia

3.1. Introduction

This chapter provides a summary of the principal theories of the underlying causes of dyslexia. While there are many theories of dyslexia, three main underlying causes are identified by the dominant theories. These are a phonological processing deficit (3.2.); cerebella/automaticity deficit (3.3) and a sensory processing deficit (3.4).

The first of these is the phonological deficit theory, which has been the dominant account of dyslexia since the 1980s (Snowling 2004). While all theories of dyslexia attempt to explain dyslexics' poor phonological skills, a great deal of the debate is centred around whether phonological processing is a cause of dyslexia or the product of a more general deficit, such as sensory processing. This chapter expands and outlines this debate.

3.2 Phonological processing deficit theory

The phonological processing deficit (PPD) theory centres on the idea that dyslexics have difficulty forming phonological representations for words (Snowling, 2000; Bradley & Bryant, 1978; Rack, 1994; Vellutino, 1979). In Rose (2009), phonological awareness is defined as the ability to identify and manipulate the sounds in words, and is recognised as a key foundation skill for early word-level reading and spelling development. For example, phonological awareness would be demonstrated by understanding that if the 'p' in 'pat' is changed to an 's', the word becomes 'sat' (p. 33).

PPD is often characterised in pre-school as a mild language acquisition problem and a difficulty with pre-reading skills such as rhyme detection. However, difficulties become more apparent in school-aged children as they start learning to read and spell. This is when the ability to break down a word in to its phonemes and map them on to graphemes is required as part of the process of learning to read. Formation of these mappings is the foundation for more automatic reading skills and spelling abilities when children rely on orthographic relationships (Frith, 1985, cited in Snowling, 2000). The importance of phonological awareness in preschool children has been demonstrated as it can predict later reading ability irrespective of IQ (Bradley & Bryant, 1983). The phonological awareness deficit PPD theory predicted semantic skills will fall within the normal range and can be used to facilitate the development of words that cannot be dealt with in orthography-phonology systems (Snowling, 2004).

These basic auditory processing deficits, such as mapping alphabetic symbols to sound, segmenting phonemes and encoding speech sounds are consistently found in dyslexics and do not dissipate with age (Snowling, Nation, Moxham, Gallagher, & Firth, 1997).

It has been argued (Vellutio & Scanlon, 1997) that reading successfully depends on the use of both semantically and phonologically based methods of word identification. As dyslexics have a deficit in phonologically mediated word identification (grapheme to phonemes conversion), difficulties for a dyslexic will continue into adulthood. Dyslexics' ability to learn to read has been argued to be heavily reliant on recognising words as a whole and reading from context learning word pairings, however they will not become fluent in the phonological components that make up these words (for reviews, see Brady & Shankweiler, 1991; Rack, 1994; Share & Stanovich, 1995; Snowling & Hulme, 1994). This results in many dyslexics displaying the appearance of being a competent reader where they encounter familiar words, however difficulties will be evident when reading poly-syllabic words (e.g. statistical, anemone) and repeating nonsense words (e.g. robstipertuary; Miles, 1993; Snowling, 1981). Difficulties are also evident in accessing the names of objects or the spoken forms of words quickly (Katz, 1986) and sometimes difficulties discriminating between similar sounding and looking words (e.g. nose noise; Snowling, Stackhouse and Rack, 1986; Miles, 1993; Snowling, 1981). This phonological processing deficit for reading novel words and non-words has been demonstrated in studies of poor readers. These studies focussed on tasks that require analysis or manipulation of the individual sounds within words - what is often referred to as phonological awareness and letter-sound decoding (for review see Muter, 2004). To examine whether dyslexics' encode rhyme relationships when they are not reading aloud, Desroches, Joanisse and Robertson (2005) investigated phonological impairments in dyslexic populations by using eyetracking. Non-dyslexic children showed disruption (eyetracking fixation rates) when rhyming items were present in the eye tracking task, however dyslexics were not affected by their presence. Biological support for the phonological deficit theory comes from post-mortem anatomical studies (e.g., Galaburda, Sherman, Rosen, Aboitz & Geschwind, 1985) and neuroimaging studies (e.g., Paulesu et al.,1996; Shaywitz et al., 1998). Both types of study have revealed, among other findings, significant differences between dyslexics and controls in the left perisylvian area, which is crucially involved in the auditory perception of words.

The PPD theory has been described as a 'near-complete explanation of the problems dyslexic children face when learning to read' (Fawcett & Nicolson, 1994). However, it was criticised for not accounting for the full spectrum of symptoms that some believe dyslexics' experience such as motor coordination and balance problems (Nicolson, 1996). It has been suggested that the phonological deficit is a symptom rather than a cause of dyslexia. Conversely, the inclusion of a wider spectrum of symptoms has been continually questioned and criticised, as these have not been found consistently in dyslexics (Snowling, 2004). Advocates of the PPD theory have argued that dyslexia includes a spectrum of learning difficulties and that the variation in difficulties faced by dyslexics can be accounted for by identifying where they are on that spectrum, or co-morbidity with other disorders (e.g. ADHD and Dyspraxia; Snowling, 2000).

It has also been argued that although there is a robust body of evidence that dyslexics have a phonological deficit, the theory is too general, and the exact nature of any deficit needs to be clarified. Ramus and Szenkovits (2008) made the case that dyslexics have normal phonological representations, the deficit lies in short term memory which affects the ability to assess phonological representations. This deficit is especially prevalent when there is a high STM load. Ramus and Szenkovits (2008) argued that the majority of phonological tasks (e.g. non word repetition, and rapid naming tasks) are not a pure measure of phonological awareness; this is because as the tasks increase in difficulty, they place a greater load on STM. Ramus and

Szenkovits (2008) highlight the need for an awareness of task requirements "notably short-term memory" (p. 139) when interpreting dyslexics' performance.

In conclusion, there is overwhelming evidence that dyslexia does involve some sort of phonological deficit. What is often dispute about the theory is whether a phonological deficit is the sole cause, a contributing factor or a symptom.

3.3 Cerebella / automaticity deficit theory

The cerebella/automaticity deficit (CAD) theory (Nicolson & Fawcett,1990; Nicolson, Fawcett, & Dean, 2001) set out to explain a wider range of symptoms than the PPD theory, i.e. more than just the literacy problems that dyslexics encounter. The key additional symptom that the CAD theory recognises as being characteristic of dyslexia is a deficit motor control (balance) while completing a secondary task. Nicolson and Fawcett (1995) describe a critical test of the CAD theory:

> "We used the task of balance (selected because it is a highly practised skill with no phonological or reading component) and established that dyslexic children do have marked balance difficulties, but only when they are prevented from consciously compensating either by administration of a concurrent dual task (Nicolson & Fawcett, 1990) or by blindfolding (Fawcett & Nicolson, 1992)."

This theory proposed that underlying dyslexics' deficits are not domain specific, therefore dyslexics do not archive automation of skills, whether they are either cognitive or motor (Fawcett & Nicolson, 2001). The CAD theory defines automation, as when a learned behaviour is so effortless it no longer requires conscious thought to carry it out. For example, Nicolson and Fawcett

(1990) used the test of completing the dual task of balancing on a beam combined with using a go/ no go a reaction time. The theory recognised the process of automation as part of a three stage learning model (Anderson, 1982). The first stage is the "declarative stage" where a task is performed slowly, broken down into many subroutines and often requires verbal mediation. During the second stage, the "intermediate procedural stage", the task is performed faster and more accurately and there is no longer the need for verbal mediation. However as the skill continues to be developed, the procedure becomes less conscious as the subroutines are assimilated and collapsed so thateventually in the third and final autonomous stage the skill becomes fluent and automatic. "This framework provided an explanation as to why there could be problems associated with motor skills, in addition to phonology, working memory and processing speed (and, of course, reading), but provided no underlying biological-level explanation." (p. 136, Nicolson & Fawcett, 2007).

The biological explanation of the CAD theory attributes the dyslexics' difficulties to a general failure in automatism skills, which is derived from cerebellar dysfunction (Nicolson, Fawcett, & Dean, 2001). This was evident in a range of clinical tests outlined below.

The implications of cerebella impairment for dyslexics are derived from the examination of a wide range of clinical tests comprising of three categories; posture and muscle tone; hypotonic (a muscle has decreased tone, or tension of the upper limbs) and complex voluntary movement (Fawcett, Nicolson, & Dean, 1996). In addition to the test mentioned previously for impairment of balance when doing a secondary task (Nicolson

& Fawcett, 1990). Some neuroimaging studies have also found anatomical, metabolic and activation differences in dyslexics' cerebellum (e.g. Brown, Eliez, Menon, Rumsey, White, & Reiss, 2001; Leonard et al., 2001; Nicolson, Fawcett, Berry, Jenkins, Dean, & Brooks, 1999; Rae et al., 1998; Baillieux, Vandervliet, Manto, Parizel, & Deyn, 2009). This supports the argument that there is a functional difference in dyslexics' cerebellum.

The phonological deficit is also accounted for by the CAD theory, in this case it is argued that the development of phonological representations relies on speech articulation. This is a motor process that is affected by the cerebella deficit. Nicolson and Fawcett (1992, p.525) stated that "phonological skills are learned from experience. They are one of the earliest skills to be automatised and so a dyslexics automatisation deficit would predict exactly the detriment that has been found. In short, the phonological deficit found among dyslexic children is interpreted naturally as a special case, albeit crucial to development of reading skills, of an automatisation deficit".

The argument that the formation of phonological representations by speech articulation was questioned by Ramus, Pidgeon and Firth (2003). In contrast to the studies into the presence of phonological deficits (for review see Vellutio et al., 2004) which have been consistently found to be present, there have been mixed results in establishing a cerebellum/automation deficit in dyslexics. For example, Nicolson et al. (2001) reported that cerebella deficits could be found in 80% of dyslexics. However, other studies profiling adults and children with dyslexia found that cerebella deficits could only be found in approximately 20% of samples (Reid, Szczerbinski, Iskierka-Kasperek, & Hansen, 2007; Ramus et al., 2003).

There have also been some studies that have failed to find motor problems (such as the ability to balance on a beam whilst completing secondary tasks; e.g. Kronbichler, Hutzler, & Wimmer, 2002; Van Daal & Dan Der Leij, 1999). A meta-analysis of studies looking at impaired balance in dyslexia found that it was not a characteristic of dyslexia, but is symptomatic of "developmental disabilities" (Savage, 2007). Savage (2007) also concluded that cerebella tasks which were measured by bead threading ability or postural stability could not be used to distinguish between children with dyslexia and children with intellectual disability, once again demonstrating that performance on these tasks are not characteristic of dyslexia. These findings were more in line with the PPD theory and account for the possibility that these additional symptoms are not indicative of dyslexia, but can be found as part of a broader spectrum of learning disabilities. It was also suggested that the impairment of balance when performing a secondary task can only be found in dyslexic children that have a high attention deficit hyperactivity disorder (ADHD). The symptomatic ratings would suggest that the impairment of balance is more indicative of ADHD than dyslexia (Wimmer, Mayringer, & Raberger, 1999; Rochelle, Witton, & Talcott, 2009). The CAD theory also failed to account for sensory disorders in dyslexia, which are at the core of sensory deficit theories that are examined below.

3.4 Sensory deficit theory's

Sensory deficit theories, in common with the CAD theory, also argued that there was an underlying cause of literacy problems in dyslexia that was not language specific, but is a general impairment. The magnocellular deficit theory (MDT) puts forward the hypothesis that there is an impairment of the visual and/or auditory magnocellular system (Hansen, Stein, Orde, Winter, & Talcott, 2001; Stein, 2001; Stein & Talcott, 1999; Stein, Talcott, & Witton, 2001; Stein & Walsh, 1997). The visual magnocellular system specialises in processing fast visual temporal information, whereas the auditory magnocellular system specialises in processing fast auditory temporal information. This would relate to the symptomatology of dyslexia by providing an explanation of problems associated with reported issues with visual fixation instability when reading (Stein, Talcott, & Witton, 2001). This also attempted to explain a wider range of symptoms than the literacy problems that dyslexics encounter. Unlike the PPD theory, the key symptom that MDT identified was that many dyslexics complain that when they are reading words and letters, they appear to move around, blur and merge with each other (Stein & Walsh, 1997). As well as other symptoms that are central to the other theories of dyslexia (such as transposing letters, phonological, memory and motor deficits), the MDT argues that this broad spectrum of symptoms can only be explained by an early processing deficit (Stein, 2001). Support for the theory comes from behavioural studies, which examined dyslexics performing at a lower level on fine visual processing and visual motion sensitivity tasks, such as the measurement of the threshold of children being able to detect coherent motion of dots in relation to alternative dots moving in a Brownian manner.

These experiments were designed to measure the visual magnocellular system's processing ability. There is also biological evidence from post-mortem studies that have found that dyslexics' magnocells (in the visual system) were up to 20% smaller than those in the control brains (Livingstone, 1991 cited in Stein, 2001). It is argued that the magnocellular system helps to keep the two eyes fixated to converge on each word during reading (Stein, 2001). Studies looking at binocular fixation have found that indeed many dyslexics have unsteady binocular fixation and hence experience unstable perceptions of print (Stein et al., 2001).

However, the visual magnocellular deficit has not been consistently found in dyslexics (Walther-Muller, 1995; Gross-Glenn et al., 1995). As with the CAD theory, this cast doubt on whether this visual deficit was truly characteristic of dyslexia or was a deficit found in a subgroup of people with dyslexia. For example in a multiple case study of dyslexic adults (over the age of 16), only two participants had visual magnocellular deficit, while 10 did have an auditory sensory deficit (Ramus et al., 2003). The visual problems linked with dyslexia were found in participants that do not have reading difficulties. This makes it more difficult to infer a causal link between the visual magnocellular deficit and dyslexia (Evans, 2004). Theories that identify the root cause of dyslexia as an auditory sensory deficit that underlies the phonological deficit have more consistent findings of a deficit than a visual deficit which is central to the MDT.

Auditory Processing Skills are considered to be important in learning to read and spell, as low-level auditory processes underpin the development of phonological representations in children (Beaton, 2004). A deficit in low-level auditory processes in dyslexics would result in the failure to successfully develop phonological representations. Goswami et al. (2002) proposed that a difficulty in perceiving aspects of speech rhythm as syllable-level information could be impaired in developmental dyslexia. Rise time is the rate of change of the onset of the amplitude envelope of a particular auditory signal (speech or non-speech). Rise time at syllable onset has been argued to be particularly important in the perception and production of rhythmic speech (Bregman, 1993). Sensitivity to the rise time of the amplitude envelope of a vowel and other auditory cues related to amplitude envelope structure, such as duration and intensity, has been demonstrated to be significantly worse in dyslexic children and adults (Goswami et al., 2002; Richardson, Thomson, Scott, & Goswami , 2004; Muneaux, Ziegler, Truc, Thomson, & Goswami, 2004; Thomson et al., 2006). To examine sensitivity, children have performed sensitivity tests where they had to detect a beat from a background sound (Goswami et al., 2002). The rise time was manipulated to create the beat, the longer the rise time the harder the beat was to detect. Ability to detect the beats and reading ability was demonstrated on a continuum; with children with advanced reading ability able to detect the longest rise time and dyslexic children performing worse. Moreover, differences in sensitivity to these auditory parameters accounted for 25 percent of the variance in reading and spelling acquisition even after controlling factors for individual differences in age, nonverbal IQ, and vocabulary were incorporated.

The auditory sensory deficit has also been demonstrated in adults with dyslexia, participants were shown to perform significantly poorer on auditory rhythmic discriminations (Thomson, Fryer, Maltby, & Goswami, 2006). The specific auditory sensory deficit account is a relatively new theory. Findings in English speaking dyslexic samples have been consistent and it this is now being examined cross-culturally in dyslexics whose first language is not English. Insensitivity to rise time in dyslexia has been found in a number of languages for example, Chinese (Liu, Shu, & Yang, 2009), French (Muneaux, Ziegler, Truc, Thomson, & Goswami, 2004). However, Boets, Wouters, van Wieringen & Gloesquiere (2006a; 2006b) failed to find significant differences on some sensory tasks, highlighting the specificity of deficits. The study examined the performance of children from 'dyslexic families' who were classed as having a high risk of developing dyslexia. These children were matched with a group with no family history of dyslexia (low risk). The high risk group showed a deficit on phonological awareness and letter knowledge (correctly identifying the name and sound of frequently used letters). No significant differences were found between the high and low risk groups on three administered auditory measures (Audiometric pure-tone detection, GAP-detection test and Tone-in-noise detection task). However when a frequency modulation detection test was used, a significant difference between the groups was identified, which related to their phonological awareness. In a second study (Boets, Wouters, van Wieringen & Gloesquiere (2006b) which examined the same population's performance on a visual measures (coherent motion detection test), no significant differences between the groups was found. Boets et al (2006b) concluded that the best indicators of the high versus low risk of dyslexia were phonological awareness and letter knowledge rather than sensory measures.

As with the phonological theory, the auditory sensory deficit focuses on an explanation of literacy difficulties and does not account for symptoms identified by the MDT and CAD theories.

3.4 Summary

This chapter focused on the underlying causes of dyslexia. As stated at the outset of the chapter, the key debate is whether a phonological deficit is a cause of dyslexia, which has been the dominant perspective. Alternatively, as other theories have proposed, a phonological deficit is a symptom of a sensory or cerebella deficit. Sensory and cerebella theories have attempted to demonstrate that there are a broader range of non-literacy symptoms which are indicative of the underlying cause (e.g. balance and fine sensory discrimination). However, to date, none of these broader symptoms have been consistently and conclusively demonstrated to the same degree as the phonological deficit. This has led to the proposition that these deficits are not the true cause of dyslexia but the additional deficits that are found in sub groups, which are on a spectrum with other disorders such as Dyspraxia and ADHD. As with the phonological deficit, STM deficits have been consistent in dyslexic populations. Chapter 4 examined the nature of these deficits in more detail, whether they are general STM deficits, which would be in line with sensory and CAD or just verbal, which would be in line with PPD.

Chapter 4: Short Term Memory Research in Dyslexic Populations

4.1 Introduction

Short-term memory (STM), working memory (WM) and cognitive processes in those with reading disabilities (RD) have been the subject of extensive research for the past 30 years (c.f. Swanson, Cooney, & McNamara, 2004). Verbal STM deficits were found in children that were identified as having developmental language disorders when compared to non-verbal intelligence matched controls, age matched controls and reading age matched controls groups (c.f. Gathercole & Baddeley, 1990; Baddeley & Hitch, 1994; Jorm, 1983; McDougall & Hulme, 1994). The strength of findings of a verbal STM impairment has led to the proposition that there is a causal relationship between verbal STM deficits and developmental language disorders (Gathercole & Baddeley, 1990). It has been argued that verbal/phonological memory is important in the acquisition of letter-sound correspondence rules, and in representing material in a phonological form in the STM and WM, and is crucially involved in sentence processing (Gathercole & Baddeley, 1989; 1990; Crain, Shankweiler, Macaruso & Bar-Shalom, 1990).

Studies specifically examining dyslexics have frequently demonstrated that STM deficits continue from childhood to maturity (For reviews see Beaton, 2004; Snowling, 2000; Vellutino, Fletch, Snowling & Scanlon, 2004). Although the presence of STM deficits are consistently demonstrated, the nature of these deficits and how they contribute to language and reading disorders has yet to be established (Pickering, 2004). Savage, Lavers and

Pillay (2007) conducted a review of WM and reading difficulties literature research, which identified four propositions for how WM contributes to reading disabilities:

The **general capacity model** suggested that the differences in working memory capacity reflect a general ability to concurrently store and process information, independent of the task used to measure this ability (Conway & Engle, 1994; Engle, Cantor, & Carullo, 1992; Turner & Engle, 1989).

The **general processing model** suggested that deficits were the result of a general processing deficiency, irrespective of the domain in reading disabled children (Bull, Johnston, & Roy, 1999; De Jong, 1998; Passolunghi & Siegel, 2001; Swanson & Ashbaker, 2000).

The **specific processing model** proposed that working memory capacity is task-specific in that the capacity is dependent on the efficiency of the processes required by each task (Daneman & Carpenter, 1980).

The **phonological storage model** implied that WM capacity reading deficits in disabled children reflected a deficiency in the temporary storage of verbal information, which related to the "bottleneck" view of higher-order skills i.e. the deficit in phonological WM prevents the fluent acquisition of skills such as reading (Jorm, 1983; Gathercoloe & Baddeley, 1990).

These models identified the importance of establishing whether STM deficits related to processing efficiency or capacity and whether impairments are domain-specific or common central system. The importance of the specificity of STM deficits also contributes to the theories of underlying cause of dyslexia debate, as discussed in chapter 3. As the phonological processing deficit account would argue that STM deficits would be confined to verbal

STM. However proponents of the cerebella/automaticity deficit would argue that STM deficits would be found on visual STM as result of difficulties in executive processing i.e. automaticity.

This chapter provides a discussion of the current evidence of the nature of STM deficits found in the verbal (4.2) and non-verbal (4.3) domains in dyslexic populations. It debates whether the impairments uncovered on STM tasks were the result of phonological processing difficulties or STM deficits *per se*, which would be indicative of a border deficit such as the sensory or cerebellar deficits as discussed in Chapter 3.

4.2 Verbal STM

Verbal STM studies have demonstrated that dyslexic readers remember fewer verbal items than expected for their age (Hulme, 1981; McDougall, Hulme, Ellis & Monk, 1994; Shankweiler, Lieberman, Mark, Fowler & Fischer, 1979). Poor readers also perform consistently below the level of normal age matched readers on a number of tests, such as rapid naming, verbal learning and confrontational naming (Vellutino et al., 2004).

Verbal STM deficits have been widely found, however a key factor to establish whether dyslexics have a specific deficit in verbal STM or are deficits akin to a developmental lag. Plaza, Cohen and Chevrie-Muller (2002) examined the relationship between verbal WM, language processing and linguistic output in French speaking dyslexic children was compared to age matched control (AC) and younger control (YC) groups. The battery of tests used to examine this relationship fell in to four categories; immediate verbal memory (backward and forward digit span; unfamiliar word repetition;

sentence repetition), word retrieval and verbal production (verbal fluency tasks general, phonological and semantic), sentence processing and verbal production (verb processing task, syntactic completion), sentence processing and acting out the meaning. The dyslexic group exhibited significant deficits on all the immediate verbal memory tasks in comparison to the AC and YC groups. The dyslexic group demonstrated significant deficits in all verbal tasks when compared to the AC. However, the group displayed more mixed results on the tasks that placed the greatest demands on verbal STM (phonological fluency, adjective and verb complementary task and syntactic completion task), as compared to the YC group, but still demonstrated a significant deficit. One of the main conclusions from the study was that dyslexics have a specific pattern of deficits and are therefore, not just operating at a developmental lag. These findings partially support the phonological storage deficit model, however there were some discrepancies, for instance dyslexics did not demonstrate the same deficits on the semantic fluency tasks as the general phonological fluency tasks, which place the same demands on verbal memory. This indicated that there is a task-specific element to dyslexic's deficits rather than a general deficit.

Similar results were demonstrated when Pickering and Gathercole (2004) administered a battery of working memory tests to 15 dyslexic children aged between 7 and 14 years old. As with Plaza et al. (2002) two control groups were established; one matched on biological age and the second matched on reading age. On simple verbal STM tasks such as digit, word and non-word list recall, the dyslexic group's scores were between the two control groups (lower than the age control but higher than the reading control). On two of the more demanding verbal STM tasks, backward digit recall and counting recall (counting the number of dots on a series of cards, then recalling the number of dots on each card), dyslexics performed worse than both the control groups. The reading span task required participants to read a true or false statement and then tell the experimenter whether a sentence was true or false. In the recall phase participants were asked to recall the last word of each of the sentences in the true/false category as mentioned above. On this demanding verbal STM task, where meaning and interpretation were required, the dyslexic group's results were slightly higher than the age control. However as the children had to think about the meaning of the sentence to judge if it was true or false, deeper semantic encoding would have taken place (Just & Carpenter, 1980). Overall, the results of the tests suggested that dyslexics do indeed have a verbal STM deficit, but that there are task-specific demands that affect its manifestation, for example extrapolating meaning as part of a verbal recall task. Moreover, the results indicated that semantic recall is unimpaired; this may be supporting verbal STM. These results were also constant with Byrne and Shea (1979) who found that poor readers made greater use of semantic coding during STM tasks.

