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An Investigation of Visual, Spatial and Visual-Spatial Working Memory, attention and learning in Dyslexic Children

by

Justin J Allman

A Dissertation submitted for the degree of Doctor of Philosophy of the University of Dublin, Trinity College, Dublin 2, Ireland

This research was carried out in the School of Psychology

October 2006

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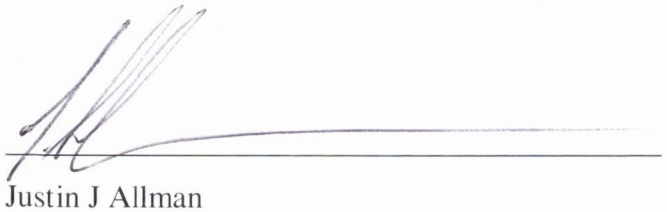

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Summary:

This dissertation investigated dyslexic children's functioning on a range of visual, spatial and visuospatial (VS), working memory (WM), attentional and learning tasks. Within the existing research which has touched upon these areas, there is a lack of consensus in respect to the level (if any) of impaired functioning in dyslexic children, or how these impairments should be conceptualised in relation to these cognitive abilities. The six experimental chapters presented in this thesis through a systematic and multidimensional approach to assessment, have attempted to offer further clarity in our understanding of dyslexic functioning across these cognitive abilities.

In chapter 2, three experiments assessed VSWM span capacity between dyslexic (D) and age matched developmentally normal control children (DN). Experiment 1.1 assessed spatial WM, while Experiment 1.2 & 1.3 examined span recall and attentional focus by introducing task-irrelevant interference into the VSWM task, with 1.2 assessing forwards and 1.3 their backwards-recall capacity. D and DN children performed similarly on the simple forwards-recall tasks, but D children were impaired on the interference and simple backwards-recall tasks.

In chapter 3, Experiment 2 assessed spatial WM using both parallel and matrix presentation displays. DN children demonstrated a significantly higher recall span than D, dyslexic children at high risk of ADD/ADHD (DAR) and reading age developmentally normal control (RA) children. Support for significant differences between D and DN children depended on the scoring method used on the matrix presentations displays. Additionally, all children were found to recall sequences presented on the matrix displays better than the parallel.

In chapter 4, visual WM and the effect of spatial interference in visual WM was assessed, using three visual representation stimuli types; animal, symbol and face, with both face and symbol stimuli having no specific long term memory representations associated with the individual stimuli items. Experiment 3.1 assessed visual WM using serial stimuli presentation. DN children had significantly higher span recall than D, DAR and RA children, with all the developmental groups demonstrating a similar shift in span recall due to changes in representation stimuli used to present sequence trials. Children recalled animal presentation sequences better than symbol, which in turn were recalled better than face stimuli

presentations. The analysis of Experiments 3.2 and 3.3 supported the position that all the developmental groups demonstrated a similar impairment in visual WM recall span due to the addition of task-irrelevant spatial interference at the presentation stage of the tasks.

In chapter 5, VSWM was once again revisited in two further experiments, using the same three visual representation stimuli as chapter 4. Experiment 4.1 presented stimuli sequences on parallel displays while Experiment 4.2 used matrix displays. Across display types the analysis indicated that DN children demonstrated a significantly higher recall span than the other 3 developmental groups, with all developmental groups demonstrating significantly better recall span on the matrix versus parallel tasks, suggesting that all children were likely using spatial encoding and/or retrieval strategies. There was some indication that D children's development of VSWM was less impaired than their literacy ability, as Experiment 4.1 indicated the D children had a significantly higher recall span than RA children.

In chapter 6, experiment 5 assessed implicit spatial learning. Significantly increased span recall and quicker response times (RTs) in sequence copying were indicated on the final versus initial assessment. Subsequent analysis offered some support for the position that the literacy impaired children demonstrated lowered implicit learning rates in span recall and RTs.

In chapter 7, Experiments 6.1-6.2 assessed sustained attention and inhibitory control. D children demonstrated an impaired capacity to sustain attention relative to their DN cohorts but showed an equivalent ability to reading age matched control (RA) children, while dyslexic children with a high risk of ADHD/ADD (DAR) needed to assert higher levels of executive control than RA children in order to sustain attention to an equivalent level. D, DAR and RA children all demonstrated more inhibitory errors than the DN children.