The use of semantic coding during STM tasks appears to be one of the strategies used to support the recall capacity. It has also been argued that dyslexic adults have good semantic recall of sentences but have impaired verbatim recall (Miles, 1993). Miles, Thierry, Roberts and Schiffeldrin (2006) demonstrated this by requiring participants (dyslexic and control) to repeat sentences of increasing complexity. If participants failed to repeat the sentence verbatim, the experimenter would repeat the sentence (up to a max of 15 repetitions) before moving on to the next sentence. Results were analysed for the number of repetitions required until the sentence was returned correctly. The analysis demonstrated that the dyslexic group required significantly more repetitions than the control group. The type of errors made during sentence repetition, for example, phonetic omission and substitution were also analysed and the proportion of omission errors was significantly greater in the dyslexic group. The study demonstrated that dyslexics did not have impairment at the 'process of meaning' but did at the phonological and verbatim levels of recall. This result is consistent of Jorm and Share's (1983) description of a child with poor phonological skills;

> "Not only will they have problems in identifying the words of a text, but they will be slow at retrieving phonological codes for storage in working memory. Thus, the functional capacity of working memory during comprehension will be reduced and comprehension difficulties will result. The child with reduced functional working-memory capacity may have problems in comprehension tasks where exact wording is important. However, comprehension tasks which assess gist for the meaning of a passage should be affected but not as much." (p. 133)

Smith-Spark and Fisk (2007) investigated STM deficits in dyslexic university students using simple digit letter and word span tasks, and similarly to Pickering and Gathercole's (2004) study they used more demanding verbal STM tasks. These required completion of a secondary task; including a reading verbal span task and a computation span task; where participants were required to solve simple arithmetic problems while remembering the addend or subtrahend (a number that is to be added/deducted from another number). Participants also answered a multiple-choice question on each sentence while attempting to remember the final word. Finally, the verbal updating task was also used, where participants recalled the last six items in a list (from a list which varied in length to between six and 12 letters long). Consistent with the verbal STM deficits found in children, dyslexic university students demonstrated a significant deficit in both simple and complex span tasks. It was found that dyslexics had a significant deficit on the complex tasks, even when simple span was taken in to account. Unlike in the Pickering and Gathercole (2004) study, dyslexics performed significantly worse on the reading span task; with 73% of participants demonstrating a significant deficit. This may be a result of the task used by Pickering and Gathercole (2004) requiring the participants to make judgments on the meaning of the sentence whereas in the Smith-Spark and Fisk (2007) study, participants only recalled features of the sentence (e.g. which month was mentioned). The Pickering and Gathercole (2004) task may have encouraged semantic processing which could account for the fact that it did not find a deficit. Overall, the Smith-Spark and Fisk (2007) demonstrated that a dyslexic's verbal STM deficits continue into adulthood.

The phonological similarity effect has been a key verbal memory phenomenon and has been used to investigate dyslexics' deficits. A range of studies have found that while poor readers do not perform as well as controls on memory tasks, they are not as affected in relation to the phonological similarity of items (Mann, Liberman, & Shankweiler, 1980; Mark, Shankweiler, Liberman, & Fowler, 1977; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). However, these findings have not been consistently replicated; for example Hall, Wilson, Humphries, Tinzmann, and Bower (1983) failed to replicate the results. Furthermore, phonological similarity effects have been shown to disappear when task difficulty is increased for the good readers

(Holligan & Johnston, 1988). This suggested that in studies where dyslexics have not demonstrated a phonological similarity effect this could be a result of floor effects. Also, it has been argued that the studies that have not found the phonological similarity effect (e.g. Mann, Liberman, & Shankweiler, 1980) have involved dyslexic children, suggesting that this effect is caused by a development lag in learning to read (McLoughlin, et al.,1994).

The Phonological similarity effect has also been examined on tasks that did not require participants to read. Macaruso, Locke, Smith, and Powers (1996) used nameable pictures as the stimulus to examine phonological coding and verbal STM without requiring participants to read. As with the previous studies, dyslexics performed significantly worse on the serial recall of pictures than the control group in all conditions. The nameable pictures were either presented in groups of pictures that represented words that rhymed, or as groups of pictures that represented words that had no rhyming significance. These groups were further sub-divided into pictures that represented long and short rhyming words; although notably, this subdivision did not exist in the non-rhyming condition. In the rhyming conditions, poor readers performed significantly worse than normal readers. However, there were no significant differences in performance between the short and long non-rhyming word length conditions. On further analysis of the serial positions, it was found that poor readers in the first few items were affected by rhyming and word length, whereas the normal readers demonstrated the effects consistently over all the serial positions. This is particularly interesting as the majority of studies that examine short term memory in dyslexia use span tasks that do not measure serial position effects. The first few items been effected by rhyming and word length suggests that the dyslexics made use of phonological coding, but to a lesser extent than normal readers, and that as the task demands increased, the dyslexics abandoned their phonological coding strategies (possibly replaced by a non-phonological strategy). Further explanation for this difference was in the dyslexic group's performance may be because they are taking longer to rehearse items. This extended rehearsal time would lead to a breakdown in cumulative rehearsal, as articulation rates have been shown to correlate with verbal memory performance (e.g. McDougall, Hulme, Ellis & Monk 1994). Both explanations are linked to the breakdown of cumulative rehearsal as task demands increase, which can account for the disappearance of phonological similarity effects when task difficulty is increased. However, it is not clear whether verbal STM deficits stem from a dysfunction in encoding phonological characteristics and representations of verbal information (Kramer, Knee, & Delis, 2000; Tijms, 2004); or as Ramus and Szenkovits (2008) argued, that phonological representations are intact. However, verbal STM deficits that affect phonological access can result in poor performance in phonological tasks where there is verbal STM content.

Overall it appears that verbal STM in adult dyslexic populations broadly demonstrated a consistent deficit (lower recall) when compared to age matched controls from childhood continuing to adulthood. Dyslexics' verbal STM deficits did not appear to stem from a developmental lag, as performance was not consistent with younger controls or reading aged matched controls. There were some findings that indicated that there was not a deficit for semantic STM, and there were also mixed findings in relation to the phonological similarity effect, which may be due to task demands. It is not clear whether such problems are due to phonological coding deficits, or ineffective rehearsal, or both (Pickering, 2004). This will be one of the issues that the experimental chapters of this thesis will attempt to address.

4.3 Non-Verbal STM

Investigations into non-verbal STM in dyslexics demonstrated more mixed results than investigations into verbal STM, partially due to methodological issues in identifying a purely non-verbal STM task. There were conflicting results with differing studies/methodologies, finding that dyslexics are better, worse or comparable to control groups. Dyslexia (or word-blindness) was initially thought of as a visual memory and sensory processing disorder (Hinshelwood, 1917; Orton, 1937). This was founded on observations made about common transposing errors that dyslexics' make (e.g. b/d, was/saw). Early work such as Carroll's (1973) reported correlations between visual STM and reading ability. However, Vellutino's laboratory published a series of studies that failed to find visual memory deficits for unfamiliar stimuli in children classified as dyslexic/poor readers (Vellutino, 1979).

One of the key debates that previous studies identified was whether the stimuli on visual tasks could be phonologically recoded. This was demonstrated by Swanson (1978, as cited in Pickering, 2004) who researched STM for nonsense shapes in good and poor readers; half of the participants from each group were taught names for the shapes, while the other half were not. Good and poor readers performed comparably in the unnamed condition. However, in the named condition, the good readers performance was better and the poor readers were worse (albeit, non-significantly).

Furthermore, Palmer (2000) investigated the performance of the phonological recoding in dyslexic teenagers matched with two control groups on both age and reading age controls. Participants completed the Corsi Block task as a measure of nonverbal STM and auditory digit span as measure of verbal STM (Corsi, 1972). The Corsi Block task requires participants to recall a sequence of spatial locations, presented to the participant by tapping on semi-randomly organised blocks fixed to a board. The Corsi Block task follows the same procedure as a verbal task by increasing the number of blocks tapped until the participant repeatedly gets the sequence incorrect. This span measure of spatial memory, widely used in clinical assessments, is designed to be the visuo-spatial equivalent of the verbal digit span task. Sequences of increasing length were presented and spatial memory span was defined as the maximum sequence length that the participant was able to reproduce. On the Corsi Block task, dyslexics performed at a comparable level to age controls and both groups performed better than the reading controls. With regards to verbal STM, dyslexics' performance was better than reading controls but worse than age controls. In addition to the above tasks, a nameable picture span task investigated the disruption to the recall caused by visual and phonological similarities of items. In this task there were two conditions; firstly a visually similar condition where drawings were visually similar and phonologically dissimilar e.g. ball, cake, face, sun, wheel. In the phonologically similar condition, drawings were visually dissimilar and phonologically similar e.g. cat, hat, map. On the nameable picture span task, dyslexics were the only group whose performance was affected by the visual similarity effect, while all groups demonstrated the phonological similarity effect. In the visual similarity effect condition dyslexics performed worse than both control groups, whereas in the phonological similarity effect condition the dyslexics performed comparably to the reading controls and worse than the age controls. This suggested that dyslexics are using both visual coding and phonological recoding on the nameable picture span task; unlike the control groups who only appeared to use phonological recoding. It was argued that holding information that can be coded in two forms may be more resource demanding, hence causing the dyslexics' deficit in this task. This was also supported by the results of the Corsi Block Task, as in this task when information should only be held visually, dyslexics performed at a comparable level to their age-matched controls. This was consistent with the findings of Vellutino (1979), that non-verbal STM was not impaired when verbal recoding does not take place. However a dyslexic's performance on the Corsi Block task and its subsequent variants was consistent in other studies. Some found an impaired ability in serial recall of spatial locations (e.g. Corkin, 1972; Morrison, Giordani & Nagy, 1977), while others found that dyslexics performed at an equivalent to controls (e.g. Palmer, 2000; Gould & Glencross, 1990).

Other studies such as Pickering and Gathercole (2004) used a matrix task (recall of blacked out squares in a matrix), which is similar to the Corsi Block test, in a simplified static condition (all items displayed simultaneously). In this case, the dyslexics' demonstrated a deficit. However in the more difficult dynamic condition (sequence of squares recalled), dyslexics did not show a deficit. Deficits in Corsi performance are more frequently observed in more demanding conditions such as backward recall condition, or under a concurrent cognitive load (e.g. Olson & Datta, 2002; Reiter, Tucha & Lange, 2004; Smith-Spark & colleagues, 2003, 2007; Swanson, Ashbaker & Lee, 1996). For example, Smith-Spark and Fisk (2007) found that on the basic Corsi Block task, dyslexics performed at an equivalent level to the control, while on a non-verbal equivalent to the reading span task, dyslexics demonstrated a significant deficit. On a more taxing spatial updating task (nonverbal equivalent to the verbal updating task mentioned earlier), dyslexics performed at an equivalent level to the controls overall, however on serial position analysis it was found that they were significantly worse at recalling earlier items.

Wide varieties of visual-spatial tasks have been used to investigate whether dyslexics have visual-spatial talents. For example, Winner et al. (2001) looked at the performance of dyslexics on a series of visual-spatial tasks, including abstract tasks and real world problems. One of the STM tasks used to look at non-verbal memory was the Rey-Osterrieth task, which requires the reproduction of complex line drawings. The results demonstrated that dyslexics performed worse on the majority of tasks (including the Rey-Osterrieth task) and at a comparable level on a few. There was one task where dyslexics out-performed non-dyslexics (but not to a significant level); participants were asked to identify whether an Archimedes screw was being turned the correct way. A follow-up study examining the findings of the Archimedes screw task in more detail (Von Karolyi, Winner, Gray, & Sherman, 2003), produced findings that suggested that dyslexics have "superior global visual-spatial processing ability". Dyslexic's were able to recognise impossible figures more rapidly than controls; however, there was no difference in accuracy between the two groups.

Jefferies and Everatt (2004) compared dyslexic children to children with other special educational needs (and a control group) on working memory tasks. The results showed that both groups performed worse than the control group on phonological measures (with dyslexics performing the worst). Dyslexics performed as well as the control group on visuo-spatial and visual-motor tasks.

To summarise the research on non-verbal STM, dyslexics demonstrated very mixed performances on nonverbal tasks, with several studies suggesting that dyslexics are unimpaired on visuo-spatial memory tasks (e.g. Brosnan Demetre, Hamill, Shepherd & Cody, 2002; Gould & Glencross, 1980; Hicks, 1980; Jeffries & Everatt, 2004; Jorm, 1983). However, there were contrary claims that visual sequencing problems and flawed orthographic representations arose from deficiencies in visuo-spatial memory (e.g. Eden, Stein, Wood & Wood, 1996; Goulandris & Snowling, 1991; Watson & Willows, 1995). One of the main issues faced when looking at nonverbal memory is identifying tasks that cannot be verbally recoded, because if this was possible then any deficit found could then be attributed to verbal STM deficits. The use of verbal recoding on different tasks could explain why there have been such mixed results in this area.

4.4 Summary

STM deficits affecting dyslexics and poor readers have been widely researched, with the majority of studies focusing on the verbal domain. As discussed in the introduction (4.1), Savage, Lavers and Pillay (2007) identified four explanations for the way WM/STM contributes to reading disabilities. These are the general capacity model (general ability to concurrently store and process information); the general processing model (general processing deficit regardless of the domain tapped); specific processing model (task-specific demands deficit) and the phonological storage model (a deficit in the temporary storage of verbal information). One of the key issues in distinguishing between these models is to identify whether dyslexics' STM deficits are solely at the verbal level or are more widespread. Although the deficits found in verbal domains are consistently found, nonverbal deficits are not as consistently found which may be a result of different methodologies used. There were also limitations in the tasks used to examine STM deficits, mainly with span measures; this will be discussed in chapter 5.

Chapter 5: Verbal Serial Recall

5.1 General introduction

This chapter focuses on the deficit found in dyslexic populations in the serial ordering of verbal information in short term memory (STM). In particular, investigation focused on phenomena associated with the behavioural performance of verbal STM tasks, such as presentation modality, serial position and irrelevant sound. These core phenomena have been used to examine the underlying processing architecture that supports the temporal preservation of sequential verbal material. The core phenomena have formed a robust model which has been used as the underlying basis of investigation in many studies (Botvinick & Plaut, 2006; Marshuetz, 2005). Baddeley and Hitch's (1974; Revised: Baddeley, 1986, 2000) multi-component working memory model[3] (WM) was the dominant model of reading difficulties, dyslexia and verbal STM, which sees the working memory accounts of these phenomena as the benchmark (see Savage, Lavers & Pillay, 2007, for review of the evidence surrounding reading difficulties). As previously discussed in Chapter 4, the STM deficits in dyslexia were most frequently accounted for by weaknesses in the phonological loop/store and in phonological coding abilities (Snowling, 1998; Gathercole & Baddeley, 1989). Evidence of this weakness was provided by simple verbal memory span tasks that assessed the phonological loop's storage capacity, these have been extensively reported (e.g. Cohen, Netley, & Clarke, 1984; Miles & Ellis, 1981; Miles, 1993; Roodenrys & Stokes, 2001; Smith-Spark, Fisk, Fawcett, & Nicolson, 2003).

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[3]Hereafter abbreviated to working memory.

This chapter presents six experiments that examined the verbal serial order deficit by using the core STM phenomena to investigate the underlying processing architecture. The first experiment examined the effects of presentation modality and serial position of digits on a serial order reconstruction (SOR) task in dyslexic and non-dyslexic adults. The following six experiments further examined the phenomena of interference, such as irrelevant sound, phonological similarity and concurrent articulation, on a dyslexic's maintenance and selective attention processes in verbal STM.

The phonological loop/store was central to the majority of accounts of dyslexics' STM deficits, and this structure was defined by Baddeley in 2003 (see Figure 5.1) as the Working Memory Model, which was used to account for the core phenomenon investigated in the experiments. Other components of WM, e.g. central executive and the episodic buffer, were also used to account for duel task performance and commutation between different components (Andrade, 2001). The WM theory set out some key constraints for the phonological loop, i.e. that buffers were specifically dedicated to the short-term maintenance of information. It also set out that items passively decay with time, and that the stores are modality specific, i.e. phonological loop is explicitly phonological in nature. Also the phonological output buffer is described as a unitary system, which cannot manage multiple streams of information, e.g. during articulation the phonological output buffer cannot transfer visual information to the phonological store.

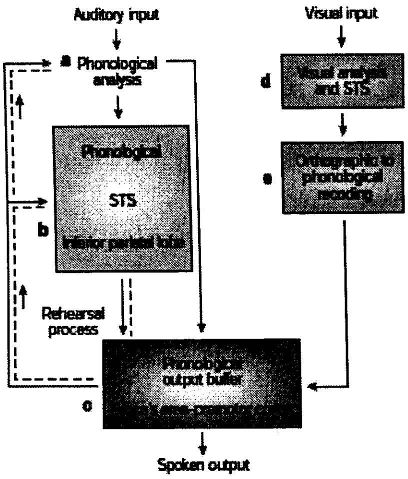

Figure 5.1. "A functional model of the phonological loop. a | Phonological analysis. b | Short-term storage (STS). c | The programming of speech output. d | Visual encoding. e | Grapheme-to-phoneme conversion." (Baddeley, 2003).

The phonological loop was further broken down into functional components that account for the differing processing paths within the loop. The core phenomena of presentation modality (auditory advantage) were accounted for by auditory items with direct access to the rehearsal loop entering at the phonological analysis components. Items then go in to the store where they can be held for a few seconds before continuing to the output buffer where they either sub-vocally articulated, passing back into the loop, or articulated where they can potently re-enter the loop as auditory input. Visually presented items have to be analysed in short term store and phonologically recoded before entering the loop; these additional levels of processing, coupled with entering the loops at the output buffer, accounted for auditory presented items and were better recalled than visual items (Baddeley, 1986). It was proposed that the underlying difficulty in phonological processing or phonological coding accounted for most difficulties in dyslexia, including STM deficits (e.g. Rack, Hulme & Snowling, 1993; Share, 1995). Rack (1994) hypothesised that dyslexics were less efficient at using phonological coding in working memory, which could result in a STM deficit. This suggested that dyslexics would have an increased auditory advantage as the recall of auditory items required less phonological recoding.

The primacy and recency effects were explained by decay in the loop; items in the list are refreshed by the output buffer, which decreases the decay but does not completely renew the item. Items typically recalled are the ones with the least decay (recency) and the ones most frequently past the thought buffer (primacy; Burgess & Hitch, 1992). It was suggested that poor readers made use of the phonological store, which may have reduced capacity due to faster decay rates or `noisy' encoding (Johnston & Anderson, 1998; Johnston, Rugg & Scott, 1987; Holligan & Johnston, 1988). This suggested that dyslexics have a reduced primacy effect, as rehearsal of to-be-remembered items would not be as effective due to faster decay rates.

Irrelevant Sound (IS) has a negative effect on recall, and has been attributed to the direct accesses of auditory material to the loop disrupting processing. Salamé and Baddeley (1982) originally attributed this to the speech processing loop (i.e. that the irrelevant sound is treated as if it were speech). Salamé and Baddeley (1989) further developed this 'Noise Filter' hypothesis into a two-stage hypothesis. At stage one, less speech-like auditory information is blocked from entering the phonological loop. At stage two, the more phonological features that the to-be-remembered and to-be-ignored information have in common, the more interference occurs. However as discussed in Jones, Macken, and Nicholls (2004), the similarity to speech of the to-be-remembered items did not appear to be important; for example, tones induced the same effect as speech, the key elements were that the sound changed and the degree to which it changed. The change in the irrelevant sound can be a change in content (i.e. the sequence A to G is more disruptive than A repeated), and changes in pitch, frequency, e.g.location and / or stream (perceived melodic line). As discussed in Chapter 4, dyslexics consistently demonstrate a deficit in verbal memory span, which was attributed to phonological loop's capacity. This suggested that IS will have a greater impact on recall as with a smaller capacity a larger portion of the phonological loop will be occupied by IS. Evidence of this came from the research by Conway, Cowan, and Bunting (2001) who found that, when looking at the 'cocktail party effect', participants with a lower memory span were unable to inhibit salient information embedded in irrelevant sound.

Suppression tasks, especially articulatory suppression or concurrent articulation, have been demonstrated to interfere with the phonological loop during serial recall tasks (Larson & Baddeley, 2003). To clarify, articulatory suppression is the verbal repetition of task irrelevant items during the task. It was thought to block both sub-vocal rehearsal and the phonological encoding of visually presented material (Baddeley, Lewis, & Valler, 1984). Manual suppression, or concurrent motor tasks, primarily interfere with the visuospatial STM, the task can be used to assess the specificity/independence of processing systems in STM. The phonological loop should be unaffected by this task as it is distinctly a phonological process; however, if the system were more motor in nature, the task should demonstrate a detrimental effect on recall. Parmer (2000) reported that dyslexic teenagers completing STM tasks showed phonological and visual similarity effects, whereas controls (matched on chronological and reading age) were only affected by phonological similarity. It was suggested that this was due to dyslexics' delay in developing an inhibitory mechanism for visual coding strategies. Therefore, it was suggested that dyslexics still use a dual encoding strategy, which is normally found in a crossover period when learning to read improves from visual to phonological encoding. The resulting additional demands on a limited STM system of holding information in two forms may account for dyslexic's deficits. Therefore, under conditions of articulatory suppression dyslexics would only be able to use a single encoding strategy and this would reduce demands on STM and result in a reduction in the I deficit.

5.1.1 General method

Despite the considerable amount of evidence for verbal serial recall deficits in dyslexics STM, as discussed in terms of the WM framework, the vast majority of experiments used span tasks. Span tasks, both simple and complex, were reviewed by Savage et al. (2007) and generally involved the presentation of serially ordered items to a participant who would then recall the items as presented. The number of items in the list gradually increases, and typically three lists of the same length were given before the list length increases. The score is reported as the list length when two out of three lists were correctly recalled. This provides the method with a quantifiable measure of performance; however, it does not capture list position effects, i.e. primacy and recency effects. In the majority of span tasks, participants respond by articulating the answers; this could promote sub-vocal rehearsal processes, and activate speech-motor output processes (Savage et al., 2007). Indeed, it was argued that if a task puts strong demands on phonological processing at an output level, it would make the task a less than pure measure of verbal STM (Snowling, Chiat, & Hulme, 1991, as cited in Savage et al., 2007). Nicolson, Fawcett and Baddeley (1991) reported that dyslexics have slower articulation rates; as time decay is considered an important factor in recall slower articulation rates could affect results. Sterling, Farmer, Riddick, Morgan and Matthews (1998) also reported that when writing under timed conditions, dyslexic university students were significantly slower and made more errors. This slower articulation rate was put forward as the cause of deficits on simple span tasks (Avons & Hanna, 1995; Hulme, Roodenrys, Brown & Mercer, 1995; McDougall & Donohoe, 2002; Nicolson, Fawcett, & Baddeley, 1994). The experiments described in this chapter, used serial order reconstruction where participants used a computer mouse to select options from a closed set on screen. The first three experiments used a serial order reconstruction task using highly familiar digits, items 1-9, in a serial order to further decrease item processing requirements, as the aim of the present study was to focus specifically on serial order STM.

5.2 Experiment 1

The first experiment examined the core phenomenon of presentation modality and serial position on verbal to-be-remembered items in a serial recall task on high-functioning adult dyslexics. Serial position effects were accounted for in terms of timing and frequency of activation; items at the beginning of the list were over activated through rehearsal, and items at the end of the list were viewed most recently; hence items at the beginning and end were well recalled. The increased recall of verbally presented information was accounted for by direct access to the phonological loop, whereas visually presented items needed to be phonologically encoded (Baddeley, 1986). Rack (1994) argued that dyslexics used phonological encoding in WM less efficiently than controls, which would results in the observed deficit. As visual and auditory modalities illicit different levels of phonological encoding dyslexics should increase performance discrepancy on visually presented items due to their inefficiency with phonological encoding.

Modality and levels of processing also have differing serial position effects; for example, auditory items have a stronger recency effect (Baddeley, 1990) The WM model attributed this to direct access to the phonological loop, as well as resulting in less decay (Burgess & Hitch, 1992). For example, Bauer (1977) reported that learning-disabled children upon immediate free recall of monosyllabic nouns showed reduced primacy effects but recency effects were comparable to that of the controls. In the same study, when a delay was included before recall, dyslexics demonstrated both reduced primacy and recency effects. Bauer (1977) suggested that dyslexics are less effective at maintaining items in the phonological loop. Crowder (1976) suggested that the reduced primacy effect in reading-disabled children was due to a deficiency in the use of elaborate encoding strategies. Furthermore, a positive correlation between reading level and recall of the first three items of each list was found and suggested that elaborate encoding was related to reading ability. Additionally, Bauer and Emhert (1984) reported reduced primacy effects comparable in reading disabled children when completing immediate-free recall of words. It was suggested that dyslexics have slower access to verbal labels which results in problems during transfers to long-term memory and increases decay. Results also suggested that presenting the items at slower presentation rates had little effect on the recency effect. Increased recall of the first few words presented was consistent with the hypothesis that slower presentation allows more time for elaborative encoding (Crowder, 1976). More importantly, slower presentation rates increased the primacy effect of reading-disabled children.

However, the described effects are not always found; for example, Byrne and Arnold (1981) did not find reduced primacy effects in their recall task. Both poor readers and controls recalled more words from the end of "the list than from the beginning, and there were no differences between groups in the number of items recalled from the start of the list. Kramer et al. (1999) used the Children's California Verbal Learning Test (Delis, Kramer, Kaplan & Ober, 1994) to examine primacy and recency regions of recall in children with dyslexia and control groups. The task involved a 20 minute interval between learning (auditory presentation) and recall of items from a list of individually presented items. Both groups performed comparably in the primacy and recency regions (the first and last four words). The dyslexic group demonstrated a deficit in the middle of seven items. All these studies reported thus far used words that could have been supported by semantic strategies as the most widely reported STM deficit is digit span,[4] which methodically is most frequently the immediate serial recall of auditory presented items. Also the dyslexics reported in the Kramer et al., (1999) study were children, who often have not developed compensatory strategy deficits.

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[4]As discussed in chapter 1 & 4.

Another study examined the digit and word spans of auditory list and performance on a letter-updating task in the same population as this thesis; in dyslexic and control university students (Smith-Spark et al., 2003). Dyslexic students performed significantly worse on digit and word spans of auditory list and performance on the letter-updating task. Serial position effects were examined on the letter-updating task and the authors concluded that the performance pattern of the dyslexic group suggested qualitatively recency-based processes.

The current experiment examined high-functioning adult dyslexic ability on serial order reconstruction of digits presented over two modalities (visual and auditory), the core phenomena of presentation modality and serial position. The control group were expected to perform at a higher level than the dyslexics, as performance would be close to ceiling. This would result in primacy and recency effect been reduced as performance in central items would also be high. Therefore, a second control group performed an eight item version of the task to allow comparison of serial position effects to the dyslexic group.

5.2.1 Method

5.2.1.1 Participants

All participants were students at Cardiff University. The 60 controls were self-reported non-dyslexics and were 15 males and 45 females with a mean age of 20.84. Forty participants were diagnosed with dyslexia by an educational psychologist. The mean age of the dyslexic group was 22.1 years, and there were 23 male and 17 female participants.

5.2.1.2 Apparatus and materials

The to-be-remembered (TBR) digits were selected from the closed set of 1-9. The seven item TBR sequences were pseudo-randomly ordered so that no digits were duplicated in the list and there were no adjacent integers. In the visually presented trials, digits were presented in the centre of the computer screen, in Times New Roman font, point 72. In the auditorily presented trials, the digits were presented in a male voice and were recorded using Sound Forge 5.0 software, each digitized file was 300ms long. All participants listened to the stimulus through sound attenuated headphones. All sounds were with the range of 65-75dB (A).

5.2.1.3 Design

A mixed design was adopted between groups (control seven item serial recall task vs. dyslexic seven item serial recall task vs. control eight item serial recall task) as the between-subject factor, and presentation modality (visual vs. auditory) as the within-subject factor. There were 40 participants in each of the seven item serial recall groups and 20 participants in the eight item serial recall group. Half the participants in each group received visual items followed by auditory items and the other half had these conditions reversed.

5.2.1.4 Procedure

Participants were instructed that they would be presented with seven digits in succession, and that at the end of the list they were to recall the items in the same order in which they were presented. The presentation of the list would be either visual or auditory. These instructions were adjusted accordingly for the eight item group.

Each of the to-be-remembered digits were presented at a rate of one per second. All digits were presented for 300ms followed by a 700ms blank screen and silence. In each trial, the digits were ordered so that they did not follow a pattern, and so that digits were not repeated within trials. After the final 700ms interval all digits, one to nine were displayed. Participants selected the appropriate digit order on screen using the mouse, and selected digits disappeared after each selection. The task was self-paced so participants controlled the amount of time taken to select the serial order; although, when the correct number of items were selected the screen went blank for one second before the next trial started.

The experimental sessions were run with up to six participants in a laboratory, where participants sat at individual computer stations wearing sound attenuated headphones. Dividers were present between each of the workstations to avoid distractions from other participants.

5.2.2 Results & Discussion

Participants' responses were scored using a strict serial order criterion: Each item had to be recalled in the correct position in order for the response to be scored correct. The serial position curves for the percent correctly recalled for each group and conditions are displayed in Figure 5.2. It appeared that each of the groups demonstrated functional equivalence across modalities, thus replicating the basic serial position and modality effects. With respect to group performance, the dyslexic group's performance was worse than the control group when completing the same task, but higher than the control group who completed the eight item task. As predicted, the control group performed the seven item task close to ceiling, which appeared to flatten their serial recall curves; however, this did not affect the eight item control group's distribution.

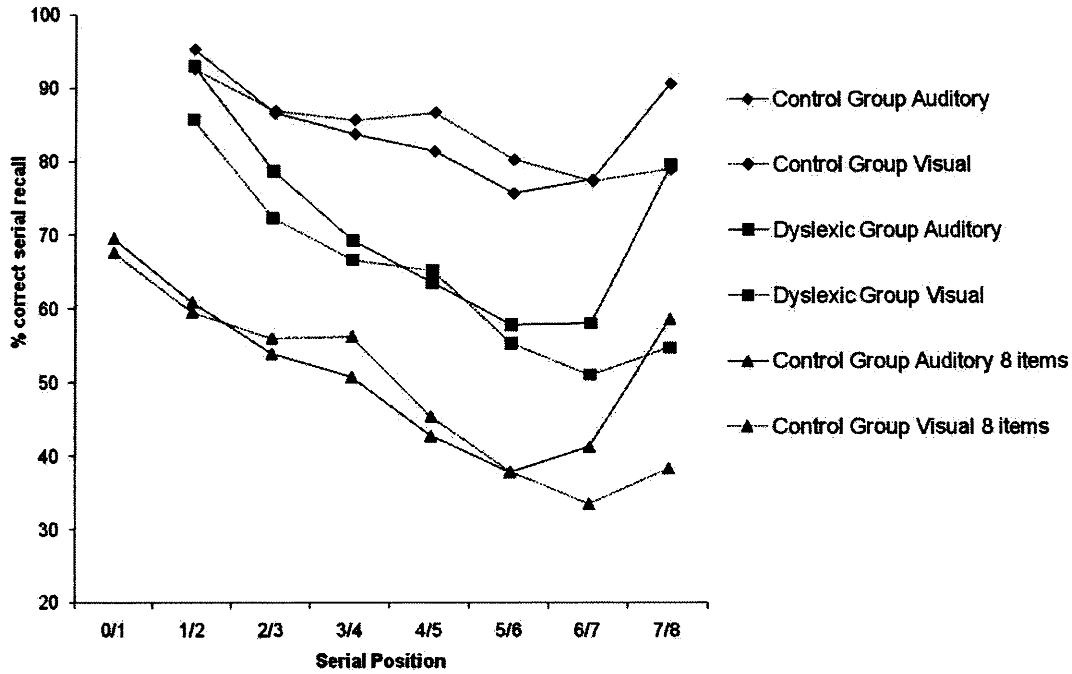

Figure 5.2. Mean percent of correctly recalled items for Dyslexics and controls across modality (visual v. auditory presentation) in the seven and eight item serial recall tasks demonstrated in Experiment 1.

The percent of incorrectly recalled items in the seven TBR items groups were examined in a mixed ANOVA[5] (modality, serial position, group). A repeated-measure ANOVA (modality, serial position) was conducted for the eight TBR item control group. Sphericity was not assumed, thus the degrees of freedom were corrected using Greenhouse-Geisser estimates.

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[5]For all ANOVAs in the chapter significance was set at .05 and all comparisons were Bonferroni adjusted.

The between-group analysis of the seven item groups demonstrated the predicted significant deficit in the dyslexic group (main effect), F (2,98)=23.97, $MSE = 3108.56, \eta_p^2 = .24$. There was a main effect of serial position, F (2.58, 200.83) = 77.46, $MSE = 359.44$, $\eta_p^2 = .50$. There was a significant interaction between group and serial position, F (2.58, 200.53) = 10.6, $MSE = 359.44$, $\eta_p^2 = .12$. Recall of items at positions three, four, and seven was significantly lower than at position two for the dyslexic group, whereas the control group's performance did not significant decrease. There was a main effect of serial position in the eight item control group, F (2.69, 51.01) = 34.72, MSE = 356.67, $\eta_p^2 = .65$, where the serial position in the eight item control group demonstrated a significant decrease in performance between items two and three. For both control groups, there was a non-significant difference between position two and the fourth item. Figure 5.2, illustrated that both control group's recall of visual items plateaued at the fourth item, and although the dyslexics also demonstrated this pattern, it was not to the same magnitude and resulted in a continued decline in performance. Thus, dyslexics demonstrated primacy effects; however, it appeared to be reduced for visually presented items, which suggested that dyslexics were not encoding or recoding visually presented items as efficiently as the control group. This was consistent with the Rack (1994) argument that dyslexics were using phonological code less efficiently than controls.

There was a significant main effect of modality, $F(1, 98) = 11.69$, $MSE = 299.86, \eta_p^2 = .14$, and an interaction of modality and group, $F(4.38, 341.42) = 30.8$, $MSE = 88.5$, $\eta_p^2 = .12$. Simple effects of modality for each group demonstrated that recall of auditory items were only significantly improved for the dyslexic group, $\eta_p^2 = .27$ (control group, $\eta_p^2 = .41$). There was also a significant interaction of modality and serial position, $F(4.38, 341.43) = 30.8$, $MSE = 88.5$, $\eta_p^2 = .28$, with a non-significant plateau for the visually presented items between positions two, three and four. There was also a significant recency effect for the auditory items but not for the visually presented items.

To further examine the magnitude of the recency effect for auditory items, and following on from the Smith-Spark et al. (2003) study's suggestion that dyslexics may be relying on recency-based processes, the groups were compared on three recency measures identified in Nicholls and Jones (2002): "(a) the *absolute measure*, which takes the accuracy with which terminal items are recalled; (b) the *relative measure*, which is based on the change in recall between terminal position and pre-terminal position; and (c) the *normalized measure,* which is calculated by expressing correct recall at the terminal position as a proportion of the sum of all correctly recalled items across all serial positions" (p15). A mixed ANOVA (group, recency measures) was conducted on these error scores. The main effect of group on the absolute measure of recency approached significance, $F(2, 97) = 3.06$, $MSE = 230.82$, $p = .052$, which demonstrated a significant difference between the dyslexic and the seven TBR item control group; the seven-item control group demonstrated significantly smaller recency effects than the dyslexic group. This could be explained by the predicted close to ceiling effects in this group. No significant differences were found on any other comparisons, which suggested that the recency effects were comparable between dyslexics and controls.

These results demonstrated that, although there was a generally lower performance in the dyslexic group for the serial recall analysis, the distribution of the dyslexic group followed the same pattern as the control group. Dyslexics were demonstrating roughly equivalent modality and serial position effects. This was not consistent with the argument that they have substantially faster decay rates, as the dyslexics did not demonstrate reduced primacy, which was proposed as an underlying cause of dyslexics' poor performance on verbal STM tasks (i.e. Johnston & Anderson, 1998; Johnston, Rugg & Scott, 1987; Holligan & Johnston, 1988). The results of Experiment 1, were consistent with the large corpus of work, finding that dyslexics have a continued verbal STM deficit, which cannot be explained by slower vocalisation of responses.

As discussed in the general method (Section 5.1.1) dyslexics have been shown to take significantly longer when verbally recalling items (Nicolson et al., 1991). The second experiment took timing measures to examine if dyslexics were slower to respond than controls, even when vocalisation was not required to recall items. No evidence has been found in Experiment 1 to suggest that there are qualitatively different processes, as suggested by Smith-Spark et al., (2003).

5.3 Experiment 2

Serial STM is impaired if task irrelevant auditory material is presented during the presentation of to-be-remembered items (e.g. Colle & Welsh, 1976; Jones & Macken, 1993; Jones, Macken, & Nicholls, 2004; Macken & Jones, 1995; Salamé & Baddeley, 1982; 1986). Salamé and Baddeley (1986) argued that the speech gained direct access to the phonological loop, which interferes with information in the phonological store. This effect is found on both auditory to-be-remembered items that have direct access to the store and on verbally recoded visually presented items. As the phonological loop has limited capacity, the irrelevant sound takes up some of the capacity resulting in reduced recall. The processing limitation hypothesis of dyslexics' STM deficit (Gathercole & Baddeley, 1990) would expect dyslexic participants to be even more sensitive to irrelevant sound and demonstrate a greater deficit. The impairment of dyslexics' STM, including serial recall, is often attributed to central executive and phonological loop impairments. This was demonstrated in Experiment 1, which was consistent with previous studies that demonstrated that dyslexics have a deficit in verbal STM (e.g. Rack, Hulme & Snowling, 1993; Share, 1995).

The phonological storage model of STM and reading difficulties (e.g. Jorm, 1983) argued that dyslexics have a smaller capacity phonological loop that would result in irrelevant sound having a greater impact on recall, as a larger proportion of the phonological loop will be occupied by irrelevant sounds. The majority of tasks used to examine how verbal STM memories are affected by secondary tasks are classified as central executive tasks. For example, Smith Spark and Fisk (2007) looked at performance on a central executive task, which required dyslexics to inhibit early list items that were no longer task relevant. On this task adult dyslexics performed with a deficit compared to controls, which suggested that dyslexics have a deficit with their inhibitory processes.

The automatism account of dyslexia suggested that dyslexics found it difficult to inhibit the irrelevant sound, and would not be able to automate streaming the irrelevant sound. Furthermore, reading-impaired children have been shown to be less likely to segregate sound streams (Ouimet & Balaban, in press), which suggested that dyslexics may find segregating the to-be-remembered items from the irrelevant sound less automatic than the control groups, and therefore, resulting in more disruption. The increased disruptive effect of changing state (as opposed to steady state) irrelevant sound has been linked to an element of habituation to the sound (Morris & Jones, 1990b). It was argued by Jones and Macken (1995) that the effect could not be solely accounted for by habituation due to the speciality of the effect.

The irrelevant sound effect has been constant within the WM and phonological loop accounts (c.f. Macken & Jones, 2003). An alternative model such as the Object-Oriented Episodic Record (O-OER) Model argued that the disruption was due to the obligatory processing of order information in to-be-ignored material and that it interfered with the deliberate processing of order information in the to-be-remembered material (Jones &Macken, 1993). However, Snowling, Goulandris, Bowlby and Howell (1986) examined the performance of children with dyslexia on a repetition task with irrelevant noise masks; where participants repeated high and low frequency words and repeated non-words, which were derived from the high and low frequency words by changing the initial phoneme or cluster. To examine speech perception, the words were presented in high and low noise masks as well as no noise. Overall, the dyslexics performed at a deficit compared to age matched controls on non-word repetition. Dyslexics were worse at reproducing low frequency words; however, they tended to classify low-frequency words as non-words. It was found that the dyslexic group were no more affected by different levels of background noise than the control group, suggesting that dyslexics do not have perceptual deficits, but the authors concluded that dyslexics demonstrated a deficit in repetition of novel words with which they are not familiar. It could be argued that the task did not sufficiently tap into the phonological loop for irrelevant sound to affect the STM.

The aim of Experiment 2 was to extend the results of Experiment 1 by examining the ability of dyslexics to inhibit irrelevant information while completing a verbal STM task that required minimal additional processing. In order to reveal the effectiveness of the inhibitory processes, steady state and changing state irrelevant sounds were presented during the same serial order reconstruction task used in Experiment 1. Of specific interest was whether dyslexics demonstrated the changing state irrelevant speech effect to the same magnitude as the control group (as in Morris & Jones, 1990). Items were again presented visually and auditorally, with or without irrelevant sound to examine whether the irrelevant sound had a greater impact on visually presented items than auditory presented items as they require dyslexics to complete verbal recoding. Also, to investigate whether dyslexics have a perceptual deficit in separating irrelevant from TBR items, the same voice was used for both the irrelevant sound and TBR items, to increase the task difficulty. In addition to examining the correct answers, the time taken to respond during recall was measured in order to examine whether dyslexics take significantly longer to respond on this order reconstruction task, and if this would replicate the slower response rates found in other studies (e.g. Nicolson, Fawcett, & Baddeley, 1991; Sterling, Farmer, Riddick, Morgan, & Matthews, 1998).

5.3.1 Method

5.3.1.1 Participants

The recruitment and screening of participants followed the same procedure as Experiment 1. All participants were students at Cardiff University. The control group of twenty were self-reported non-dyslexics, with a mean age of 21.1 years and there were 19 females and one male. Twenty participants had a diagnosis of dyslexia by an educational psychologist, with a mean aged of 20.23 years with 9 males and 11 females. All of the educational psychologists' reports stated that the individual had an average or above average intelligence level, however only 85% reported an IQ score on the WAIS III (other reports either did not report an IQ score or used different versions of the tests e.g. WAIS-R/WISC III). The mean of the reported IQ scores was 111.11.

5.3.1.2 Apparatus and materials

The same recall task was used as in Experiment 1 with the addition of a response timer and blocks of irrelevant sound trials. Irrelevant sound items consisted of the letters A to G, recorded in the same monotone male voice as the auditory presented numbers and were presented for 500ms. In the Steady State condition, participants heard the same letter, e.g. letter 'A', in the 500ms interval between the offset and onset of the digits, and in the Changing

State condition, letters from the alphabetic sequence A to G were played during the interval.

5.3.1.3 Design

The factors of modality (visual or auditory presentation) and the irrelevant sound conditions (Quiet, Steady State, Changing State) were presented in blocks. All participants completed all six blocks containing 18 trials of to-be-remembered lists. The blocks were quasi-randomly ordered to create 20 sequences, one for each participant in each group (dyslexic and control). The trials of to-be-remembered lists were also ordered within the 20 sequences.

5.3.1.4 Procedure

The procedure was the same as in Experiment 1 with the additional instructions that in some blocks participants would hear letters being said over the headphones, and that they were to ignore any sounds other than the to-be-remembered numbers, as the recall task only required the recall of the numbers.

<u>5.3.2 Results & Discussion</u>

As with Experiment 1, participant's responses were scored by a strict serial order criterion. The correct scores were collapsed over serial position; the mean percent correct for each modality and irrelevant sound condition between groups are presented in Figure 5.3.

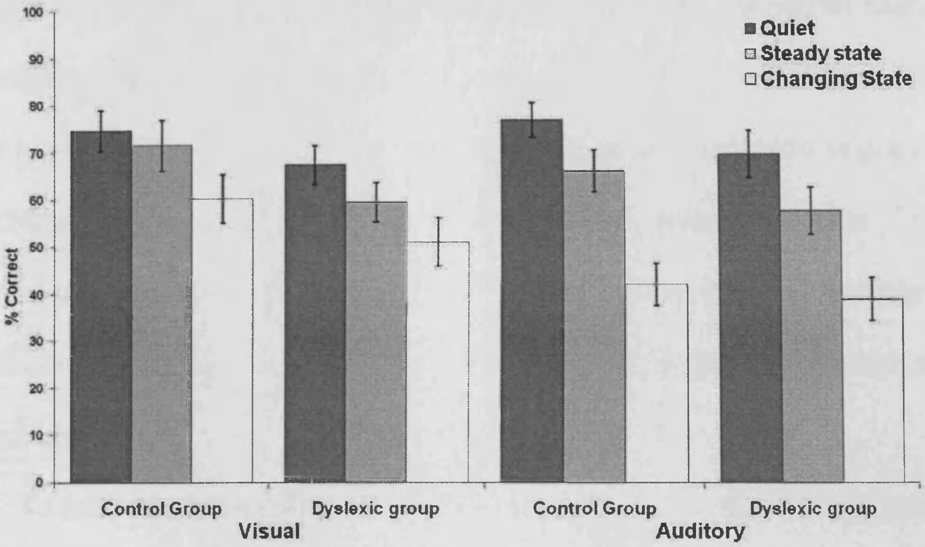

Figure 5.3. Mean percent correct for each condition between groups. Error bars are SEM.

A 2(modality) by 3(sound conditions) by 2(group) Mixed ANOVA was conducted on the percentage of errors made[6]. There was a significant effect between group performance, $F(1, 41) = 3.67$, $MSE = 1136.17$, $p < .05$, $\eta_p^2 = .08$, with the dyslexic group making a greater number of errors than the control group. There were no significant interactions involving groups.

There was a significant effect of sound condition, $F(2, 82) = 104.13$, $MSE = 102.76$, $p < .05$, $\eta_p^2 = .72$, and modality, $F(1, 41) = 7.08$, $MSE = 311.11$, $p < .05$, $\eta_p^2 = .15$. There was an interaction of sound and modality, $F(2, 82) = 21.39$, $MSE = 85.78$, $p < .05$, $\eta_p^2 = .34$, during the changing state condition, performance in the visual modality was significantly better that the auditory($\eta_p^2 = .41$). However, there was not a significant effect of modality for the quiet and steady sound conditions. Although the quiet condition was not

[6] Additional analyses including the effects of serial position were performed which showed a consistent pattern in line with Experiment 1. Both groups demonstrated the same serial position effect.

significant the performance on auditory presented items was higher than in the visual group; this was reversed in the irrelevant sound conditions where visual presented items had a high rate of recall, which reflected the greater impact that the irrelevant sound had on the auditory presented items. This reflected that dyslexics performed at a deficit consistent with the findings of Experiment 1; however they demonstrated the same effect of irrelevant sound as controls.

To further examine the magnitude of the irrelevant sound effect, the quiet conditions were used as a baseline from which the irrelevant sound conditions were subtracted. A 2 (modality) by 2 (sound conditions) by 2 (group) Mixed ANOVA was conducted on the difference in error scores. This demonstrated there was no significant difference between the groups, $F(1,40) = .114$, $MSE = 489.62$, $p = .74$, $\eta_p^2 = .003$, whilst it demonstrated the same significant main effects of sound condition ($F(1,40) = 73.31$, $MSE = 157.13$, $p<.05$, $\eta_p^2 = .65$) and modality ($F(1,40) = 30.90$, $MSE = 353.71$, $p<.05$, $\eta_p^2 = .44$). There was an interaction of sound and modality ($F(1,40) = 25.12$ $MSE = 120.14$, $p< .05$, $\eta_p^2 = .39$), which demonstrated that the magnitude of the irrelevant sound effect was greater in the auditory presentation condition. There was also the same effect of presentation, which suggested that although dyslexics are performing at a deficit, functionally there is not a difference.

In addition to examining accuracy of recall, times taken to recall items were also recorded; the cumulative recall times are shown in Figure 5.4. and illustrated a similar pattern to the error results, i.e. that although there is a delay in recalling the first item, the subsequent items are recalled at a comparable rate.