The thesis offers clear evidence that dyslexic children demonstrate deficits in visual, spatial and VSWM ability, as well as impaired functioning in sustained and focused attention. While there was some evidence of impaired implicitly-derived spatial learning, the dyslexic children did not demonstrate an impaired capacity to encode the novel face or symbol stimuli relative to their literacy unimpaired cohorts. Arising from the constellation of findings in the present thesis and the findings from the broader field of dyslexia research, a new causal model of dyslexic is proposed.

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List of Abbreviations:

95%CI	95% Confidence Interval
AB	Attentional Blink
ADD	Attention Deficit Disorder
ADHD	Attention Deficit Hyperactivity Disorder
AMA	Average or above average Mathematics Ability
AOA	Age Of Acquisition
BAM	Below Average Mathematics ability
CBA	Computer-Based Assessment
CE	Central Executive
CFQ	Cognitive Failures Questionnaire
CRT	Total number of Correctly Recalled sequence Trials
CGI-P	Conner's Global Index-Parent
CW	Correct Withhold
CW-RT	Response Time that precedes or follows a Correct Withhold response
D	Dyslexic children
DAD	Dyslexia Automatisation Deficit
DAR	Dyslexia children At high Risk of ADHD/ADD
DN	Developmentally Normal chronological age matched literacy unimpaired children
DVN	Dynamic Visual Noise
Go-RT	Go Reaction Time for Go trials
Go-RT-SD	the standard deviation of Go-RT
GPC	Grapheme-Phoneme Correspondences
ICV	Intra-individual Coefficient of Variation
LTM	Long Term Memory
MS	milliseconds
NARAII	Neale Analysis of Reading Ability, second edition
PL	Phonological Loop
RA	Reading Age matched developmental normal literacy unimpaired
REM	Rapid Eye Movement
RT	Response Time
SD	Standard Deviation

SE	Standard Error
SEN	Special Educational Needs
SART	Sustained Attention to Response Task
SOA	Stimulus-Onset Asynchrony
SWS	Slow Wave Sleep
T1	First Target
T2	Second Target
TBI	Traumatic Brain Injury
STM	Short Term Memory
VSSP	Visual Spatial Sketch Pad
VSWM	Visual Spatial Working Memory
WM	Working Memory
WMTB-C	Working Memory Test Battery for Children
WOND	Wechsler Objective Numerical Dimensions
WRAT-III	Wide Range of Achievement Test, Third Revision

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General Introduction

Introduction

Almost as many theories of dyslexia have been proposed as there are dyslexic individuals, from Hinshelwood's initial conception of "word blindness" to the proposed pathology of superiority (Geschwind & Galaburda, 1987), the phonological theory of dyslexia (Stanovich, 1988), and the more recent dyslexia automatisation deficit (DAD) (Nicolson & Fawcett, 1990) or magnocellular theory of dyslexia (Stein & Walsh, 1997). While the focus and emphasis differ dramatically among these paradigms, the continuous conceptual path that links these theories is an attempt to gain a satisfactory explanation as to why individuals with normative intellectual abilities experience such difficulties with the acquisition and performance of literacy-related tasks.

Fawcett (2002), drawing links from the "medical model", suggested the usefulness of distinguishing between cause, symptom and treatment. Thus theorists are driven towards uncovering the underlying cause(s) of dyslexia, educational psychologists directed towards dyslexic symptomology, and practitioners focussed on its treatment. It is only in recognising such distinctions that theoretical insights can be directed towards useful applications. Directing the emphasis of research towards uncovering those precursors of later literacy difficulties that can be recognised before a reading/spelling deficit is apparent, could lead to directed intervention into the underlying causes of later learning difficulties.