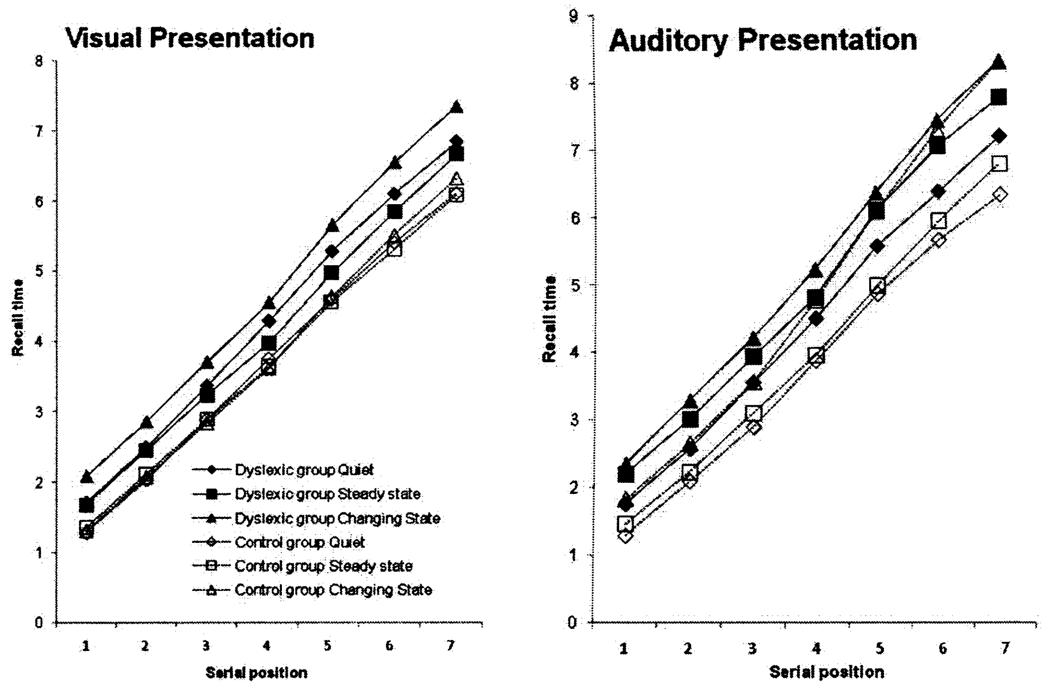

Figure 5.4. *Mean cumulative recall time (seconds) on correct items for each condition.*

A 2 (group) by 2 (presentation modality) by 3 (sound conditions) by 7 (serial position) mixed ANOVA was carried out on the time taken between each response (see figure 5.5). There was no main effect of group, however there was an interaction between serial position and group ($F(2.47,101.13)$ = 7.54, MSE=.82, p<.01, $\eta_p{}^2$ =.15). Pairwise comparisons showed that dyslexics were only significantly slower to recall the item at position 1, in the following tasks, there was no significant difference between the groups at each serial position. There were no other significant interactions of group. This suggests that although the dyslexic group took longer to start recalling the items, they did not have a generally slower recall rate.

	Serial Position	*1*		*2*		*3*		*4*		*5*		*6*	
	Group	C	D	C	D	C	D	C	D	C	D	C	D
Sound condition								Visual presentation					
Quiet		1.28	1.70	0.75	0.79	0.85	0.87	0.87	0.91	0.84	1.00	0.81	0.8
Steady		1.35	1.68	0.76	0.78	0.77	0.78	0.74	0.74	0.91	0.99	0.75	0.8
Changing		1.30	2.08	0.76	0.78	0.77	0.84	0.77	0.85	1.02	1.11	0.88	0.9
								Auditory presentation					
Quiet		1.29	1.76	0.80	0.81	0.80	0.97	0.98	1.07	0.98	0.80	0.80	0.8
Steady		1.46	2.20	0.77	0.81	0.87	0.92	0.85	0.88	1.03	1.29	0.96	0.9
Changing		1.75	2.35	0.79	0.94	0.87	0.92	1.15	1.02	1.27	1.14	1.16	1.0

Figure 5.5. Mean incremental recall time (seconds) on correctly recalled items for each cc Dyslexic (D)

There was a main effect for presentation modality ($F(1,41) = 26.56$, MSE=.26, $p<.01$, $\eta_p^2=.39$),where items presented visually were recalled more rapidly. There was also a main effect of sound conditions ($F(1.51,62.08) = 8.77$, MSE=.46, $p<.01$, $\eta_p^2=.18$), where participants took significantly longer to recall items in the changing state irrelevant sound condition than in the quiet and steady state conditions. There was an interaction between presentation modality and sound conditions ($F(1.45,59.37) = 4.26$, MSE=.35, $p<.03$, $\eta_p^2=.09$). When comparing the modality of items presented auditorally these were recalled significantly slower during irrelevant sound conditions, with auditorally presented items in the changing state condition having the longest recall times. This was reflected in the accuracy data; the conditions that had the longest recall times also had the lowest percentage of correct answers.

There was a main effect of serial position ($F(2.47,101.13) = 76.49$, MSE=.82, $p<.01$, $\eta_p^2=.65$). The only positions that took significantly longer to recall than all others were items at positions 1 and 5, with position 5 been recalled faster than position 1. Items at position 2 were recalled significantly faster than items at positions 3 and 4. There were no other significant differences between position and time taken to recall. There was an interaction of sound conditions and serial position ($F(5.65,231.8) = 4.02$, MSE=.24, $p<.01$, $\eta_p^2=.09$). Comparing irrelevant sound conditions and each serial position revealed that the participants took significantly longer to recall items at position 1 and 6 in the changing state condition, and position 4 in the steady state condition.

While overall levels of performance were lower in dyslexics than controls, dyslexics demonstrated the same pattern of performance as controls in all conditions. This is consistent with Snowling, Goulandris, Bowlby and Howell's (1986) results that found that dyslexics did not demonstrate a functional difference in decoding relevant information from a mask. These results also suggested that streaming the TBR items from the irrelevant sound did not have any greater effect on dyslexics' ability to remember items. These results are not consistent with the dyslexics reduced capacity of the PL and automatic entry of auditory item to the PL. This could suggest that dyslexics having intact inhibitory processes for irrelevant information therefore they did not affect the PL. The results are not consistent with studies that have found that while completing secondary tasks, dyslexics demonstrated a greater deficit (Pickering & Gathercole 2004; Smith-Spark et al., 2003). This could be due to the irrelevant sound being inhibited prior to the PL and does interfere to a degree which reveals the dyslexics' deficit. Larson and Baddeley (2003) argued that secondary tasks, such as articulatory suppression, make the efficient use of the phonological loop impossible. The next experiment explores the effect of suppression tasks in conjunction with irrelevant sound.

5.4 Experiment 3

Suppression tasks have been used to examine the effect of occupying aspects of the WM components. For example, articulatory suppression has been proposed by Baddeley (1986) to prevent the rehearsal of items in the PL and recoding of visual information to the PL. Only auditory items were used in Experiment 3 to explore the proposal that participants were not able to rehearse items. Building upon the findings from Experiments 1 and 2, using the same task, Experiment 3 examined the effect of articulatory suppression on STM. A deficit in rehearsal was suggested to underlie dyslexics' verbal

STM deficit (Bauer 1977). Therefore, if the control group are also unable to use the PL effectively then their performance should be comparable to the dyslexic group. Done and Miles (1979; Done & Miles, 1978 cited in Aaron, 1989) found that steady state articulatory suppression (repeating "*the*") had more of an adverse effect on controls in a delayed seven digit recall task than it did on dyslexics; the reduced level of performance of the control group was comparable to that of the dyslexics. However, when there was no delay in recall the control group were not affected by the irrelevant sound. Done and Miles (1979) argued that the results suggested that controls had a heavier reliance on verbal rehearsal strategies, since the controls recalled more digits than the dyslexics did in an immediate recall condition with no distracters.

In experiment 2, the dyslexic group took significantly longer to start recalling items, which could be a result of taking longer to rehearse items. As discussed in section 5.1.2, slower articulation rates were put forward as the source of dyslexic's deficits on simple span tasks (i.e. Avons & Hanna, 1995; Hulme, Roodenrys, Brown & Mercer, 1995; McDougall & Donohoe, 2002; Nicolson, Fawcett, & Baddeley, 1994). The longer time taken to sub vocally articulate the items during rehearsal would result in a delay in starting recall. As the irrelevant task of articulatory suppression should inhibit rehearsal, the first item delay should not be apparent in these conditions.

In Experiment 3, the changing state suppression tasks used by Jones, Macken and Nicholls (2004) was replicated, in combination with the irrelevant sound, which previously had a significant impact on immediate serial recall performance. The study found that under conditions of suppression the changing state irrelevant sound effect was abolished in serial recall, Jones, Macken and Nicholls (2004). The suppression task required participants to whisper "X,Y,Z" repeatedly, this creates disruption from articulating a changing sequence, however, it did not act as another form of irrelevant sound. In the control condition participants completed a changing state tapping task to examine whether the effect was due to participants performing a secondary task or the articulatory nature of the task.

5.4.1 Method

5.4.1.1 Participants

All participants were students at Cardiff University. The control group of 25 were self-reported non-dyslexics (23 females and two males with a mean age of 20.04). Twenty participants had a diagnosis of dyslexia by an educational psychologist (9 males and 11 females with a mean age of 21.9). All dyslexics education psychologists' reports claimed average to above average intelligence, 87% of the reports contained an IQ score on the WAIS III which was a mean of 113.43 for the group.

5.4.1.2 Apparatus and materials

The same program was used as in Experiment 2, although with some alterations: Before each block a screen displayed a message informing participants which suppression task (or absence of suppression task) to complete in that block.

5.4.1.3 Design and Procedure

The factors of suppression (articulatory suppression, manual suppression) and the irrelevant sound conditions (Quiet, Steady and Changing) were blocked. During the study all participants completed all six blocks containing 18 trials of to be remembered lists. The blocks were quasi randomly shuffled to create 20 sequences of the blocks one for each participant in each group (dyslexic and control). The trials of to-be-remembered lists were also shuffled within the 20 sequences.

The same procedure was used as in Experiment 2, with the addition of instructions about the suppression tasks prior to the experiment and before each block. For the articulatory suppression conditions, participants were asked to whisper "X", "Y", "Z" repeatedly at a rate of three items per second during the presentation period. In the manual suppression condition, at the same rate, participants taped keys marked "X". "Y", and "Z" on the number pad (X on key 7, Y on key 5, and Z on key 3). The suppression conditions were explained in the instructions and the experimenter coached the participants in the correct rate and loudness (articulatory) of the tasks. Participants were monitored closely throughout the experiment to ensure that they completed the suppression tasks in line with instructions.

<u>5.4.2 Results & Discussion</u>

As in Experiment 2, results were scored in strict serial order shown in Figure 5.5, collapsed across serial positions. Overall, the results replicated the findings of Experiment 2 with the dyslexic group making a greater number of errors than the control group, while demonstrating the same effect on irrelevant sound and suppression tasks.

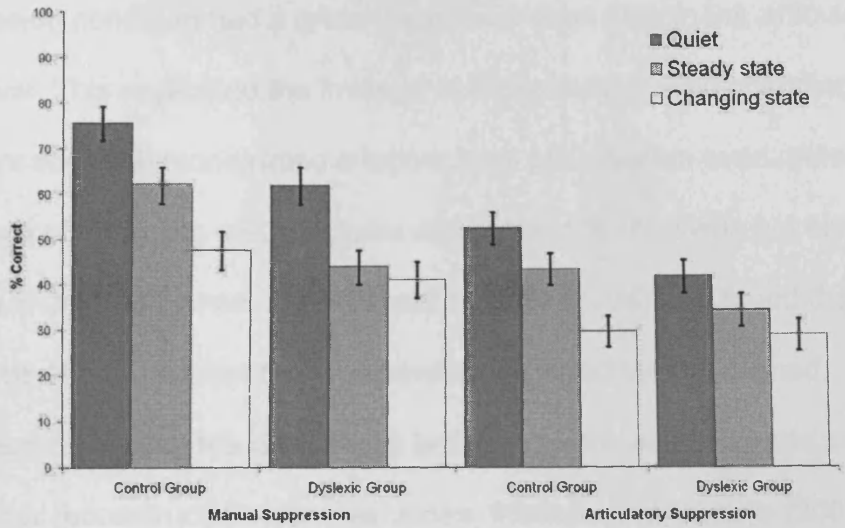

Figure 5.5. Mean percent correct for each condition between groups. Error bars show standard error of the mean.

A 2 (Group) by 2 (suppression task) by 3 (irrelevant sound condition) mixed ANOVA was conducted on the percent of errors made. As with previous experiments, there was a main effect on group, where dyslexics performed at a significant deficit to controls ($F(1, 46) = 10.49$, $MSE = 660.99$, $p < .05$, $\eta_p^2 = .17$). There were also main effects of sound condition ($F(2, 92) = 93.51$, $MSE = 114.30$, $p < .05$, $\eta_p^2 = .67$) and suppression task ($F(1, 46) = 162.75$, $MSE = 128.63$, $p < .05$, $\eta_p^2 = .78$). There was an interaction of sound and suppression task ($F(2,92) = 6.57$, $MSE = 59.87$, $p < .05$, $\eta_p^2 = .13$). Pairwise comparisons (sound and suppression task) revealed that there was a significant increase in errors made in all the articulatory conditions in comparison to the manual suppression conditions. Each of the sound conditions were also significantly different to one another, with changing state sound conditions having the highest rate of errors and quiet conditions having the least in both suppression conditions (Articulatory $\eta_p^2 = .64$, and Manual $\eta_p^2 = .73$). However the introduction of irrelevant sound in the manual suppression condition had a grater negative impact than in the articulatory conditions. This replicated the findings of Experiment 2, with changing state irrelevant sound demonstrating a higher level of disruption even under conditions of changing state suppression conditions. This was not consistent with the findings of Jones, Macken and Nicholls (2004) who found that under conditions of suppression the irrelevant sound effect was abolished. This may have been a result of the differences between tasks, as the current study used order reconstruction whereas Jones, Macken and Nicholls (2004) used serial recall.

There was an interaction of sound and group ($F(2,92) = 6.13$, $MSE = 114.30$, $p < .05$, $\eta_p^2 = .12$), the dyslexic group performance in the changing state condition was not significantly lower than their performance in the steady sate conditions. However the control group's performance significantly decreased between the steady state and changing state conditions, which resulted in there being no significant difference between the group changing state condition.

There was also an interaction of suppression task and group ($F(1,46) = 4.91$, $MSE = 128.63$ $p < .05$, $\eta_p^2 = .10$). Pairwise comparisons revealed that there was a significant increase in errors made in all the articulatory conditions in comparison to the manual suppression conditions (Control $\eta_p^2 = .72$, Dyslexic $\eta_p^2 = .54$). Each of the groups were also significantly different to one another with the dyslexic group having the highest rate of errors in both suppression conditions (Articulatory $\eta_p^2 = .12$, Manual $\eta_p^2 = .19$). However the Control group demonstrated a greater difference in performance between the suppression conditions than the dyslexic group. This suggests that articulatory suppression had a greater negative effect on the control group performance on the task. This is in line with the findings of Done and Miles (1979; Done & Miles, 1978 cited in Aaron, 1989), who argued that dyslexics did not use articulatory forms of rehearsal as much as Control groups. The greater impact of the articulatory suppression could be attributed to the control group being more heavily reliant on articulatory forms of rehearsal. There was not a three way interaction of sound, suppression task and group $F(2,92) = 1.92$, $MSE = 84.986$, $p > .05$, η_p^2=.02.

As in Experiment 2, the time taken to respond was examined for between group differences in response time under suppression. A 2 x (group) by 2 (suppression task) by 3 (auditory conditions) by 7 (serial position) mixed ANOVA was carried out on time between each response. Mauchly's test indicated that the assumptions of Sphericity had been violated for the main effect of serial position, therefore Greenhouse-Geisser estimates were reported.

The main effects followed the same pattern as errors made. The main effects demonstrated that response times were longer for articulatory suppression ($F(1,46) = 22.85$, MSE=.52, p <.01, η_p^2 =.33). The main effect of sound condition indicated that response time increased from the quiet condition to the changing state condition ($F(2,92) = 4.00$, MSE=.27, p<.05, η_p^2 =.80), which revealed that the increase was only significant between the quiet and changing state. There was a main effect of serial position ($F(1.65, 76.07) = 73.68$, MSE = .87, p <.01, η_p^2 =.62), where only the first serial position was significantly different to all other positions. There was main effect of group ($F(1,46) = 7.28$, MSE=2.31, p<.01, η_p^2 =.14) with the dyslexic group taking longer to respond. There were interactions between serial position and suppression task ($F(1.75,80.31) = 6.64$, $MSE=.77$, $p<.01$, $\eta_p^2=.13$), sound condition ($F(4.70, 216.09) = 6.78$, $MSE = .32$, $p <.01$, $\eta_p^2=.13$; no other interactions were significant. Simple effects comparisons of serial position and suppression task indicated that participants were significantly faster to recall items one to five in the manual suppression condition($\eta_p^2=.20$, .41, .31, .19, .20 respectively). This suggested that items one to five were rehearsed in the manual condition allowing faster recall than in the articulatory condition. Items six and seven would have received the minimum rehearsal, therefore were not significantly affected by the task. Simple effects of the sound conditions by serial positions revealed that at serial position one there was a significant ($\eta_p^2=.31$) increase in time taken to respond between each of the sound conditions (quiet the fastest, and changing the slowest). The only other significant difference found was faster recall in the quiet condition than the irrelevant sound conditions at serial position six ($\eta_p^2=.17$). The significant difference at the sixth position can be accounted for by the recency effect being evident earlier when there is no irrelevant sound.

Overall, the results of Experiment 3 replicated the findings of Experiment 2 with the dyslexic group demonstrating the same pattern of results as the control group in irrelevant sound and suppression conditions. This suggested that dyslexics do not have a general deficit inhibiting irrelevant tasks and demonstrate functional equivalence to the control group. Whilst the dyslexic group performed with a deficit on the task, they demonstrated a smaller effect of articulatory suppression, which may suggest that they are less reliant on articulatory forms of rehearsal. Palmer (2000) argued that dyslexics demonstrated dual-coding systems on memory tasks using both visual and phonological, whereas control groups use phonological alone. As the dyslexic group were less affected by articulatory suppression, this may suggest the use of dual coding, which resulted in the visual representation being less affected by the suppression task. However the suppression tasks had an effect in respect to response time as the dyslexic group took longer to start recalling items in the articulatory condition. Macken and Jones (1995) demonstrated that the changing state articulatory suppression has greater effect on serial recall when identifying a missing item from a closed set of items. This demonstrated that the changing-state effect was confined to tasks that required the retention of order information. Experiment 4 explored whether dyslexics demonstrated the same specificity of disruption by the changing-state effect by examining performance across tasks.

5.5 Experiment 4

Experiments 1, 2, and 3, demonstrated that dyslexic participants have a consistent deficit on the serial recall of verbal material. This experiment examined where the serial element of recall is, whether dyslexics have difficulty or whether it is a more general memory deficit. Miles (1993) observed that dyslexic students do not have difficulty repeating sentences in terms of the meaning, but that they had difficulty getting the words into the exact order. Studies such as Miles, Thierry, Roberts and Schiffeldrin (2006) examined this concept by looking at 'verbatim' and 'gist' recall of sentences, as both of these studies used tasks that evoked both phonological and semantic processing. There was not sufficient evidence to dissociate between whether this lack of deficit on a memory task was due to semantic processing or an artefact of dyslexics' demonstrating a specific deficit with serial recall.

Evidence that memory for serial order is a critical feature of memory tasks that increase vulnerability to disruption comes from the irrelevant sound and changing state effects studies (e.g. Morris, Quayle & Jones, 1988; Salamé & Baddeley, 1990; Macken & Jones, 1995). For example, Salamé and Baddeley (1990) found no effect of irrelevant speech on memory for items when they could be recalled in any order. The differential effects of the retention of serial information was demonstrated by the effect of irrelevant sound on tasks that have identical presentation conditions, but differ on the need to recall serial order information. The missing item task, where participants are presented with a random permutation of a familiar closed list that misses one member, and participants are then required to identify which item is missing. The probe item task followed the same procedure; however, at the end of the lists presentation, participants identified which item followed another. These two tasks were designed to be equivalent in the majority of factors to isolate the effect of having to recall serial information. These tasks demonstrated that irrelevant sound only disrupts performance on the probe item task (Morris, Quayle & Jones, 1988). Furthermore, it was shown that the features of the irrelevant sound can manipulate the magnitude of disruption (e.g. Jones & Macken, 1993; Macken & Jones, 1995) As demonstrated in experiments 2 and 3, whether the sound is steady or changing state is key to the amount of disruption caused. This effect was also demonstrated using articulatory suppression compared to manual suppression condition as in

Experiment 3. Articulatory suppression was shown to have a greater impact on the recall of serial information (Macken & Jones, 1995).

The goal of Experiment 4 was twofold, to examine whether dyslexic's performance was specifically impaired when asked to recall order information and, secondly, to examine the effect of articulatory suppression (prevented verbal rehearsal) across the tasks. To avoid participants adapting their encoding strategy to the task, participants did not know whether they needed to recall serial information until the point of recall. The missing item conditions did not require rehearsal; therefore they should have been less affected by the articulatory suppression. The procedure for the suppression tasks was the same as Experiment 3; however it used visual presentations to examine if the dyslexic group demonstrated the same magnitude of effects when verbal recoding was required to verbally rehearse items. It was thought that performance of the dyslexic group would be equivalent to the control group on the missing item task if the deficit was specific to the recall of order information as suggested by Miles (1993), and Miles, Thierry, Roberts, and Schiffeldrin (2006).

5.5.1 Method

5.5.1.1 Participants

Recruitment followed the same procedure as the previous experiments; all participants were students at Cardiff University. The groups consisted of 23 control participants (20 females and 3 males) and 20 dyslexic participants (17 females and 3 males).

5.5.1.2 Apparatus and Materials

The experiment ran using a bespoke program written in visual basic 6. The digits for recall were numbers 1 to 9, and were presented in the centre of the screen, in point 72 Times New Roman font for 500ms.

5.5.1.3 Design and Procedure

All participants completed the missing item and probe item questions in the articulatory suppression condition. There were also two control conditions: one requiring manual tapping (as in experiment 3) as well as a no secondary task condition. The suppression tasks were split into blocks, and within each block there were an equal number of question types (probe, missing) presented in a random order. The participants completed 28 trials in one block before moving on to the next block. The position of the probe item and the likelihood of the missing number were controlled and equally distributed. Twenty three input files for the program were created with quasi-random orders of blocks and within block questions; one participant in each group completed each order. The trials and digits were ordered so that they did not follow a pattern and so that items were not repeated within trials (quasi-randomly).

The same procedure for instructions and suppression conditions was followed as Experiment 3. For the other conditions instructions were shown on screen prior to the no suppression block, explaining that no secondary task was to be completed in that block. Within the trial, the to-be-remembered digits were presented for 500 ms followed by a 500ms off the screen gap between digits. At the end of the list of seven digits, the recall screen appeared with the eight response buttons numbered 1 to 8. On the missing item trials, participants were asked which of the options below was *not* presented as part of the list. For the probe item trials, the screen was the same, however the question was; " which item immediately followed "X" in the list. Please click on one of the options below". The trials were self-paced so that the participant had to make a response before the program moved on to the next trial.

5.5.2 Results & Discussion

The percentages of correctly recalled items for the two tasks across the three suppression conditions were presented in Figure 5.6.

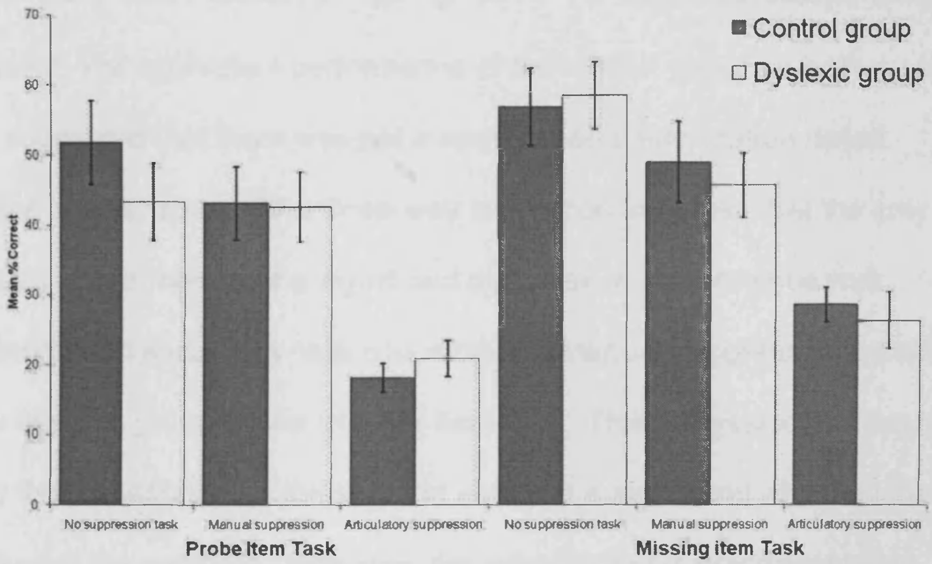

Figure 5.6. Mean percent correct for each condition between groups. Error bars show standard error of the mean.

A 2 (Group) by 2 (Recall Task) by 3 (Suppression condition) mixed ANOVA was conducted on the percentage of errors made. Mauchly's test indicated that the assumptions of Sphericity had been violated for the main effect of suppression condition. Therefore degrees of freedom were corrected using the Greenhouse-Geisser estimates.

There was a significant main effect of task with performance on the missing item better then the probe item task, $F(1,41) = 19.02$, $MSE = 188.54$, $p < .01, \eta_p^2 = .32$. The improved performance suggested that recognition of a missing item was easier than recalling order information. There was also a significant main effect of suppression conditions ($F(1.66,68.23) = 52.14$, $MSE = 451.78$, $p < .01$, $\eta_p^2 = .56$). There was a significant performance decrease between each of the conditions, performance was highest where there was no secondary task and lowest on the articulatory suppression. There was no main effect of group ($\eta_p^2 = .01$), but there was a three way interaction ($F(1.83, 74.93) = 3.21$, $MSE = 120.90$, $p = .05$, $\eta_p^2 = .07$). No other interactions were significant. The equivalent performance of the control group on both recall tasks suggested that there was not a specific serial information deficit. Pairwise comparisons of the three-way interaction indicated that the only condition where there was a significant decrease in performance was between the no secondary task condition and manual suppression condition by the dyslexic group on the missing item task. This suggested that tapping during the presentation of the item did not have a significant effect on the encoding of the numbers. However, the articulatory condition had a significant effect on the performance on both tasks, but a greater effect on the probe item. This suggested that although verbal rehearsal was beneficial to performance on the missing time task, it was not as important as it was for the recall of serial information. The overall pattern of performance was in line with previous studies (e.g. Macken & Jones, 1995); however, in previous studies participants were able to adapt their encoding to the task demands. In the current study, participants did not know which information was required at recall until after encoding. There was a secondary effect of not allowing participants to adapt their encoding strategy to the task, which may have reduced the control group's performance on the task. As the dyslexic group performed at an equivalent level to the control group on both tasks, it suggested that dyslexic's deficit may be a result of weak encoding strategies.

A 2 (Group) by 2 (recall task) by 3 (suppression condition) mixed ANOVA was also conducted on the time taken to respond. Mauchly's test indicated that the assumptions of sphericity had been violated for the main effect of suppression task; therefore the Greenhouse-Geisser estimates were reported.

There was a significant main effect of task, where the time to respond was longer on the missing item task than the probe item task (F (1,41)= 22.76, MSE=2.07, p <.01, η_p^2 =.35). There was also a significant main effect of suppression conditions (F(1.68,69.02) = 4.33, MSE = 3.32, p <.05, η_p^2 =.10). Contrasts revealed that participants were only significantly faster to respond on articulatory suppression conditions than the manual suppression condition. There was a significant interaction effect between suppression condition and recall task, (F(2, 82) = 9.14, MSE = .75, p<.05 , η_p^2 =.18). No other interactions were significant. Simple effects indicated that responses were significantly faster on the missing item task participant's than the other conditions when completing articulatory suppression (η_p^2 =.25). On the probe item task there was no significant difference between the response times of each of the suppression conditions. The response times on the articulatory suppression conditions were not significantly different between tasks (η_p^2 =.021), whereas the responses were significantly faster on the probe item task in the other suppression conditions (Recall only η_p^2 =.34; Manual η_p^2 =.40). Unlike the results of the Experiments 2 and 3, where participants took longer to respond in the most changing conditions, the reverse was the case in the current study. This suggested that when serial information is not required for recall, participants do not use the same recall strategies, unless rehearsal has been prevented. The missing item task had the best performance and the longest response times when the secondary task was present and in the manual tapping conditions, which suggested that participants used a strategy such as checking off all the items as they recalled them before making a response.

As with serial recall in Experiments 3, dyslexic participants demonstrated the same pattern of disruption by articulatory suppression as the control group. However, the dyslexic group's performance and the disruptive effect of the articulatory suppression was equivalent to the control. The equivalent group performance was constant across both tasks, which suggested that dyslexics do not have a specific deficit for serial information. However, as the tasks did not allow participants to adapt their encoding strategy to task, this suggested that the dyslexics' deficit may be a result of encoding strategies. Experiment 5 sought to explore this further by examining phonological confusion at encoding.

5.6 Experiment 5

The fifth experiment investigated the effects of irrelevant sounds that are phonologically similar as the to-be-remembered (TBR) items, as well as exploring the effect of different to-be-remembered items. Thus far, Chapter 5 solely used digits as the TBR items, as Smith-Spark and Fisk (2007) demonstrated that dyslexics had the largest deficit on digit span tasks. Smith-Spark and Fisk (2007) demonstrated that the effect size of dyslexics' difference in performance to the control group on the span tasks varied depending on the TBR items. There was a smaller dyslexic deficit found for letter span than number span task. Experiment 5 used letters as the TBR items on the same tasks used in Experiments 1, 2 and 3 to examine if dyslexics demonstrated the same functional equivalence of changing state irrelevant sound. Experiment 4 suggested that dyslexics may have a deficit in adapting encoding strategies to task demands. To further explore the dyslexic ability to inhibit irrelevant sound, Experiment 5 manipulated between stream similarities. Jones and Macken (1995) demonstrated that between-stream similarity was not a principal causal factor for disrupting performance. Jones and Macken's (1995) experiment 3a showed that although changing state irrelevant sound, consisting of words, had a significant negative impact on serial recall of letters, however "there was no effect of similarity between heard streams and the to-be-remembered list"(p.109). This suggested that in populations with no known disability the content of irrelevant sound can be successfully inhibited, whilst the broader characteristic of the changing state still has an impact.

Dyslexics have been argued to have deficits in phonological processing that are derived from a general difficulty in the perception of auditory stimuli, especially when it is rapidly changing (Tallal, 1980; Reed, 1989; McAnally &Stein, 1996). There was also some evidence that children with dyslexia have a deficit when categorizing or discriminating phonemes presented auditorally (Godfrey, Syrdal-Lasky, Millay & Knox, 1981; Mody, Studdert-Kennedy & Brady, 1997; Werker & Tees, 1987). There was also some evidence that between-category discrimination rates are impaired in dyslexic children on discrimination tests (Breier, Fletcher, Denton & Gray, 2004; Breier, Gray, Fletcher, Foorman & Klass, 2002; Serniclaes, Sprenger-Charolles, Carre & Demonet, 2001; Werker & Tees, 1987). This increased difficulty with the phonological processing at early stages of processing could result in dyslexics having a deficit with the segregation of streams of phonologically similar TBR and irrelevant sound. As discussed in Chapter 4, the phonological similarity effect of TBR items (within stream) have been examined in dyslexic populations with varying results. Some studies have found that dyslexics are less affected by TBR item phonological similarity (e.g. Mann et al., 1980), other studies have found an effect on phonological similarity (e.g. Macaruso et al., 1996). Experiment 5 implemented the auditory presentation of the TBR items to avoid between group recoding differences and increase the confusability of the irrelevant and TBR items. As with Experiments 2 and 3, the dyslexic group was expected to perform at a deficit on the task, however they were expected to demonstrate functional equivalence to the control in the phonologically different condition. However, if dyslexics have early stage phonological processing and streaming deficits, it would be expected that performance should demonstrate an increased impact of the phonologically similar sound.

5.5. 1 Method

5.5. 1.1 Participants

All participants were students at Cardiff University, the control group of 20 were self-reported non-dyslexics. Twenty one participants had a diagnosis of dyslexia by an educational psychologist (71% with IQ scores on WAIS III with a group mean of 115). There were 19 females and 1 male in the control group, the dyslexic group consisted of 8 male and 14 female participants.

5.5. 1.2 Apparatus and materials

The TBR letters used were not rhyme confusable e.g., A, I, L to avoid within list confusability effects (full list shown in Figure 5.6). The bespoke computer program used in Experiment 2 was adapted for Experiment 4. Irrelevant words were recorded in the same monotone male voice as the TBR letters. The letters and word were recorded and presented for 500ms. During the irrelevant sound condition, participants heard irrelevant sounds made up of the words paired the TBR letters. The irrelevant words sounded like a letter in the sequence in the 500ms interval between the offset and onset of the letters.

	Phonologically similar	*Phonologically different*
A	Clay	Inn
I	Pie	Stone
L	Bell	Shed
M	Stem	Pump
O	Toe	Wine
P	Bee	Pine
R	Star	Knee
U	Crew	Troop
Y	Tie	Wire

Figure 5.6. Words used in irrelevant sound.

5.5. 1.3 Design and Procedure

The irrelevant sound conditions (quiet, phonologically similar and phonologically different) were blocked. During the study, all participants completed all three blocks containing 18 trials of to-be-remembered lists. The blocks and trials of to-be-remembered lists within blocks were quasi randomly shuffled to create 21 sequences of the blocks, one for each participant in each group (dyslexic and control). The experimental procedure was the same as Experiment 2.

5.5.2. Results and Discussion

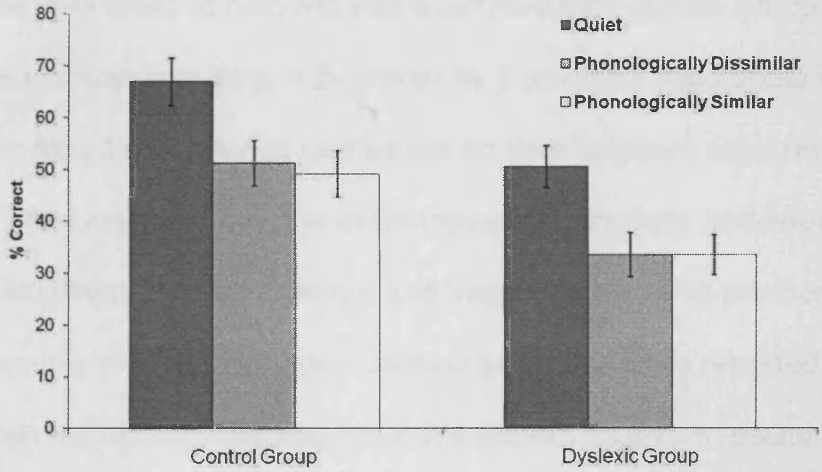

Figure 5.6. Mean percent correct for each condition between groups. Error bars show standard error for mean.

A mixed ANOVA 2 (Group) by 3 (irrelevant sound condition) was conducted on the percent of errors made. Overall the dyslexic group performed significantly worse than the control group, $F(1,39)=14.70$, *MSE*=572.60, p <.05, η_p^2 =.27. There was a main effect of irrelevant sound (F(2,78)= 69.84, *MSE*=55.99, p<.05, η_p^2 =.64), which revealed that the only a significant decrease in performance was between the quiet and irrelevant sound conditions.

There was no significant interaction between irrelevant sound and group (F(2,78)=.196, *MSE* = 55.99, *ns*, η_p^2 =.01). To examine the magnitude of the irrelevant sound effect between the groups, the quiet condition was used as a baseline to calculate the increase in errors. A mixed ANOVA 2 (Group) by 2 (irrelevant sound) revealed no significant main effect for group (F(1, 39)=.01, *MSE*=196.37, *ns*, η_p^2 <.01), which demonstrated that although the dyslexic group performed at a lower level, the irrelevant sound affected performance to the same magnitude.

The time taken to respond was examined for between group differences in response time. A 2 (group) by 3 (auditory conditions) by 7 (serial position) a mixed ANOVA was carried out on time between each response. Mauchly's test indicated that the assumptions of sphericity had been violated for the main effect of serial position, and the sound by serial position interaction, therefore Greenhouse-Geisser estimates were reported.

The main effects followed the same pattern as errors results. The main effect of sound condition indicated that response time increased from the quiet condition to the irrelevant sound conditions (F(2,78) = 5.70, *MSE*=.27, p<.05, η_p^2 =.128), which revealed that the response time increased from quiet but there was no significant difference between the irrelevant sound conditions. There was a main effect of serial position (F(2.85,111.21) = 66.51, *MSE* =1.00, p<.01, η_p^2 =.63), which revealed that only the first serial position was significantly different to all other positions. There was a main effect of group ($F(1,39) = 8.26$, $MSE=2.93$, $p<.01$, $\eta_p^2 =.18$) with the dyslexic group taking longer to respond. There were interactions between serial position and sound condition ($F(5.79, 225.95) = 8.18$, $MSE =.27$, $p <.01$, $\eta_p^2 =.17$) and between serial position and group ($F(6, 234) = 5.03$, $MSE=.48$, $p<.01$, $\eta_p^2 =.11$). No other interactions were significant. Simple effects comparisons of serial position and sound condition revealed that participants were significantly slower to recall item one in the irrelevant sound conditions in comparison to quiet ($\eta_p^2 =.47$). This indicated that it took longer to start recalling items in the irrelevant sound conditions but there was no difference between sound conditions and once participants had started recalling items the intervals were the same for all conditions. Simple effects comparisons of group across serial positions revealed that the dyslexic group only took significantly longer to start recalling items ($\eta_p^2 =.28$), which was consistent with performance in Experiments 2 and 3. The dyslexic group also had longer intervals between items three and four ($\eta_p^2 =.13$), which suggested that primacy effect may dissipate earlier in the dyslexic group.

Overall Experiment 5 demonstrated that the dyslexic group did not have greater between stream confusion when the items were phonologically similar, which suggested that any phonological processing deficits in dyslexics did not result in a between-stream phonological similarity effect. The performance was consistent with the pattern found in the previous experiments of performance being quantitatively different but qualitative performance was the same as the control group.

5.7 Experiment 6

The aim of Experiment 6 was to follow up on the findings of Experiment 5 by investigating the within stream phonological similarity effect. It was suggested that dyslexic readers are noticeably less sensitive to the within stream phonological similarity effect when performing short term memory tasks (Byrne & Shea, 1979). However, other studies found within-stream similarity rhyming effects in experiments demanding the recall of series of letter strings (e.g., Hall, Wilson, Humphreys, Tinzmann, & Bowyer, 1983; Johnston, 1982; Johnston, Rugg, & Scott, 1987, 1988), words, sentences (Jorm, Share, Maclean, & Matthews, 1984 cited in Rack,1994), and drawings (Macaruso et al., 1996; Morais, Cluytens, Alegria, & Content, 1986). Possible reasons for these conflicting results were that there were floor effects, as the within stream phonological similarity effect disappeared when performance dropped too low (Holligan & Johnston, 1988). Also it may be that the lack of sensitivity was the result of a development lag as it was only found in young children who have weaker phonological representations (McLoughlin, Fitzgibbon & Young, 1994).

To examine the phonological similarity effect, the missing item and probe item tasks were used to avoid possible floor effects. In Experiment 4, dyslexics performed at an equivalent level to the control group on the task; therefore, the phonological similarity effect should affect both groups if the lack of sensitivity is only found in children. It was argued that the reduced phonological similarity was the result of dyslexics' weak phonological recoding so both visual and auditory presentation modalities were examined. The missing item and probe item tasks were mixed on Experiment 4 so that participants were unable to adapt their encoding strategies to the different tasks. Experiment 6 also explored whether this was a factor in the equivalent performance between groups. Experiment 6 was sub divided into Experiments 6a and 6b. In Experiment 6a the same procedure as was used as Experiment 4, however in Experiment 6b, participants knew which recall task they were completing before the list was presented. This allowed participants in Experiment 6b to adapt their encoding strategy to the task demands.

5.7. 1 Method

5.7. 1.1 Participants

All participants were students at Cardiff University. In experiment 6a there were 20 participants in the control group and 21 dyslexic participants. In experiment 6b there were 26 participants in the control group and 20 dyslexic participants.

5.7. 1.2 Apparatus and materials

The experiment was run using a bespoke computer program adapted from Experiment 4 written in Visual Basic 6. The to-be-remember items consisted of two closed sets of letters which were created based on the lists used in Jones, Macken, and Nicholls (2004). As in their Experiment 2, the items were phonologically similar sounding letters (B, C, D, E, G, P, T, V) and phonologically dissimilar letters (F, H, J, M, Q, R, W, Y). The letters were recorded in a male voice at an approximately even pitch and were then digitally edited so that each lasted 500ms. All participants listened to the stimulus stereophonically through sound attenuated headphones. All sounds were with the range of 65-75dB (A). The letters were presented in the centre of a computer VDU, in point 72 Times New Roman font for 500ms in the visual conditions.

5.7. 1.3 Design and Procedure

In both experiments all participants completed each presentation modality (visual, auditory) in blocks, each letter set (phonologically similar, dissimilar letters) in blocks, and task (probe, missing item) quasi-randomly ordered within blocks. The participants completed 24 trials in each block. The position of the probe item and the likelihood of a missing letter were controlled and equally distributed. Twenty six input files for the program were created with quasi-random orders of blocks and within block questions; one participant in each group completed each order. The trials and digits were ordered so that they did not follow a pattern and that items were not repeated within trials (quasi-randomly).

Within the trials the to-be-remembered digits were presented for 500 ms, followed by a 500ms off the screen gap between letters. At the end of the list of seven letters, the recall screen appeared with the eight response buttons. On the missing item trials, participants were asked which of the options were not presented as part of the list. On the probe item trials the screen was the same, however, the question was "Which item immediately followed "X" in the list. Please click on one of the options below". The trials were self-paced, so that the participant made their response before the program moved on to the next trial. All participants clicked on a start button to begin the presentation of the to-be-remembered letters; however, in

Experiment 6b, above the button, a message told them if it was a missing item or a probe item trial.

As in previous studies instructions were given both verbally and presented on screen prior to the start of the experiment. The two closed sets of the letters were included in the instructions. The instructions explained the blocks and the tasks; In 6a participants were told that they would not know which question would be asked prior to the presentation of the list. In 6b participants were told that prior to the list they would be told whether they would be asked a missing or probe item question at the end.

5.7.2 Results & Discussion

5.7.2.1 Experiment 6a Results

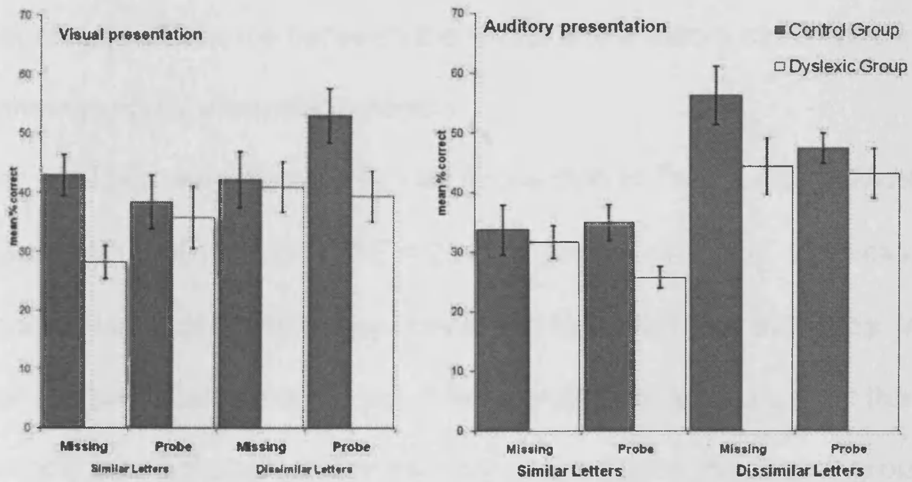

Figure 5.7. Mean percent correct for each condition between groups. Error bars show standard error of the mean.

A mixed 2 (Group) by 2 (recall task) by 2 (Letter) by 2 (Modality) ANOVA was conducted on the percentage of errors made (percentage correct was illustrated in Figure 5.7). There was a significant main effect of to-be-remembered letters with better performance on the phonologically different letters (F (1,39) = 45.97, MSE = 252.34, p <.01, η_p^2 =.54. There was also a significant main effect of the dyslexic group performing worse than the control group (F(1,39) = 4.51, MSE = 1004.91, p <.01, η_p^2 =.10). There was an interaction between recall task and presentation modality (F(1, 39) = 4.65, MSE = 198.47, p<.05 , η_p^2 =.11). On the missing item task, participants performed better in the auditory presented letters conditions, however on the probe item task, participants performed better when the letters were visually presented. There was also an interaction of to-be-remembered letters and modality (F(1, 39) = 8.17, MSE = 193.56, p<.05 , η_p^2 =.18). Performance on the phonologically similar letters was worse in both modalities. Recall of the phonologically similar letters presented in the auditory conditions was significantly worse than in the visual condition (η_p^2 =.12). There was no significant difference between the visual and auditory conditions with the phonologically dissimilar letters.

There was also a four way interaction of Task, Letters, Modality and Group (F(1, 39) = 6.79, MSE = 291.49, p<.05 , η_p^2 =.15). Pairwise comparisons of the four-way interaction indicated that dyslexics' performance on the two recall tasks did not differ significantly across any of the other conditions. Although, in the majority of conditions the control group also did not demonstrate a difference between recall tasks; performance was significantly better on the probe task (compared to the missing item task) when the phonologically different letters were presented visually (η_p^2 =.13). The pattern of poorer recall of the phonologically similar letters was consistent across conditions and there was no significant difference on the visually presented missing item task by the control group and the visual probe item task by the dyslexic group. Comparisons of group revealed that on auditory presented items the dyslexic group performed comparably to the control group in all but the phonologically similar letters on the probe item task where performance was lower than all other conditions.

Overall both groups demonstrated the phonological similarity effect on the auditory presented items on both tasks. On the probe task dyslexic's maintained an average of 40% correct in all but the auditory presentation of phonologically similar letters, where performance dropped to 26% correct. The control group maintained a consistent pattern of better performance on the dissimilar letters in comparison to the phonologically similar letters. This pattern was maintained by both groups in the missing item task, with the exception of the control group with visually presented letters, where there was no detrimental effect of similarity.

5.7.2.1 Experiment 6b Results

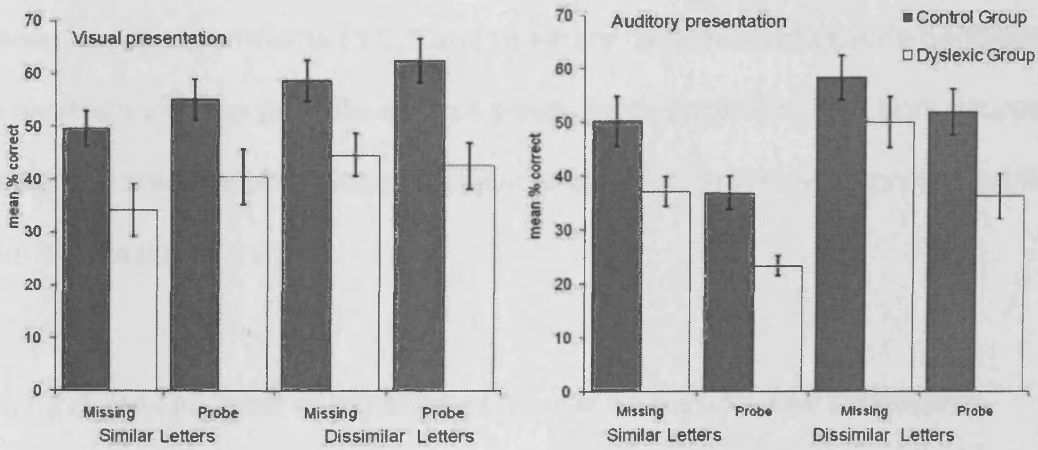

Figure 5.8. Mean percent correct for each condition between groups. Error bars show standard error of the mean.