Frith (1997) made the further distinction that theoretical accounts could be further subdivided into three categories: theories that primarily relate biological or brain-based processes, theories that relate to the mind or cognitive processes, and theories that relate to behaviour. The current research thesis looks at the world of dyslexia from a predominantly cognitive theoretical and symptomatic perspective. To this end, the research focused primarily on assessing dyslexic children's ability ranges in a number of key areas: visuospatial working memory (VSWM) (Jeffries & Everatt, 2004), visual attention (Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Smith-Spark, Fawcett, Nicolson, & Fisk, 2004), and implicit learning (Gombert, 2003). The reasoning behind this perspective is threefold. Firstly, it recognises that to label a child as dyslexic is not to make an actual diagnosis. Rather

it is to identify that a complex problem exists, the most overt symptom of which is that the child is failing to read to an expected level. It is believed that by looking at lower-level cognitive abilities one can gain further understanding of the dyslexic condition and perhaps further insight into the causal development of the condition. This would enable one to say that, beyond a dysfunction on phonological-related tasks such as reading and or spelling, dyslexic individuals also experience difficulties in skill automatisation (Nicolson & Fawcett, 1990), phonological recoding (Palmer, 2000a), focusing attention (Facoetti, Paganoni, & Lorusso, 2000), etc., and that from such insights one can then direct the focus of intervention and possible remediation. Secondly, it recognises that these "secondary" deficits in ability that co-occur in literacy-impaired individuals can have a diagnostic potential as soft-signs for later reading disabilities, and that by recognising these soft-signs of possible literacy impairment one can actively intervene and remediate, without the need for reading failure to occur. Thirdly, it recognises that these co-occurring impairments in functioning beyond their diagnostic potential may actually play a causal role in the development of dyslexia.

Of the six experimental chapters in this research thesis, four are primarily focused on assessing aspects dyslexic children's VSWM ability (chapters 2 & 4-6). Chapter 3 primarily addresses dyslexic children's ability on a visual measure of sustained attention, and chapter 7 investigates visuospatial implicit learning.

Definition and the Movement towards a general model of Dyslexia

Probably the most often cited definition of dyslexia is that of the World Federation of Neurology, which defined dyslexia as *"a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence, and sociocultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin*" (Critchley & Critchley, 1978). The difficulty with using such a definition relates to the exclusion criteria as set out in the definition. By this definition, in order to be classified as dyslexic, one must have experienced normal sociological and pedagogical environments and be of normal intelligence or above. While using such exclusionary criteria can be helpful methodologically in separating causal from co-occurring conditions, it is hard to see

why an individual who has experienced impoverished home or schooling environments, who is also experiencing emotional problems, could not be classified as dyslexic.

Tønnessen (1997) remarked that any given definition of reading disorder should specify the pattern of disabilities one would expect to see in an individual so affected. The problem with applying such a criterion to dyslexia is that given its heterogeneous nature, one would require an almost infinite number of dyslexia subtypes to allow a definition for each individual sufferer of dyslexia. A looser interpretation would imply our definition is derived from such general exemplars that it does little to inform us about any specific dyslexic individual. Importantly though, Tønnessen suggests that to avoid restricting possible avenues of research and thereby our understanding of the condition, we should strive for a symptom-based definition rather than one derived from an over-arching, causal account or theory. Thus, our first point of reference should be to treat definitions of dyslexia as working hypotheses, enabling us to approach research bearing in mind the question: is this distinction a meaningful one and does it have value? With this perspective, further clarity is gained by distinguishing between primary and secondary symptoms, primary symptoms being those that form a core of the deficit and are present in almost 100% of cases, while secondary symptoms are seen less frequently within the sample but are more often found in dyslexic than in literacy-unimpaired individuals.

According to the British Dyslexia Association (2006):

> *"Dyslexia is best described as a combination of abilities and difficulties that affect the learning process in one or more of reading, spelling, writing. Accompanying weaknesses may be identified in areas of speed of processing, short-term memory, sequencing and organisation, auditory and/or visual perception, spoken language and motor skills. It is particularly related to mastering and using written language, which may include alphabetic, numeric and musical notation.*
>
> *Some dyslexics have outstanding creative skills. Others have strong oral skills. Some have no outstanding talents. They all have strengths. Dyslexia can occur despite normal intellectual ability and teaching. It is independent of socio-economic or language background"*

Coltheart and Jackson (1998) made the further distinction between proximal causes (an abnormal system that leads to literacy difficulties) and distal causes (the reasons why this system is operating abnormally), suggesting that there should be a movement away from a definition of exclusion. The approach denies that dyslexia should be lumped under one core causal hypothesis, instead it advocates the view that for normal reading ability to occur there is a reliance on the functioning of multiple processing subsystems and that an impairment or a slowed development in any of these subsystems will lead to deficit in reading ability. Critical to this viewpoint is the acknowledgement that children should be evaluated relative to age-appropriate norms and that while children may present with the same impairment in ability, it is important that an effort is made to uncover the proximal causes of that impairment, so that intervention can then be tailored to the child's individual needs. This position implies that "*the term dyslexia has no role to play when this approach is adopted*" (P15).