A 2 (Group) by 2 (recall task) by 2 (Letter) by 2 (Modality) mixed ANOVA was conducted on the percentage of errors made (the percentage correct are illustrated in Figure 5.8). There was a significant main effect of to-be-remembered letters with higher performance on the phonologically different letters (F (1,44) = 31.34, MSE = 272.63, p <.01, η_p^2 = .42). There was a significant main effect of modality with higher performance in the visual condition (F (1,44) = 6.86, MSE = 390.14, p <.05, η_p^2 =.14). There was a significant main effect of task with higher performance in the missing item task (F (1,44) = 4.50, MSE = 361.49, p < .05, η_p^2 =.09). There was also a significant main effect of group, the dyslexic group performed worse than the control group (F(1,44) = 17.04, MSE = 1098.10, p <.01, η_p^2 =.28). There was an interaction between recall task and presentation modality (F(1, 44) = 23.10, MSE = 226.42, p < .05 , η_p^2 =.34). There was no significant effect of presentation modality on the missing item task, however on the probe item task participants performed better when the letters were visually presented. No other interactions were significant.

Overall, in Experiment 6b the constant pattern was found as in the serial recall experiments (1,2,3 and 5) where dyslexic participants performed consistently worse than the control group. As in Experiment 6a both groups demonstrated the phonological similarity effect on the auditory presented item on both tasks.

5.7.2.3 Joint analysis of Experiment 6a and 6b Results and Discussion

The results of Experiment 6b demonstrated that, unlike experiment 6a, dyslexics performed consistently worse than the control group. The control groups' increase in performance suggested that the control group were able to adapt their encoding strategy to the task demands. To compare the difference in performance between experiments 6a and 6b, two mixed ANOVAs (2 (Experiment) by 2 (Group) by 2 (Recall task) by 2 (Letter)) were conducted; one for the auditory conditions and one for the visual conditions. The main purpose of this analysis was to examine the between-group performance on the experiments.

The results of the auditory conditions analysis indicated that there was a main effect of group ($F(1, 83) = 13.82$, $MSE = 591.88$, $p <.05$, $\eta_p^2 =.14$), where the control groups was significantly better than the dyslexic group. There was not a significant main effect of Experiment ($F(1, 83)=1.58$, $MSE = 591.88$, $p >.05$, $\eta_p^2 =.02$), there was also no interaction of group and experiment ($F(1,83)=1.25$, $MSE=591.88$, $p>.05$, $\eta_p^2 =.02$). However, simple effects comparisons demonstrated that the control group significantly improved between experiment 6a and 6b ($F(1, 83) = 2.97$, $MSE = 147.97$, $p<.05$ (one way) , $\eta_p^2 =.035$). The dyslexic group did not demonstrate a significant improvement between experiment 6a and 6b ($\eta_p^2 >.01$). The results of the visual condition indicated that there was also a main effect whereby the control group performed significantly better than the dyslexic group ($F(1, 83) = 16.43$, $MSE = 761.44$, $p<.05$, $\eta_p^2 =.17$). There was also a main effect of experiment, showing there was higher performance on experiment 6b ($F(1, 83) = 8.00$, $MSE = 761.44$, $p<.05$, $\eta_p^2 =.90$). However there was no significant interaction between group and experiment ($F(1, 83) = 2.01$, $MSE = 539.51$, $p>.05$, $\eta_p^2 =.02$). Simple effects comparisons of experiment by group revealed that the control group performed significantly better on experiment 6b than 6a ($\eta_p^2 =.1$). The dyslexic group did not demonstrate a significant improvement between experiment 6a than 6b (η_p^2 =.01). This suggested that the control group were better able to adapt their encoding strategy to the task demands in Experiment 6b, resulting in improved performance.

The visual condition analysis also revealed an interaction between experiment and task ($F(1,83)= 5.20$, $MSE = 276.67$, $p<.05$, $\eta_p^2 =.06$). Simple effects comparisons showed that there was a significant improvement between Experiment 6a and 6b on the missing item task ($\eta_p^2 =.04$) but not on the probe item task ($\eta_p^2 <.01$). This suggested that in Experiment 6a participants were using a serial rehearsal strategy; however, in Experiment 6b participants adapted their strategy to a more successful one for the missing item task. This was only found in the visual analysis, which may be a result of the phonological similarity effect having a greater detriment effect on the auditory conditions.

Overall experiment 6 demonstrated that the dyslexic group were affected by the phonological similarity effect on the missing item and probe item tasks. This was more evident when items were presented auditorily. The equivalent level of performance between groups in Experiment 4 was a result of the control group performing at a lower level on the task as they were unable to adapt their encoding to the task demands.

5.8 General discussion

The main finding of Chapter 5 was that although dyslexics show an overall impairment in performance of serial recall tasks, the pattern of disruption was consistent with that found in the control group. It was claimed that a phonological loop deficit could explain many language disorders (e.g. Gathercole & Baddeley, 1989). In this chapter, the experiments discussed examined the verbal serial order deficit by using the key STM phenomena serial position (Experiments 1), presentation modality (Experiments 1, 2, & 6), Irrelevant Sound (Experiments 2, 3, & 5), concurrent articulation (Experiments 3 & 4), and phonological similarity (Experiments 5 & 6).

The serial position effects found in Experiment 1 indicated that dyslexics demonstrated roughly equivalent modality and serial position effects. Primacy effects were argued to be the result of more frequent rehearsal of items at the beginning of the list than items presented later (Burgess &Hitch, 1992). It was also argued that dyslexics' STM deficits were a result of slower processing and less efficient rehearsal rates (e.g. Bauer, 1977, Dempster, 1981; Breznitz, 1989, 2001). This was not consistent with Experiment 1's finding of intact primacy effects, which suggested that rehearsal was intact. Recency effects were accounted for by item decay in the phonological loop, so that final list items have decreased decay (Burgess & Hitch, 1992). It was argued that dyslexic's STM deficits were a result of substantially faster decay rates (e.g. Johnston & Anderson, 1998; Johnston, Rugg, & Scott, 1987; Holligan & Johnston, 1988). This was also not consistent with the finding that the dyslexics' had equivalent recency effects, which suggested that items are not decaying faster (Experiment 1).

Presentation modality effects were suggested to occur, as verbal materials presented auditorally, would have direct access to the phonological loop, whereas visually presented material must be converted from visual code to phonological, to access the phonological loop (Baddeley, 1986). It was suggested that dyslexics are unable to recode visual material effectively, resulting in poorer recall (e.g. Rack, Hulme & Snowling, 1993; Share, 1995). However, Experiments 1, 2, and 6 found that dyslexics have equivalent modality effects for recalling simple items, which suggested that there was not a basic recoding deficit.

Irrelevant sound was argued to interfere with information in the phonological loop (Salamé & Baddeley, 1986). Experiments 2, 3, and 5 examined the ability of dyslexics to inhibit irrelevant sound as well as examining whether disruption was the followed the same pattern as the control groups, i.e. whether changing state irrelevant speech was more disruptive than steady state, and if phonological similar irrelevant sound causes greater disruption. The magnitude of the irrelevant sound effect for the groups was assessed again and the same presentations and contents were assessed. It was suggested that dyslexics were able to successfully stream to-be-remembered items from the irrelevant sound.

Concurrent articulation, or articulatory suppression, was examined in Experiments 3 and 4. In Experiment 3, dyslexics demonstrated a smaller effect of articulatory suppression, which suggested that they are less reliant on articulatory forms of rehearsal. However in Experiment 4, dyslexics performed at the same level as the control group, which suggested that dyslexics do not have a general deficit inhibiting irrelevant tasks.

Experiments 5 and 6 examined phonological similarity effects emerging from competition among items in the phonologically loop (Baddeley, 1986). It was suggested that dyslexic readers are noticeably less sensitive to the within stream phonological similarity effect when performing short term memory tasks. It was demonstrated that the recall for phonologically similar items was poorer than for lists of dissimilar similar items in both groups.

In conclusion, the experiments in this chapter demonstrated that dyslexics have an overall impairment in performance on serial recall tasks. However, the pattern of performance and magnitude of interference caused by external factors was the same for both dyslexics and controls. This suggested that in relation to the ability to separate irrelevant material from to-be-remembered items, dyslexics do not have an underlying deficit in the processing and maintenance of verbal material. However, in Experiment 6, dyslexics did not demonstrate the same benefit of knowing the task demands, which suggested that they are less able to adapt their encoding strategy.

Chapter 6: Semantic Short Term Memory

6.1 General Introduction

This chapter explores the semantic coding ability of dyslexic participants (including the disruption of these processes by the semantic content of irrelevant sound). The experiments discussed in Chapter 5 indicated that dyslexics consistently demonstrated a deficit on verbal short term memory tasks. However, irrelevant sound did not have a greater impact on the dyslexic group's performance, which suggested that auditory selective attention is intact. The irrelevant sound caused greater disruption when it was a changing-state property, however phonological similarity did not cause any greater distraction. This chapter continued the investigation of selective attention by examining the auditory-semantic distraction: Experiments 8 and 9 (Section 6.3, & 6.4).

Semantic coding impairments are not considered to be a factor in reading difficulty, however it was suggested that dyslexics use semantic strategies to support weaker phonological systems (Vellutino, Scanlon, & Spearing, 1995). Vellutino, Scanlon, and Spearing (1995) reported that poor readers performed at an equivalent level to good readers on memory for word lists which were classified as being high in meaning, however when the lists were low in meaning, they performed significantly worse.

Although poor readers successfully use semantic strategies to support reading and memory, the heavy reliance could make them more susceptible to semantic interference. Byrne and Shea (1979) examined the memory capacity of good and poor readers matched for IQ. Poor readers reported more false positive responses when semantically similar items were presented on a continuous monitoring task, while good readers made significantly more false positive responses to items that were phonologically similar. The results suggested that poor readers exhibited a strong reliance on the semantic strategies in the absence of verbal coding strategies. Rack (1994) argues that this suggests that dyslexics attend to different features of stimuli to controls and/or encode them in a different way in long-term memory. It would appear that rather than performing a phonological feature analysis, dyslexics encode the semantic features of an item.

Semantic strategies have been reported to be used by dyslexics to support performance on tasks such as alliteration (Reid, Szczerbinski, Iskierka-Kasperek, & Hansen, 2006). The study looked at cognitive profiles of dyslexic adults on alliteration and semantic fluency tests. No significant differences between the performance of dyslexics and controls were found. However it was reported that the tasks can be significantly affected by strategic effects, some dyslexics used semantic categories (e.g. food or clothes) to retrieve words starting with a given sound in the alliteration task.

This suggests that dyslexics are using semantic processing to complete a primary task. However prior to examining auditory-semantic distraction on STM, Experiment 7 was conducted to support the validity of intact semantic processing in dyslexics. This was conducted by using a category-clustering paradigm that is generally accepted to induce semantic processing strategies (e.g., Bousfield, 1953).

6.2 Experiment 7

The category-clustering paradigm evaluated memory and encoding strategies that may have been used by the participants. The memory for relatively long lists was proposed to have two distinct levels of organisation, primary and secondary (Tulving, 1968). Primary organisation was based on the presentation of the serial order of the list; e.g., the primacy and recency effects. Secondary organisation occurs when a participant applies pre-existing conceptual relationships and/or semantic associations to guide encoding and retrieval of episodic information. This secondary level organisation was closely linked with learning and is often an automatic process. Participants appeared to be unaware that they use this strategy (Tulving, 1964, 1968; see also Howard & Kahana, 2002).

A task that has been well established for examining this secondary process involved free recall of relatively long, semantically-categorisable lists. This was accomplished by compiling a target list which consists of words presented for recall (e.g., “strawberry”, “pigeon”). The words were made up from several semantic categories (e.g., “Fruit”, “Birds”). The list was classed as categorisable as it contains a number of exemplars from a number of semantic categories. However, the items from the semantic categories were not presented as part of that category. It was well established that when a relatively long list of semantically-categorisable words are presented, participants tend to recall clusters of items of semantic category exemplars. The participants were not told about the categories in advance or instructed to recall by semantic category, therefore the process has been described as spontaneous categorisation (e.g., Bousfield, 1953; Jenkins & Russell, 1952; Smith, Jones, & Broadbent, 1981). This semantic category-clustering implied that participants used existing semantic/conceptual relationships to assist encoding and retrieval of episodic information. Rather than just relying on the serial-order strategies of the list (Tulving, 1964, 1968; see also Howard & Kahana, 2002), participants appear to use semantic category-clustering in preference to mnemonic strategies based on serial-order. The use of semantic category-clustering tends to be the more effective strategy (Pellegrino & Ingram, 1979). The above implied that the presentation of semantically-categorisable lists may offer a setting in which semantic mnemonic strategies can be studied in relative isolation from mnemonic strategies that involve serial-order: That is, if one considers that the degree of semantic category-clustering reflects the degree to which semantic factors are used to encode, store, and retrieve the relevant material (e.g., Murphy, 1979).

The California Verbal Learning Test- Children's Version (CVLT-C) (commercial variant of the above task) was used to assess semantic coding in children with dyslexia, and found that semantic coding was equivalent to those of the controls; however demonstrating lower levels of recall and a slower rate of learning (Kramer, Knee, & Delis, 2000). However, Kibby (2009) found that children with dyslexia performed at an equivalent level to the control on the test. Overall, both studies suggested that dyslexic children are using semantic strategies on the task.

6.2.1 Method

6.2.1.1 Participants

The control group consisted of 20 participants and 22 Dyslexic participants. All participants were students at Cardiff University at the time of the study.

6.2.1.2 Apparatus and Materials

Eight to-be-remembered lists were used for recall. These were taken from the list originally created for Marsh, Hughes and Jones (2009; Experiment 1). Marsh et al., (2009) used eight categories, which were chosen from each of 72 categories in the Yoon et al. (2004) norms, in order to construct 8 lists of 32 words, each list having four categories. The categories had minimal category-exemplar overlap. Exemplars and categories were not repeated between or within lists, and exemplars chosen were sampled outside of the 10 most frequently produced instances (to reduce the likelihood that items could be recalled by simple free association or guessing). Categories were quasi-randomly assigned to each list, but with the constraint that associated categories (e.g., "Flowers" and "Trees") did not appear together. Category-exemplars within each list were also arranged quasi-randomly, so that no two members of the same category were presented adjacently and that each category was represented equally in each quarter of the list.

6.2.1.3 Design and Procedure

All participants were presented with eight lists. The experiments were run in sessions of up to five participants in a laboratory. The participants sat at an individual computer wearing sound attenuated headphones to dampen any background noise from others in the room. Between each of the work stations there were dividers to stop participants being distracted by others in the laboratory. Lists of category-exemplars appeared in lower case black 72-point Times New Roman font, one word at a time against a white background. Each word appeared for two seconds with an interval of one second between. Retrieval was immediate with the end of the list being notified by the visual appearance of a red 'RECALL' cue to commence recall.

The participants were given verbal and written explanations of the instructions by the experimenter. Participants were informed that they would be presented with eight 32-word lists. Each list would be presented one after another, one word at a time, on the computer monitor in front of them. They were asked to memorise as many words as possible and write the words they remembered down in any order on recall sheets when a 'RECALL' cue appeared on the screen. Participants were not explicitly told that the lists were categorisable. Participants were informed that they would have two minutes to retrieve words and that after this time a tone would sound to prepare them for the onset of the next list. Participants were instructed that there would be a practice trial prior to the experimental trials where a 16-word list would be presented with an allotted retrieval time of one minute.

6.2.2 Results and Discussion

6.2.3.1 Recall Measures.

Recall measures were distinguished in terms of the total number of category-exemplars correctly recalled, the total number of exemplars per category recalled, and the number of categories recalled. Table 6.1 displayed the results of the various recall measures between groups. On each of the recall measures the control group recalled more, but there was no significant difference between the groups on the total recalled $t\ (40) = 1.10$, $p > .05$ recall per category $t(40) = 1.06$, $p > .05$. Number of categories recalled was not normally distributed however was also not significant between groups $U=115.50$, $z=-1.71$ $p>.05$.

6.2.3.2 Clustering Measures.

Whilst there are several potential ways of measuring semantic-categorisation (see Murphy, 1979, for a review); this experiment restricted the analysis to the *Z* score measure of category clustering in free recall proposed by Frankel and Cole, 1971). The Z-score was calculated using Mood's (1940 cited in Frankel & Cole 1971) mean (M_r) and variance (V_r) for the number of runs adapted by Wallis and Roberts (1957 cited in Frankel & Cole 1971). The number of observed number of runs (O_r), the Z score was then calculated[7]:

$$Z = \frac{O_r - M_r}{\sqrt{V_r}}$$

---

[7] These were calculated with all repeat and intrusion errors removed.

Table 6.1 displayed the results of the Z Scores. The Z score mean was higher for the dyslexic group however it was not found to be a significant increase $t(40)=1.26$, $p<.05$.

	Dyslexic Group	Control Group
	Mean (SD)	Mean (SD)
Total Recalled	15.91(5.10)	17.40 (3.48)
Recalled Per Category	3.98(1.27)	4.34(.87)
Number of Categories	3.73(.30)*	3.89(.15)*
Z Scores	3.47(1.66)	2.77(1.9)

*Table 6.1 Mean recall and clustering measure split by experimental groups. * Median Dyslexic group=3.81 Control Group=3.94*

Overall the dyslexic group behaved as expected, performing at an equivalent level to the control group on both recall measurers and clustering. This suggests that dyslexics are using semantic strategies to support the recall of verbal material. These results are consistent with Kibby (2009) and Kramer et al. (2000) who found that dyslexic children also use semantic strategies on an equivalent task. Category clustering has been considered an automatic processing component of the free recall task, thereby suggesting that dyslexics' automatic semantic processing is intact. Category clustering is argued to be a characteristic of the secondary level of organisation, suggesting this is unaffected by the dyslexics' deficit. The aim of this experiment was to establish whether dyslexics' are using semantic strategies to support verbal recall (Vellutino, Scanlon, & Spearing, 1995).

Poor readers have been shown to make more errors based on semantic similarity on a verbal monitoring task (Byrne & Shea, 1979). Experiment 8 examines whether dyslexics' experience disruption from the semanticity of irrelevant sound when this has been shown not to affect non-dyslexic performance.

6.3 Experiment 8

The role of semantic information on has been shown to have little influence on serial recall (Marsh, Hughes, & Jones, 2008). As with phonological similarity in Experiment 5 (Section 5.6) between-stream semantic similarity, (i.e. the similarity in the semantic content between to-be-remembered (TBR) items and irrelevant sound items is also an unimportant factor). For example lists of TBR items (e.g., “robin,” “pigeon”) drawn from a semantic category (e.g., “Birds”) are no more disrupted by semantically-similar items (e.g., “sparrow”, “seagull”) than semantically-dissimilar items (e.g., “hammer,” “spanner”) in the irrelevant sound. Semantic similarity between streams has been examined using words (Neely & LeCompte, 1999; Marsh et al., 2008) and digits (Buchner, Irmen & Erdfelder, 1996). Buchner et al. (1996) also demonstrated that the “semantic distance” between the TBR and irrelevant items also played no role in the degree of interference, i.e. irrelevant digits which were within the same decade two or five above or below the TBR items, produced as much disruption as those drawn from two to five decades above or below the TBR numbers. Neely and LeCompte (1999) found a slight increase of disruption when semantically associated items (“head”-“foot”), were paired between streams as opposed to non-associates (“hill”-“foot“). LeCompte and Shaibe (1997) demonstrated a small effect meaningfulness between streams, however methodological issues with the study were highlighted by Jones (1999). Overall, these studies indicated that semantic similarity between to-be-remembered and to-be-ignored items in serial recall tasks do not have a negative effect on recall.

Dyslexic performance was expected to be equivalent to that of the control group on the serial recall task, because serial recall has not appeared to be the source of the deficit (as demonstrated in Experiments 4 & 6). Also Experiment 7 demonstrated that dyslexics used semantic strategies to support recall. However the results of Byrne and Shea's (1979) study suggested that dyslexics' may be susceptible to semantic similarity of the irrelevant sound, unlike the control group. However experiments in Chapter 5 suggest that dyslexics do not have a deficit in overall inhibitory systems, therefore suggesting that their performance will be not be affected. Semantic similarity of the to-be-remembered items was also examined.

6.3.1 Method

6.3.1.1 Participants

The control group consisted of 20 participants and 22 Dyslexic participants. All participants were students at Cardiff University at the time of the study.

6.3.1.2 Apparatus and Materials

To-be-remembered material and irrelevant material consisted of lists of category-exemplars selected from thirty-eight categories in the Yoon et al., (2003) norms. Category-exemplars chosen for TBR lists comprised seven items from the 9th to the 18th most frequently produced single word responses to chosen category names. Category-items chosen for irrelevant material comprised of the eight most frequently produced responses to the category names. The order of presentation of the exemplars within each TBR, and irrelevant, list was random, but this order was the same for each participant. For the auditory presented words, each item was digitally recorded in an even-pitched male voice and sampled with a 16-bit resolution, at a sampling rate of 44.1KHz using *Sound Forge 5* software (Sonic Inc., Madison, WI; 2000). As with previous experiments a bespoke program was written in Visual Basic 6 to run the experiment.

6.3.1.3 Design

A mixed design was used with one between-participants factor (group), where all participants completed the six within participant conditions. Four conditions with no irrelevant sound were manipulated by two factors: Modality (visually or auditorally presented) and TBR lists (TBR items were from the same semantic category or were from different semantic categories). The same words were used for both list conditions.

In addition to the four no irrelevant sound conditions included there were also two irrelevant sound conditions: semantically similar irrelevant sound and semantically unrelated irrelevant sound. The TBR items in the two irrelevant sound conditions were visually presented lists of semantically similar words. All six conditions were quasi-randomly ordered to create 20 sequences, one for each participant from each group.

6.3.1.4 Procedure

Participants were told that they would be presented with list of seven words that would either be auditorally presented through headphones or presented onscreen. There was a between block prompt that informed participants whether the TBR item would be presented visually or auditorally and whether there would be irrelevant sound to be ignored in the upcoming block. Participants were instructed that the aim of the task was to remember and recall the words according to their original order of presentation when the recall screen appeared.

TBR list items were presented for 1000 ms with an inter-stimulus interval (ISI – offset to onset) of 1000 ms between successive list items. After the final item was presented and following 1000ms interval the recall screen was presented and response timings began.

Participants recalled words by using the mouse to click on buttons on screen containing the list words. The order of words on the recall buttons was quasi-randomly ordered, to ensure participants did not follow a pattern or predicable order. This also acted as a respite point for participants, in total the experiment lasted approximately 30 minutes.

6.3.2 Results & Discussion

The recall data was scored according to strict serial recall criteria, as used in previous chapters. Figure 6.2 illustrated the overall percentage of correct recall, which was collapsed across serial position as a function of each presentation and list condition in the quiet conditions and across groups. The most noteworthy aspect of the results was that on this verbal short term memory task, the dyslexic group did not demonstrate a deficit when compared to the control group.

To examine the effect of irrelevant sound a 3 (Sound condition) by 2 (group) mixed ANOVA was conducted on the percentage of errors made. There was No significant main effect of Group ($\eta_p^2 < .01$). There was a significant effect of irrelevant sound, $F(1,38) = 6.44$, MSE=87.51 $p<.05$, $\eta_p^2 = .15$, with the lowest performance in the irrelevant sound conditions. However there was no significant difference between the irrelevant sound conditions. This was in line with Experiment 5 where the content of the irrelevant sound did not have a significant effect on serial recall.