While Coltheart and Jackson's thesis makes a valuable contribution to the field of assessment, there is considerable evidence that there remains merit in distinguishing between dyslexic and garden variety slow readers. That is, if a garden variety slow reader who is experiencing difficulties in grapheme-phoneme correspondences were to receive adequate additional instruction and remediation, we would expect them to eventually "grow out" of their literacy impairment. In contrast, a dyslexic individual presenting with the same symptoms is unlikely to ever reach completely normative levels of ability given the established lifelong persistence of dyslexia, in which reading retardation can be seen as just one of its many manifestations (Ramus et al., 2003).

Within the arena of dyslexia research there are three leading theories which have attempted to give further clarity to these underlying biological or cognitive causes: the phonological deficit, the magnocellular deficit and the cerebellar deficit theory.

The phonological deficit hypothesis

Central to the development of reading skills is the requirement to set up a system of mappings between letter strings of written words (orthography) and the sound correspondences of speech sounds (phonology), such that the individual letter correspondences are grafted to the speech sounds to form graphemes. The

phonological deficit theory posits that dyslexics have a specific impairment in their ability to encode speech sounds, their storage and/or retrieval (Snowling, 2001). Critical to the account is the idea that dyslexic children have a lowered level of phonological awareness, which is the ability to perceive the individual phonemes that combine to create words. Specifically, this relates to an impairment in the acquisition of grapheme-phoneme correspondences. As the speech sounds on both a syllabic and phonemic level are imprecisely represented, stored and retrieved in dyslexic individuals, this leads to difficulties in setting up letter sound correspondences (Snowling, 2000), which in turn leads to reading and spelling difficulties. This implies that dyslexia relates to a core deficit in phonological ability and that it is this deficit that leads to problems with word retrieval, rapid naming, poor phonological mappings for new words, and verbal short-term deficits.

The problem with such a theory is that it amounts to something of a tautology. That is, individuals with dyslexia have problems with phonological tasks because they have a phonological deficit. Secondly, while it is recognised that phonological deficits exist in the vast majority of dyslexic individuals, and that this deficit in phonological ability is only said to relate to a congenital dysfunction in the left hemisphere of the perisylvian brain areas (Paulesu et al., 2001), the hypothesis has great difficulty explaining the high co-occurrence of sensory and motor disorders also found in dyslexic individuals. Given that Wolf and Bower's (1999) double-deficit hypothesis indicated that there are at least three distinct dyslexic subtypes: those with a phonological core deficit, those with a processing speed deficit and a combined type, who suffer from both impairments, it is hard to see how the phonological theory could account for dyslexic individuals who do not experience an impairment related to phoneme awareness. Thirdly, it may be argued that phonological dysfunction is really a higher order effect caused by a lower level impairment which, in the case of auditory tasks, may relate to frequency discrimination impairment (McAnally & Stein, 1996) or a deficit in temporal order judgement (Tallal, 1980). Lastly is the recognition that even with intensive phoneme awareness training, coupled with letter/sound phonological linkage training, some children (up to 25%) do not show an improvement in literacy ability (Hatcher et al., 2006).

The magnocellular deficit hypothesis

The magnocellular hypothesis states that dyslexia relates to a pan-sensory deficit across visual, auditory and kinaesthetic sensory inputs (Stein & Walsh, 1997), specifically fast incoming sensory information. Recently the theory has aligned itself more closely with the functioning of the cerebellum. Given that the cerebellum receives a massive degree of input from the magnocellular system neurons, impaired input from these systems is likely to affect the development of the cerebellum. Stein (2001) suggests that due to impaired development of the magnocellular layers in the lateral geniculate nucleus in dyslexics, they experience a reduced sensitivity to motion, unsteady binocular fixation and poor visual localisation, amongst other symptoms. The suggested symptoms of visual magnocellular impairment may manifest as a mini left neglect (Hari, Renvall, & Tanskanen, 2001), or, when reading, individuals with a magnocellular deficit may experience words blurring into one another as the visual instability causes the perception that letters are moving around the page. From an auditory perspective, magnocellular impairment manifests as an impaired sensitivity to high frequency and amplitude modulation in sounds, which, in line with the phonological deficit hypothesis, leads to impaired mappings between sensory stimulation and phonological representations. In contrast to the phonological theory of dyslexia, Stein's magnocellular hypothesis does seem to be able to account for highly variant manifestations found amongst dyslexics, be they auditory, visual, phonological, motor and even tactile impairments.