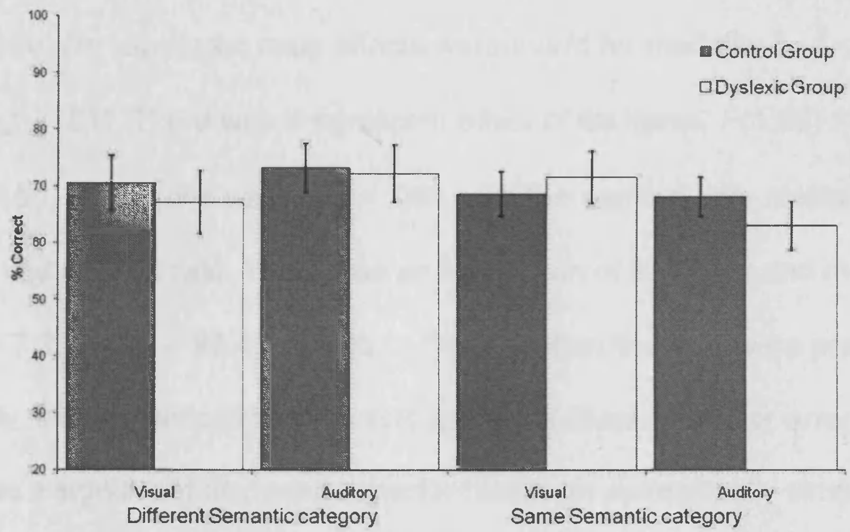

Figure 6.2: serial recall percentage correct for visual and auditory presented lists of same/different category lists words with no irrelevant sound.

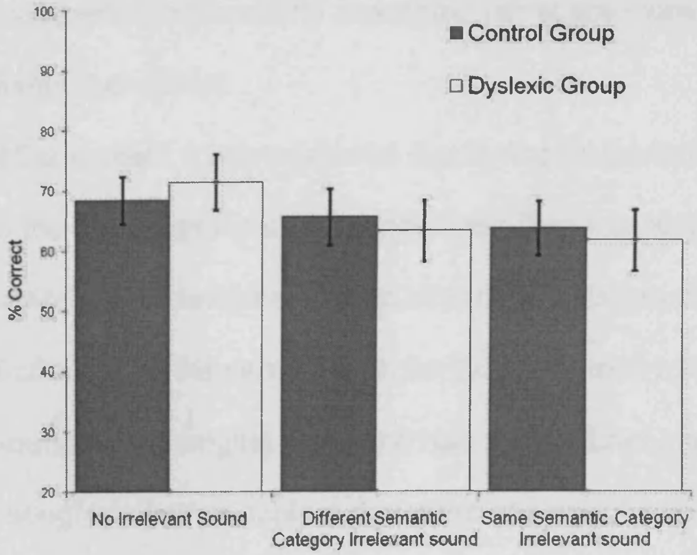

Figure 6.3: serial recall percentage correct of same semantic category visual presented lists of to-be-remembered words with different and same category irrelevant sound.

To examine the effect of modality and list content a 2 (modality) by 2 (list items) by 2 (group) mixed ANOVA[8] was conducted on the percentage of errors made. No significant main effects were found for modality ($\eta_p^2 < .01$), or Group ($\eta_p^2 < .01$). There was a significant effect of list items, $F(1,38) = 3.71$, MSE= 97.50, $p<.05$ (one way), $\eta_p^2 = .089$, with the semantically similar lists having a higher error rate. There was an interaction of list items and modality, $F(1,38) = 7.23$, $MSE = 98.47$, $p< .05$, $\eta_p^2 = .16$, when the lists were presented auditorally, the semantically similar lists had a significantly higher error rate. There was a significant decrease in performance on semantically similar lists between visual and auditory presentation ($\eta_p^2 < .01$). There was no significant change in performance in the different category lists conditions (η_p^2

[8]For all ANOVA's in the chapter significance was set at .05 and all comparisons were Bonferroni adjusted.

= .25), which suggested that auditory presented items are more susceptible to semantic similarity than visual.

Overall Experiment 8 demonstrated that dyslexics performed equivalently to the control group on all conditions. This suggested that they were able to inhibit the irrelevant semantic information successfully. Serial recall was not affected by the semantic similarity of the irrelevant sound; however the sound was changing state and had a significant impact on recall. Experiment 9 sought to further explore the effect of semantically similar irrelevant sound on free recall. Free recall has been shown to be negatively affected by semantically similar irrelevant sound (Marsh et al., 2008)

6.4 Experiment 9

Interference by the content of the irrelevant sound did not significantly affect performance in Experiments 5 and 8. This suggested that dyslexics' inhibitory processes were successfully preventing interference with serial recall. Dyslexics performed equivalently to control groups in Experiments 7 and 8, which suggested that they successfully use semantic strategies to support their recall. This would suggest that dyslexics are more reliant on secondary organisation systems than the control group.

The negative effect of semantically similar irrelevant sound on free recall has been successfully demonstrated by Marsh et al. (2008), and Neely and LeCompte (1999). This implied that secondary organisation was used in the encoding and recall of items.

Experiment 9 compared dyslexic and control group's free recall under conditions of semantically similar and dissimilar irrelevant sound. Auditory presentation was used as in Experiment 8 semantic similarity, had a greater impact on recall. It set out to explore whether dyslexics were more susceptible to the semantically similar irrelevant sound effect because of their use of semantic strategies. This was demonstrated by the semantically similar irrelevant sound having a greater impact on dyslexics' free recall performance.

6.4.1 Method

6.4.1.1 Participants

The control group consisted of 20 participants and 22 dyslexic participants. All participants were students at Cardiff University at the time of the study.

6.4.1.2 Apparatus and Materials

To-be-remembered material consisted of 30 lists of category-exemplars selected from thirty-eight categories in the Yoon et al., (2003) norms. Category-exemplars chosen for TBR lists comprised ten items from the 9^{th} to the 18^{th} most frequently produced single word responses to chosen category names. As in the preceding experiments, category-items chosen for irrelevant material comprised the eight most frequently produced responses to the category names. The order of presentation of the exemplars within each TBR, and irrelevant list was random, but this order was the same for each participant. The category-exemplars for the TBR lists were recorded in a female voice and sampled with a 16-bit resolution, at a rate of 44.1kHz using

SoundForge 5 software (Sonic Inc., Madison, WI; 2000). The speech was played to participants at 65-70dB(A) via stereo headphones that were worn throughout the experiment.

The irrelevant material consisted of 8 exemplars from the same 30 categories as the TBR lists. These were the 1^{st} to the 8^{th} highest dominance or most frequently produced of the same thirty category names as those chosen for the TBR lists. In semantically similar conditions exemplars from the same category were presented as irrelevant sound. In the semantically dissimilar conditions, exemplars were selected (ensuring that there were no semantic similarities), from the other 30 categories. The irrelevant material was recorded in a male voice and sampled with a 16-bit resolution, at a rate of 44.1kHz using SoundForge 5 software (Sonic Inc., Madison, WI; 2000).

6.4.1.3 Design and Procedure

A mixed design was used with one between-participants factor (group). All participants completed the semantically similar and dissimilar irrelevant sound conditions. Participants were informed to only remember/recall the words said in a female voice, the word said in a male voice were irrelevant and should be ignored. The same procedure was used as in Experiment 7.

6.4.2 Results

Participants' responses were scored correct if recalled from the TBR list. Items recalled from the irrelevant sound were classified as intrusions.

Semantically similar items recalled which were neither from the list or irrelevant sounds were classified as semantically similar additions.

6.4.2.1 Correctly recalled exemplars

Recall in the semantically similar irrelevant sound conditions was lower than the semantically dissimilar irrelevant sound conditions for both groups, as is illustrated in Figure 6.4.

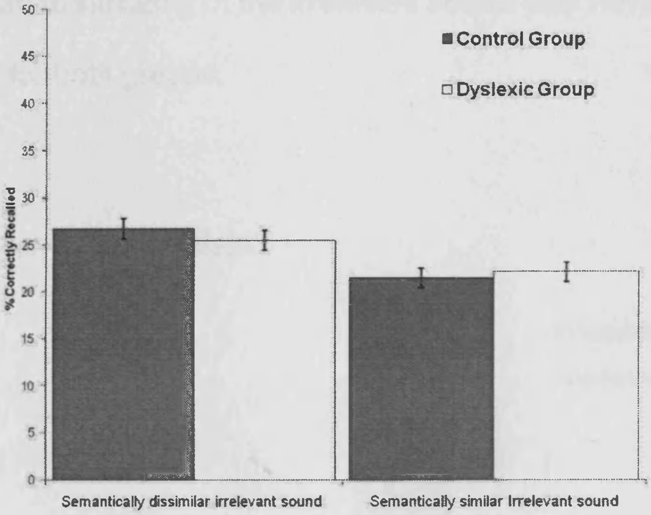

Figure 6.4: percentage correct of free recall by sound conditions and group error bars represent standard mean error.

A 2 x (group) by 2 x (irrelevant sound condition) mixed ANOVA was conducted on the percentage of correctly recalled items. A main effect was found of irrelevant sound condition F (1, 38) =87.38, MSE=31.73, p< .01, η_p^2=.70. Comparisons revealed that performance was significantly better on the semantically dissimilar irrelevant sound conditions. No significant main effect was found for group (η_p^2<.01). This demonstrated that dyslexics were performing equivalently to the control group in both irrelevant sound conditions. There was a significant interaction effect between group and irrelevant sound condition, $F\,(1, 38) = 4.18$, MSE=31.73, $p<.05$, $\eta_p^2=.09$. Simple effects revealed that the control group recalled more words than the dyslexic group in the semantically dissimilar irrelevant sound condition (not significant $\eta_p^2=.02$); whereas in the semantically similar irrelevant sound condition the dyslexic group recalled more words than the control group (not significant $\eta_p^2=.01$). However there was a significant difference between the irrelevant sound conditions in both groups (Control $\eta_p^2=.63$; Dyslexic $\eta_p^2=.41$). Overall the semantic similarity of the irrelevant sound was having a significant impact on recall for both groups.

6.4.2.2 Intrusion and addition data.

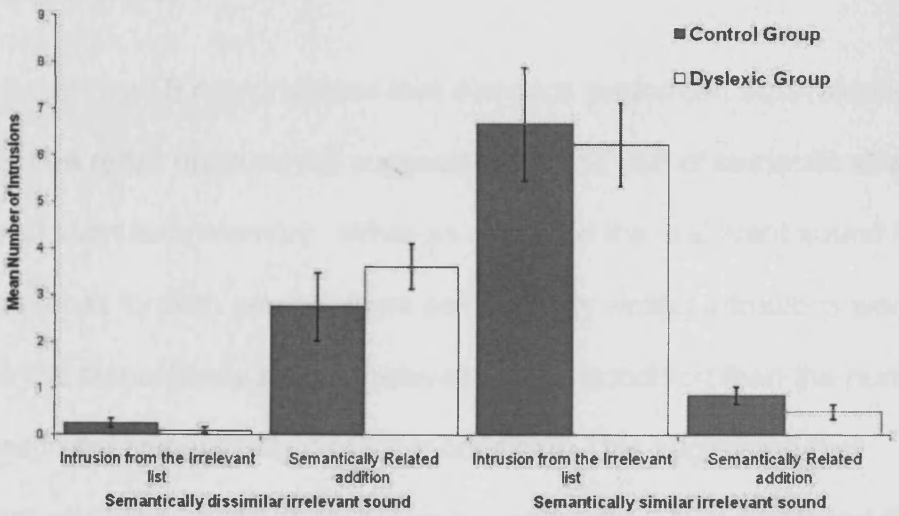

Figure 6.5 mean number of intrusions by sound condition and group

A 2 x (group) by 2 (irrelevant sound condition) by 2 (intrusion type) mixed ANOVA was conducted on the mean number of intrusions made. A main effect was found for sound condition *$F\,(1, 38) = 26.55$, MSE=5.30, $p<.05$, $\eta_p^2=.41$.* Significantly more intrusions were made in the semantically related irrelevant sound condition. There was also a main effect, showing that intrusions from irrelevant sound were significantly more likely than related additions overall, $F\,(1, 38) = 13.83$, MSE=5.47, $p < .05$, $\eta_p^2 = .27$. However an interaction was found between irrelevant sound condition and intrusion type $F\,(1, 38) = 88.20$, $MSE = 8.68$, $p < .05$, $\eta_p^2 = .70$. Simple effects revealed that there are significantly more intrusions from irrelevant sound in the semantically related irrelevant sound condition; whereas significantly more semantically similar additions were made in the semantically dissimilar related sound condition. No significant main effect group was found ($\eta_p^2 < .01$) dyslexics demonstrated equivalent patterns of intrusion type as the control group.

6.4.3 Discussion

Experiment 9 demonstrated that dyslexics performed equivalently on both the free recall tasks, which suggested that the use of semantic strategies to support short term memory. While as expected the irrelevant sound had an effect on recall for both groups, more semantically similar intrusions were made in the semantically similar irrelevant sound condition than the number of additions in the semantically dissimilar condition. This suggested that irrelevant sound had a direct impact on intrusion type. This replicated the findings of Marsh et al. (2008), and Neely and LeCompte (1999)

The irrelevant sound did not have a greater impact on dyslexics, which suggested that although dyslexics used semantic strategies to support recall, this did not affect their susceptibility to the irrelevant sound.

6.5 General discussion

Unlike the results from the experiments outlined in Chapter 5, where dyslexics demonstrated a consistent deficit, in all three experiments outlined in this chapter, dyslexics performed comparably to the control groups. However, the results of these experiments are consistent with the findings in Chapter 5, in that dyslexics demonstrated the same pattern and magnitude of disruption as the control group. Overall this suggested that dyslexics do not have a general verbal short term memory deficit and their inhibitory processes are intact. Therefore by factoring out these semantic processes this provides further evidence to isolate the short term memory deficit in dyslexia. Chapter 7 explores whether these equivalent patterns of interference are applicable to non-verbal memory. It also explored whether dyslexic perform at an equivalent level to controls on non-verbal memory tasks.

Chapter 7: Non-Verbal Short Term Memory

7.1 General Introduction

Non-verbal STM has been of much interest to dyslexia researchers, as proponents of the phonological processing deficit theory (e.g. Snowling, 2000) predicted that dyslexics would not have a deficit in this area. This contrasts with the predictions of proponents of the cerebella theory (e.g., Fawcett & Nicolson, 2001). However findings from studies looking at non-verbal short term memory have been inconsistent. For example, inconsistent performance on visuo-spatial tasks was demonstrated in a study by Winner et al. (2001) who investigated the performance of dyslexics on 15 visual-spatial tasks, including abstract tasks (such as in the Vandenbeg test of mental rotation); and practical tasks (such as pyramid wood block puzzle test). The results demonstrated that on the majority of tasks, dyslexics either performed at a comparable level or worse on visual-spatial tasks. There was one task where dyslexics did out-perform non-dyslexics (but not to a significant level). This task involved identifying whether an Archimedes screw was being turned the correct way. A follow-up study examining the findings of the Archimedes screw task in more detail, (Karolyi, Winner, Gray, & Sherman, 2003) produced findings to suggest that dyslexics have "superior global visual-spatial processing ability". The tasks where dyslexics demonstrated this ability were in recognising impossible figures more rapidly than non-dyslexic participants. However there was no difference in accuracy between the two groups. The study also concluded that the working memory demands of many visual-spatial tasks, e.g. the Rey-Osterrieth task (which involved reproducing a complex line drawing), may account for a dyslexic's impaired performance on these tasks.

The Corsi blocks task is a popular test for quantifying the capacity of the visuo-spatial subsystem of the working memory model, and is frequently included as part of IQ tests (WISLER R). Smith-Spark and Fisk (2007) demonstrated that dyslexic participants have a deficit on a computerised Corsi blocks and spatial working memory task, but not on a spatial updating task. On all verbal tasks dyslexics showed a clear deficit (digit, letter and word span tasks).

Jefferies and Everatt (2004) compared dyslexic children to children with other special educational needs (and a control group) on working memory tasks. The results demonstrated that both groups performed worse than the control group on phonological measures (with dyslexics performing the worst), however dyslexics performed as well as the control group on visuo-spatial and visual-motor tasks where the bead threading task of the Dyslexia Screening Test (DST; Fawcett & Nicolson, 1996) and the pointing task of the Bangor Dyslexia Test (BDT; Miles, 1993) were used.

The visuo-spatial subsystem of the working memory model has also been studied in some detail. For example, Smith-Spark, Fisk, Fawcett and Nicolson (2004) attempted to isolate the visuo-spatial subsystem of the working memory model by employing tasks that presented "to- be-remembered" items in a 5x5 matrix in static and dynamic conditions (Smith-Spark, Fisk, Fawcett, & Nicolson, 2004). Results of the study suggested that dyslexics only show significant deficits in visuo-spatial short term memory in the most taxing conditions.

In spite of the many investigations into visuo-spatial serial memory, there is often a problem with testing the verbal recoding of the "to- be-remembered" stimuli, thus resulting in inconclusive interpretation of results for non verbal memory. In tasks such as the Corsi blocks test, there are a fixed number of spatial locations which can be given arbitrary names or named groups (the limitations of such tasks are discussed by Jones, Farrand, Stuart, & Morris 1995; Farrand & Jones, 1996; Farrand, Parmentier, & Jones, 2001; Tremblay, Macken, & Jones, 2001. Smith-Spark and Fisk (2007) suggested that because dyslexics have phonological impairments, they would be less likely to verbally recode information. However as verbal coding is a common way of dealing with remembering a list of items, it is prudent to include a task that will minimise the chance of verbal recoding for both control and dyslexic groups.

This study compared the performance of dyslexics and the control group on a spatial serial recall task. The spatial task adopted for this experimental series was similar to that used by Jones, Farrand, Stuart, and Morris (1995), Farrand, Parmentier, and Jones (2001), Parmentier, Tremlay and Jones (2004), and Parmentier, Mayberry, and Jones (2004). This involved testing serial recall of seven dots presented one at a time in different spatial locations on a computer screen. After the presentation of the last dot, nine dots appeared on screen (seven in the original positions plus two dummy dots). The participants then used the mouse to click on the dots in the order that they saw them. The task required participants to reconstruct the order of presentation from the nine options given. Participants were given nine options to allow parity with verbal order reconstruction tasks in Chapter 5. In designing the task several precautions were taken to minimise the likelihood that the spatial information could be verbally recoded. The spatial locations of the dots varied across trials and the positional uncertainty of the presented stimuli was high, so that items could not be recoded using a simple set of verbal labels. Furthermore, other visual cues that might lead to verbal recoding, such as grid lines, were excluded.

This series of experiments tested the dyslexic's ability to serially recall without verbal recoding. The aim was to further explore how dyslexics' serial recall abilities responded to a number of experimental manipulations that have previously been shown to have a detrimental effect on recall.

Experiment 10 investigated the effect of increasing difficulty levels of the task by varying the sequence in which the dots appeared on the screen, creating more complex paths to follow by varying the number of cross-points and path length (Parmentier, Elford, & Mayberry, 2005; Andrés , 2006). It was demonstrated that if you were to plot the path that the dots follow as they appear on screen, the longer the path and the more times it crosses will increase the difficulty of the recall task. Experiment 11 investigated the effect of irrelevant sound on recall, which has been shown to have a detrimental effect (Jones et al., 1995; Tremblay, Macken, & Jones, 2001) but the effect has failed to be replicated in a number of studies, when looking at complexity of path and irrelevant sound (Parmentier personal commutation, 2007).

Experiment 12 looked at the effect of manual and articulatory suppression, which has also been shown to have a detrimental effect on serial recall (Jones, Farrand, Stuart, & Morris, 1995). The phonological deficit hypothesis would predict that dyslexics would perform comparably to control groups throughout the experiments, as there were no verbal components to the task. However, the magnocellular and cerebella accounts would expect the deficits found in Chapter 5 to continue to be found even when it is non-verbal memory task.

7.2 Experiment 10

Parmentier et al. (2005), and Parmentier and Andrés (2006) demonstrated that increasing the path length and number of path crossings in a to-be-remembered sequence has a detrimental effect on visuo-spatial serial recall. This experiment examined the performance of dyslexics on the dots task, while increasing the difficulty by manipulating the path length and number of crossings, as Smith-Spark et al. (2003) only found a difference on the most demanding part of their task.

Parmentier et al. (2005) looked at manipulation of the number of crossings, increasing to three and six crossings while increasing path length. The current study will analyse the relationship between recall and number of path crossings by looking at the difference between none and three crossings. The results were expected to show that dyslexics perform at a comparable level to non-dyslexics, as this task minimises the possibility of verbal recoding. This is in contrast to many other visuo-spatial tasks, e.g. Smith-Spark, Fisk, Fawcett and Nicholson (2003), which involved presenting spatial information in grid lines which may have led to verbal recoding. The results were also expected to show a relationship between increased difficulty and performance in both groups

7.2.1 Method

7.2.1.1 Participants

Two Groups of Cardiff University students participated. The control group consisted of 20 (19 female, 1 male) self reported non-dyslexics, recruited from the psychology department's Human Participant Panel System. The control group's mean age was 20.29 (*SD* = 3.98). The dyslexic group consisted of 20 (8 male, 12 female), the mean age of the dyslexic group was 20 (*SD* = 1.69).

7.2.1.2 Apparatus and Materials

The experiment was conducted on a PC computer using the mouse to collect participants' responses. The experiment was programmed in Visual Basic 6 using black dots (diameter 15 mm) as the stimuli on a white computer screen. The computer was set up with a 41cm VDU resolution 1024 by 768.

7.2.1.2 Design

There were 20 possible screen locations for the dots to appear in; these were distributed across the screen. No dot locations were symmetrical and they could not fall into a grid or form a recognisable pattern.

Each of the locations was used at the same frequency across the 84 trials conducted. The paths described by the dots did not follow any obvious patterns or symmetry.

There were 4 separate levels of difficulty within the experiment, crossings and increased length of path (significant increase in each condition $p<.001$). This ranged as follows: 1 = no crossings, average length 31cm; 2 = 1 crossing, average length 38cm; 3 = 2 crossings, average length 47cm ; 4 = 3 crossings, average length 61cm.

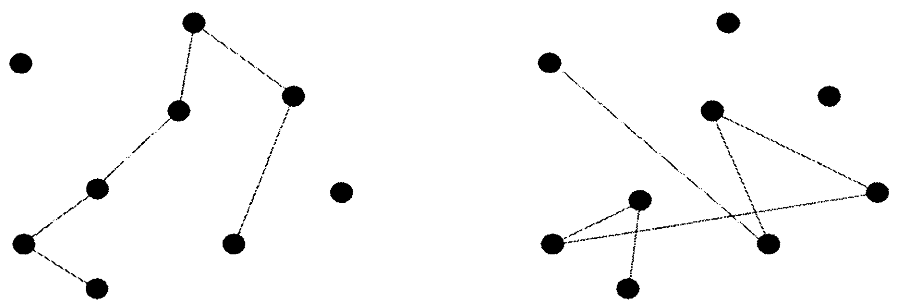

Figure 7.1 levels 1 and 4 in difficulty

A one way ANOVA showed that there is a significant difference between each of the levels on their path length, $F(3,79)=106.034$ $p<.001$. Bonferroni adjusted pair wise comparisons showed that all levels were significantly different from one another ($p<.005$). There were 21 trials of each level of difficulty. 20 quasi-random orders of the 84 trials were created.

7.2.2.3 Procedure

The experiments were run in sessions with up to five participants in a laboratory. The participants sat at an individual computer wearing sound attenuated headphones to dampen any background noise from others in the room. Between each of the work stations there were dividers to stop participants being distracted by others in the laboratory.

The participants were given verbal explanations of the instructions by the experimenter before completing a computer generated form, which recorded age, gender and asked participants to confirm whether they were dyslexic and whether they thought that there was a possibility that they may be dyslexic.

Each trial consisted of seven dots, appearing individually in different locations on screen for 700ms, followed by 300ms of blank screen. During the presentation period the mouse pointer disappeared from the screen. After the 300ms of blank screen after the last dot in a trial, the seven original dots re-appeared simultaneously on screen in their original positions; these were accompanied by two dummy dots and the mouse pointer.