However, there is considerable evidence against a strong core magnocellular deficit in dyslexic individuals, given that there has been considerable difficulty in replicating the findings relating to visual deficits (Johannes, Kussmaul, Münte, & Mangun, 1996), as well as suggestions that the deficits are only specific to a subset of dyslexic individuals (Borsting, Ridder, Dudeck, & Kelley, 1996). Furthermore, when visual deficits are found they are inconsistent with a magnocellular account (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Skottun, 2000a, 2000b). Beyond these findings, there remain inconsistencies with the research hypothesis itself (Skottun & Parke, 1999), which are most revealingly highlighted in a recent study which demonstrated that when magnocellular deficits were present in dyslexic individuals they were negatively correlated with phonological impairment: dyslexic children with

the weakest phonological ability demonstrated normal ability on magnocellular tasks (Sperling, Lu, Manis, & Seidenberg, 2003).

The cerebellar deficit hypothesis

The cerebellar deficit hypothesis is an attempt to offer a biological grounding for the automaticity hypothesis as originally put forth by Nicolson and Fawcett (1990). The hypothesis suggests that dyslexics will show an impairment in developing any skill to an automatic level of functioning, the argument being that for dyslexic individuals all tasks require a degree of conscious compensation to maintain normal functioning. This lack of automaticity in dyslexics is suggested to be a causal consequence of a mildly dysfunctional cerebellum (Nicolson & Fawcett, 1999; Nicolson, Fawcett, & Dean, 2001), which is suggested to affect both the initial learning process and the subsequent reactivation of over-learned skills. The advocacy of the cerebellum as a possible causal core to dyslexia-related impairment stems from a large body of research which has suggested the cerebellum is heavily associated with task automatisation. Although traditionally this relationship was linked primarily to motor skill automatisation, the cerebellum is now acknowledged as playing a critical role in almost all actions, from temporarily remembering a telephone number, to imagining throwing a dart at triple 20 (Allen, Buxton, Wong, & Courchesne, 1997; Fawcett & Nicolson, 2004). Critically, the cerebellum's involvement in our actions takes place on a subconscious level, thus allowing processes such as driving a car or walking down the street while simultaneously holding a conversation. These processes can be carried out in a fast acting and efficient manner which runs in parallel with conscious activity but does not require conscious monitoring to maintain established performance levels. Significantly, the cerebellum, due to its bi-directional connections to almost every other area in the brain, has a seemingly unique vantage point, in that a point impairment or series of impairments in its vast network of connections could offer a parsimonious explanation as to why dyslexic individuals so often present with not just deficits in phonology, as suggested by the phonological deficit theory, but also present with deficits in balance, motor skill acquisition, temporal discrimination tasks and so on. The cerebellar hypothesis thus offers a connective link between these seemingly separate but co-occurring impairments in ability found in dyslexic individuals, but also a possible explanation as to why

literacy impairments in the form of laboured reading or poor spelling remain a lifelong impairment even after years of intensive phonological training.

Evidence of impaired cerebellar functioning has been supported by the poor performance of dyslexic children on a battery of clinical tests for cerebellar functioning (Fawcett, Nicolson, & Dean, 1996), as well as impaired automatisation of balance ability when required to dual task (Nicolson & Fawcett, 1990), lowered cerebellar activation (Nicolson et al., 1999; Rae et al., 1998), as well as anatomical differences in the cerebellum of dyslexics (Leonard et al., 2001). In the study conducted by Rae and colleagues, ~80% of dyslexics demonstrated abnormal activation patterns in the cerebellum (Nicolson et al., 2001). Counter-evidence for the cerebellar deficit hypothesis comes from studies that have failed to find any motor impairments in dyslexics or that motor impairment is only present in dyslexic children with co-occurring attentional problems (Wimmer, Mayringer, & Raberger, 1999) or have only found them in a sub-sample of dyslexics (Ramus et al., 2003).