In the recall phase, participants used the mouse pointer to click on the dots. After a dot had been selected, it disappeared from screen (no information about clicks outside the dots were recorded). After the seven dots had been selected, the program automatically moved on to the next trial. There was a 1000ms interval (blank screen) between the seventh dot being selected and the appearance of the first dot in the next trial.

Participants were instructed to recall the dots in the order that they were presented. During the presentation period participants were not permitted to use hand gestures to rehearse the dot locations.

7.2.2. Results and discussion

The participants' responses were scored using a strict serial order criterion: Each item had to be in the correct position in order for the response to be scored as correct. The correct scores were examined in relation to each serial position and also collapsed over the serial position the mean percent correct for each level of difficulty for each group is presented in Figure7.2.

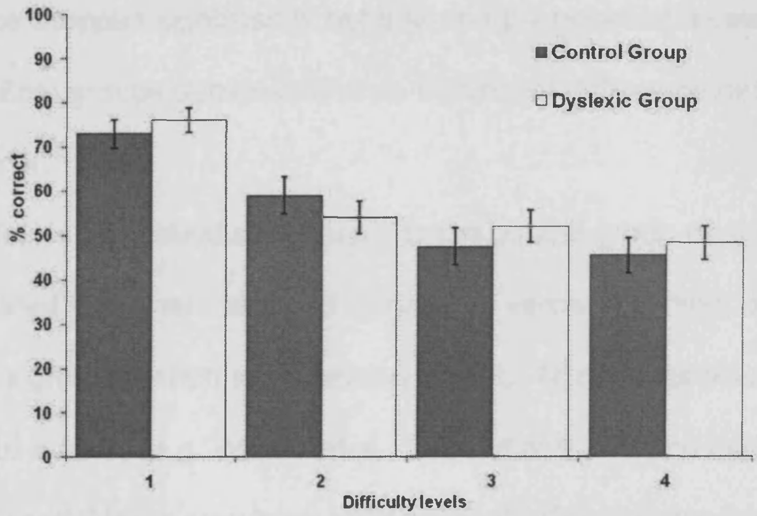

Figure 7.2. Results from experiment 10. Mean percentage correct serial recall across difficulty levels. Error bars represent standard error of the mean.

A mixed ANOVA[9] was carried out on the data with difficulty (4, difficulty levels of increasing line length and crossings) and group (2, Control and Dyslexic groups) as factors. There was no significant between the groups in performance, F (1, 38) =.03, MSE=28.06, p >.05, η_p^2=.96. There was a main effect of difficulty levels, performance decreased as the number of crossing and path length increased F (3,114) = 137.23, MSE = 98.73, p < .05, η_p^2=.77.

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[9] For all ANOVAs in the chapter significance was set at .05 and all comparisons were Bonferroni adjusted.

Performance at difficultly level three was not significantly different to level four, however all other between level comparisons were significantly different. There was a significant interaction between group and level of difficulty,($F(3, 114) = 4.23$, $p < .05, \eta_p^2=.10$), there was no significant difference between groups at each level. The dyslexic group's performance only dropped significantly between difficulty level one and two, whereas the control group's performance dropped significantly but less sharply between levels one, two and three. Both groups demonstrated no significant difference between levels three and four.

Dyslexics performed comparably to the control group on the dots task. This suggested that where tasks do not involve verbal recoding, dyslexics do not show a significant short term memory deficit. The results also suggested that previous studies (e.g. Winner et al., 2001) that found that dyslexics show a deficit on spatial tasks may have been a result of verbal recoding of the visuo-spatial stimuli.

The results replicated those of Parmentier et al. (2005); they demonstrated that increasing the path length and the number of path crossings does have a detrimental effect on recall (Parmentier et al. 2005; Parmentier & Andrés, 2006). The novel finding in this experiment was that including just one crossing and a small increase of path length also had a detrimental effect, where previous studies had only identified this effect where three crossings and above existed. The results were expected to show a linear relationship between difficulty level and performance, there was a trend of constantly decreasing performance but the largest decrease was between level one and two, the decline in performance then plateaued. This suggested that including one crossing has the most detrimental effect on recall, although including further crossings had a subtle effect on short term memory performance.

This experiment has shown that dyslexics can perform at a comparable level to control groups on non-verbal short term memory tasks over four levels of difficulty. It also demonstrated that increasing the difficulty level does not have a detrimental effect on dyslexics, but has the same effect on both groups. However, Smith-Spark et al. (2004) argued that visuo-spatial short term memory deficits are only apparent during the most taxing conditions. In Experiment 3, irrelevant sound had a significant impact on the number of items recalled on a verbal serial recall test. Experiment 11 explored this further by including irrelevant sound during the presentation period of the dots.

7.3 Experiment 11

This experiment was designed to investigate the robustness of dyslexics' ability to perform equivalently to the control group on a non verbal serial recall task (Experiment 10). The objective was also to further explore the findings of Experiment 3, identifying whether the results could be replicated on a non verbal serial recall task. As in Experiment 3, irrelevant sound conditions (quiet, steady state and changing state) were used. Verbal serial recall evidence (e.g. Jones et al., 2004; Jones, Macken & Murray, 1993) demonstrated that irrelevant sound, especially changing state irrelevant sound has a detrimental effect on short term memory. This has also been demonstrated in the dots task by Jones et al. (1995) and Tremblay et al. (2001). However, some studies have failed to replicate the irrelevant sound effect on the dots task (Parmentier, personal communication, 2007). The experiment also explored the argument made by Smith-Spark et al. (2004) that dyslexics' deficits are only apparent on non-verbal short term memory tasks in taxing conditions.

7.3.1 Method

7.3.1.1 Participants

The Control group consisted of 20 (19 female 1 male). The mean age was 20.29. The Dyslexic group consisted of 20 participants; the mean age of the dyslexic group was 20.

7.3.1.2 Materials

The experiment was conducted using the same program as in Experiment 10. Irrelevant items consisted of letters A to G recorded in a monotone male voice which was presented for 500ms each. The irrelevant sound was presented by sound attenuated headphones. The steady state condition participants heard the letter A, in the changing state condition, a letter from the alphabetic sequence A to G, was used.

7.3.1.3 Design

The factors of irrelevant sound conditions (Quiet, Steady and Changing) were blocked. During the study all participants completed all six blocks containing 18 trials. Each of the blocks contained an equal number of the difficulty conditions as had been previously used in Experiment 10.

7.3.1.4 Procedure

The same procedure was used as Experiment 10 with the following modifications. The irrelevant sound was introduced in the intervals between the appearances of the dots on the screen.

As part of the instructions, participants were told to ignore any spoken letters they heard, but to recall the numbers in their order of presentation as soon as the recall screen appeared.

7.3.2 Results and Discussion

As with Experiment 10, a strict serial recall criterion was used to score the data. The correct scores were collapsed over serial position; the mean percent correct for each level of irrelevant sound conditions between groups is presented in Figure 7.3[10].

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[10] Difficulty level was not included in analysis as there were not enough trials per condition.

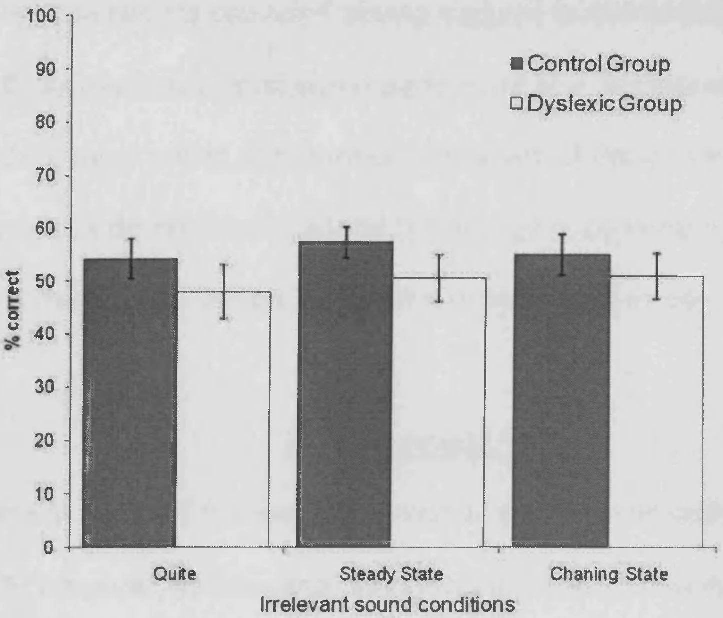

Figure 7.3. Results from experiment 11. Mean percentage correct serial recall across the irrelevant sound conditions. Error bars represent standard errors.

A mixed factorial ANOVA 3 (irrelevant sound conditions) by 2 (group) was carried out on the data sound conditions. There were no significant main effects for group (F (1, 38) =1.85, MSE=731.92, p >.05, η_p^2=.05) and also for irrelevant sound conditions (F (2, 76) =2.61, MSE=47.69, p >.05, η_p^2=.06). There was no significant interaction between group and sound conditions (F (2,76) =0.63, MSE=47.69, p >.05, η_p^2=.02).

The introduction of irrelevant sound conditions demonstrated an inconclusive result as there was no effect on recall for both groups. The effect of irrelevant sound on visuo-spatial short term memory is problematic to replicate. Jones et al. (1995) and Tremblay et al. (2001) have previously shown a clear significant effect, whereas others have failed to gain a similar result, as is the case in Experiment 11 (Parmentier personal communication 2007). This suggested that there are other unidentified mediating variables.

However, the results provided strong support to the findings of Experiment 10, as dyslexics once again performed at a comparable level to the control group, even under demanding conditions of irrelevant sound. This suggested dyslexics do not have general phonological processing problems, performance is maintained across conditions of irrelevant sound.

7.4 Experiment 12

Experiment 12 used the same non-verbal serial recall task as Experiment 11; however, in this case, the irrelevant sound was replaced by manual and articulatory suppression tasks. In Experiment 3, manual and articulatory suppression decreased the performance of the verbal serial recall task. The manual suppression affected performance to the same magnitude in both dyslexic and control groups, however the articulatory suppression had a reduced impact on the dyslexic group. Experiment 12 explored the effect of these suppression tasks in non-verbal serial recall. Parmentier and Andrés (2006) have previously demonstrated that including a tapping task (manual suppression) during a retention interval, decreases performance on the dots task. This suggested that a suppression task would have a significant impact on non-verbal serial recall. However, in line with Experiment 3, the manual and articulatory suppression tasks during the presentation of the dots, examined the effect of suppression at encoding. This also allowed for the comparison of the effect of a suppression task on verbal and non-verbal serial recall tasks. The dyslexics have been shown to perform at a comparable level to the control group on the dots task (Experiments 10 and 11). Therefore it was expected that the dyslexics would again perform at a comparable level to the control group, but (as in Experiment 3) both groups would display a drop in recall when the manual suppression task was introduced.

7.4.1 Method

7.4.1.1 Participants

The control group consisted of 20 (19 female 1 male) self reported non-dyslexics mean age was 20.29. The dyslexic group consisted of 20 participants; the mean age of the dyslexic group was 20

7.4.1.2 Apparatus/Materials

The experiment was conducted on a PC computer using the mouse to collect participants' responses. The experiment was programmed in Visual Basic 6 using black dots (diameter 15 mm) as the stimuli on a white computer screen. The computer was set up with a 41cm VDU resolution 1024 by 768.

7.4.1.3 Design and Procedure

The design was maintained from Experiment 11; however the irrelevant sound conditions were replaced with suppression tasks. The suppression task instructions from Experiment 3 were replicated. For the articulatory suppression conditions, participants were asked to whisper "X", "Y", "Z" repeatedly at a rate of three items per second during the presentation period. In the manual suppression condition, at the same rate, participants tapped keys marked "X". "Y", and "Z" on the number pad ("X" on key 7, "Y" on key 5, and "Z" on key 3). The suppression conditions were explained in the instructions and the experimenter coached the participants in the correct rate and loudness (articulatory) of the tasks. Participants were monitored closely throughout the experiment to ensure that they completed the suppression tasks in line with instructions.

7.4.2 Results and Discussion

As with Experiment 11, a strict serial recall criterion was used to score the data. The correct scores were collapsed over serial position and the mean percent correct for each condition presented in Figure 7.4.

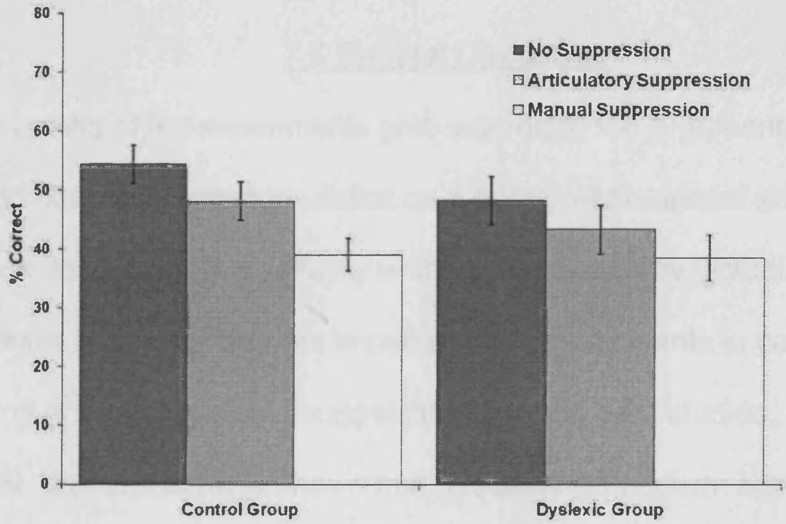

Figure 7.4. Results from experiment 12 Mean percentage correct serial recall across the articulatory and manual suppression conditions. Error bars represent standard error of the mean.

A mixed ANOVA 3 (secondary task) by 2 (group) was completed. There was no main effect of group ($F(1,38) = 2.44$, $MSE=457.51$, $p > .05$, $\eta_p^2=.06$), but there was a main effect of task ($F(2,76) = 36.59$, $MSE=44.87$, $p<.05$, $\eta_p^2=.49$). Simple effects comparisons both within and across groups confirmed that each task condition was significantly different to another, performance decreased from the no task to the manual suppression ($p <.05$).

There was no interaction between group and task ($F(2,76)=1.07$, $MSE=44.87$, $p > .05$, $\eta_p^2=.03$).

The suppression tasks had a significant effect on performance of the task which is in line with previous findings, that manual suppression has a significant impact on performance of the dots task (Parmentier & Andrés, 2006). As the introduction of demanding suppression tasks have an equal effect on the control and dyslexic groups' performance, this suggested that they are using the same processes to complete the task and deal with the suppression task, this replicates the findings of Experiment 3.

7.5 General Discussion

The results of the experiments give support to the argument that dyslexics do not have a memory deficit on a purely visuo-spatial short term memory task. Increasing the difficulty at the presentation by including irrelevant tasks or sound does not impair dyslexic participants in comparison to the control group. This would suggest that tasks in past studies, such as Winner et al. (2001) that have shown that dyslexics do perform significantly poorer on some visuo-spatial tasks, may have been compromised by verbal recoding. Experiments 11 and 12 demonstrated that the dyslexic group does not have a deficit in their ability to inhibit irrelevant tasks and could perform at an equivalent level to the control group. This is in contrast to studies such as Smith-Spark et al., (2003) that argued that dyslexics have a deficit in higher organization systems, such as the working memory model's central executive.

In conclusion, these experiments established that on a task which is devoid of verbal recoding of to-be-remembered material, dyslexic participants consistently perform comparably to control groups. This suggested that dyslexics' short term memory deficit results from the verbal processing systems. The experiments also demonstrated that dyslexics do not have a general order processing and reconstruction deficit in short term memory. Experiment 10 also expanded on the work of by Parmentier, Elford, and Mayberry (2005) and Parmentier and Andrés (2006) which investigated the effect of path on complexity, showing that the first and second crossings in the spatial sequence have the most significant effect on short term memory in both control and dyslexic groups. Experiment 11 was unable to replicate the findings of Jones et al. (1995) and Tremblay et al. (2001) in identifying a detrimental effect of irrelevant sound on recall in the dots task, however this did show that the dyslexic group were able to effectively ignore irrelevant verbal material without detriment to the task, showing that the impairment is not a deficit within the perceptual organisation. Experiment 11 supported Parmentier and Andrés (2006) findings showing that suppression tasks have a detrimental effect on serial recall in the dots task, with manual suppression having a greater effect than articulatory, and this was to the same magnitude in both control and dyslexics groups.

Chapter 8: General Discussion

8.1 Summary

The aim of the experiments reported in this thesis was to isolate dyslexics' short term memory deficits. This aim was achieved through the use of similar tasks for the analysis of verbal and non verbal memory and used similar manipulations on those tasks. It has provided a detailed characterisation of impaired and unimpaired STM performance in dyslexia, demonstrating that dyslexics' short term memory deficit can be isolated to verbal short term memory unsupported by semantic strategies. Throughout, the studies examined the role of processes including auditory perceptual organisation, speech planning and output and nonverbal spatial processing. It explored the susceptibility of these processes to interference from irrelevant tasks and sound.

The series of experiments on verbal short term memory presented in Chapter 5 consistently demonstrated that dyslexics had quantitatively deficited performance; however qualitatively, performance was equivalent to that of the control groups. Serial position analysis of dyslexics' performance demonstrated that they were displaying equivalent primacy and recency effects on serial recall tasks.

The results of the investigation into the inhibition of irrelevant sound and suppression tasks demonstrated that dyslexics' processes appear to be intact. Dyslexics demonstrated the same phonological similarity effect within stream and were no more affected between streams. This suggested that dyslexics are successfully encoding the phonological characteristics of the to-be-remembered items.

Chapters 6 and 7 both demonstrated that dyslexics' short term memory deficit is specific to semantically unsupported verbal short term memory. In Chapter 6, where tasks involving semantic information were manipulated, dyslexics performed equivalently to control groups as well as demonstrating the same effect to the manipulations to the same magnitude. Chapter 7 explored non-verbal short term memory using manipulations that had been previously used in Chapter 5, but this time demonstrating that the manipulations had the same effect on a task where the dyslexics were not demonstrating a quantitative deficit. The series of experiments in Chapters 6 and 7 established that on non-verbal and semantically supported short term memory tasks, performance in the dyslexic group was both qualitatively and quantitatively equivalent. This suggested that dyslexics' short term memory deficit is isolated to non-semantically supported short term memory.

In summary, the experiments reported in this thesis provide evidence that dyslexics do not have a general short term memory deficit as proposed by the cerebella/automaticity deficit (CAD) theory (Nicolson & Fawcett, 1990; Nicolson, Fawcett & Dean, 2001).

The phonological processing deficit (PPD) theory (Snowling , 2000; Bradley & Bryant, 1978; Rack, 1994; Vellutino, 1974) appeared to be the most successful in proposing a specific deficit; however the theory is normally framed within the working memory model, as described in Chapter 5, which is not consistent with the findings of the manipulations used in the empirical chapters. In the light of these limitations, the findings suggested that the phonological processing deficit is a good account of dyslexics short term memory but should not be applied within the confines of the working memory model. The following discussion examined the implications of the current results to the theories of dyslexia.

8.2 Theories of dyslexia

8.2.1 Phonological processing deficit theory

Unlike the cerebella and sensory deficit theories, the phonological theory specifies a specific processing deficit which will affect semantically unsupported verbal short term memory (Snowling, 2000). This is supported by the results of the present studies, which isolated STM deficits to the area predicted by the theory.

8.2.2 Cerebella / automaticity deficit theory (CAD)

This theory proposed that dyslexics' deficits are of a more general nature (Nicolson & Fawcett, 1990; Nicolson, Fawcett, & Dean, 2001). This was not supported by the experiments presented in this thesis. In the studies that looked at the effect of irrelevant sound and suppression tasks, the CAD theory would predict that these tasks would have a greater impact on dyslexics' performance. This was not found to be the case, as dyslexics appear to have successful automisation of inhibitory skills and are able to perform secondary tasks without demonstrating a more significant effect on the primary tasks. This would imply that CAD is not providing an adequate account of the deficits as the broader symptoms have not been evidenced in these experiments.

8.2.3 Sensory deficit theories.

Although this thesis did not specifically study the auditory magnocellular system (Hansen, Stein, Orde, Winter, & Talcott, 2001; Stein, 2001; Stein, Talcott, & Witton, 2001; Stein & Walsh, 1997), or the magnocellular deficit theory (Goswami et al., 2002), the studies demonstrated that the dyslexic group had a comparable modality effect to the control group. This does not indicate that there is a sensory deficit. If sensory deficits exist, this would imply that they are very specialised and do not impact on processing in short term memory.

8.3 Future Directions

8.3.1 Diversifying populations

The results of the experiments presented in this thesis provided a clear picture of dyslexics' short term memory deficits in high functioning dyslexics. This population was examined as they would be a homogenous group as they have all continued into higher education. This now needs to be extended to a broader adult population with different educational profiles who may reflect a broader spectrum of difficulties. Studies also need to focus on participants from different age groups to see if the isolation of deficits is a consistent pattern, that can be found in childhood and which then continues on to adulthood.

The phonological theory proposes that dyslexia is on a spectrum of learning disabilities. The findings of a specific pattern of short term memory deficits in dyslexics now needs to be compared with participants classified with other learning disabilities such as Dyspraxia and AD(H)D to demonstrate whether this pattern of performance is specific to dyslexia or is characteristic of a wider range of learning disabilities. If this pattern of performance were isolated to dyslexics this would then suggest that this was the core deficit that they experience.

8.3.2 Verbal short term memory

On the basis that verbal short term memory has a specific deficit; future directions could investigate ways of mediating that deficit. This would involve the identification and development of strategies to lessen the effects. Studies would need to be conducted into the effects of strategies, such as the use of timing differences to promote chunking in STM. An example would be varying the timings in between the items presented, which would promote the chunking of to be remembered items.

Another future direction would be to use the manipulation of the to-be-remembered items to examine the sensory deficit theories of dyslexia (e.g. Goswami et al., 2002; Stein, 2001). For example studies could be conducted on the effects of making the to- be-remembered items more difficult to discriminate from irrelevant streams.

8.3.3 Semantic short term memory

The disruption of semantic short term memory could be further examined using more varied tasks such as verbal fluency. This would expand the results from the limited range currently used to make the conclusions broader and more generally applicable.

All the experiments reported in this thesis have looked at immediate recall of items, future studies could look at recall after time intervals. Long term memory processes have been implicated in the semantic strategies used to organise information on short term memory tasks (Marsh et al., 2008) and also the use of recall intervals could examine whether the items had been successfully transferred to long term memory.

8.3.4 Non-verbal short term memory

The dots tasks used in this thesis was successful at demonstrating that dyslexics can perform equivalently to control groups on a non-verbal memory task. However, other more widely used non verbal memory tasks, such as the Corsi blocks span task (Milner, 1971) have produced more varied results (Palmer, 2000; Smith-Spark et al., 2003, 2007; Winner et al., 2001). Further studies need to be completed to compare performance across these tasks to establish whether the difference in performance is due to methodological issues, e.g. verbal recoding or population differences.

Studies reporting a deficit on non verbal short term memory tasks have more frequently reported a deficit in backward recall conditions and under a concurrent cognitive load (e.g. Olson & Datta, 2002; Reiter, Tucha & Lange, 2004; Smith-Spark et al., 2003, 2007; Swanson, Ashbaker & Lee, 1996). Although Experiments 11 and 12 demonstrated that dyslexics' performance does not suffer under a concurrent cognitive load, a further study into backward recall, using the dots test would be desirable to establish whether this was a factor.

8.4 General Conclusions

To conclude, the experiments reported in this thesis provided convincing evidence that dyslexics' short term memory deficit is confined to verbal short term memory which is not supported by semantic strategies. The specific nature of the deficits reported in this thesis would suggest that the phonological processing deficit account provides a good explanation for the specificity of deficits in dyslexia. STM deficits affecting dyslexics have been widely researched but the literature has often produced an inconclusive picture of dyslexics STM deficits. This thesis demonstrated an isolated deficit, which suggested that previous inconsistencies found may be a result of the different methodologies used and the models they have been framed within.

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