It is hardly surprising that motor deficits were not present in the Ramus et al. study, given that the dyslexic adults in the sample were particularly high functioning, e.g. they all had literacy skills in the average to high average range. The major criticism of the theory, though, concerns the cerebellum's bidirectional connections to almost everywhere in the brain. As such it would hardly be surprising if a particular brain area, other than the cerebellum, were dysfunctional, for it in turn to affect the development and functioning of the cerebellum, creating a magnocellular deficit for example (Stein, 2001; Zeffiro & Eden, 2001). From this perspective it is important to keep in mind the chicken and the egg – that is, while there is considerable evidence that suggests a co-occurrence between cerebellar dysfunction and literacy impairment, it is still plausible that the cerebellum stands unfairly accused of its causal role in developmental dyslexia (Zeffiro & Eden, 2001). A second related criticism suggests that even if the hypothesis is 100% correct in labelling the cerebellum as the core deficit in dyslexia, this can hardly be heralded as a major breakthrough in pinpointing the seat of the disorder, given that the cerebellum contains half the brain's neurons.

If the cerebellar hypothesis is presented as a starting point, one that will hopefully encourage debate and new research, which seems to be the case (Fawcett & Nicolson, 2004), it does offer the most parsimonious explanation as to why there are such varying degrees of additional co-occurring impairments with phonological and

literacy impairment. Literacy development and fluent reading may require more cross-communication and more smoothly integrated relations between brain areas than any other task (Stein & Walsh, 1997). It is therefore hardly surprising that an impairment in the relay station serious enough to lead to an impairment in temporal processing or motor impairment would almost certainly also lead to literacy-related impairment.

The present thesis advocates a modified version of the cerebellar theory, the critical point being that dyslexic individuals will not in fact uniformly demonstrate a generalised impairment in automatising all tasks. Instead, they should only experience automatisation difficulties on those processes which are reliant on relaying information through impaired areas of the cerebellum. As literacy-related skills require more cross communication between individual brain areas, an impairment that would lead to a deficit in automatising literacy skills may not always lead to automatisation difficulties on the majority of tasks.

Suggested avenues of research development

One of the most often cited and well replicated findings in dyslexic individuals is impaired verbal working memory (WM) ability (Ackerman & Dykman, 1993; de Jong, 1998; Pennington, Cardoso-Martins, Green, & Lefly, 2001; A. M. Wilson & Lesaux, 2001). Indeed, Ellis and Large's (1987) longitudinal research project with intelligence-matched reading-impaired and unimpaired children (5-7 years old) found that the WISC subtest 'digit span' (a measure of verbal working memory) was one of 3 out of 44 variables which could reliably discriminate between the 2 groups. Unsurprisingly, in line with the general dearth of research that has focused on visual spatial working memory (VSWM) (Logie, 1995), there have been disproportionately few research projects addressing VSWM functioning in dyslexic individuals. The research studies that have addressed the issue have suggested a relatively mixed bag of results concerning impairments in VSWM in dyslexic children (Helland & Asbjornsen, 2003; Kibby, Marks, Morgan, & Long, 2004; McDougall, Hulme, Ellis, & Monk, 1994; Reiter, Tucha, & Lange, 2005; Smith-Spark, Fisk, Fawcett, & Nicolson, 2003; Swanson, 1984). Thus, there is a critical need to take a more rigorous and fine-grained approach to research involving VSWM, as it is only then that one can ascertain whether the inconsistencies in the research can indeed be related to differences in the methodologies used or samples studied. In

dyslexia research there is an often cited though seldom quantified claim that dyslexic individuals experience an advantage in visual spatial tasks (Geschwind & Galaburda, 1987; Swanson, 1984; Winner & Casey, 1992). If dyslexic children do in fact demonstrate a VSWM advantage, it would be of enormous diagnostic benefit, as dyslexic children could then be differentiated from literacy-unimpaired children both on a deficit (verbal WM) and an advantage (VSWM) standpoint, possibly leading to earlier and more accurate screening.

Fawcett (2004), in her key-note address to the 6th BDA conference, suggested there was a critical need for more research in the areas of attention and learning (Fawcett & Nicolson, 2004). Interestingly, there is also existing research which has suggested that the cerebellum may play an important role in these cognitive activities (Justus & Ivry, 2001). Given that VSWM ability also relies in part on the adequate functioning of these cognitive abilities, it was decided to assess functioning in these areas from a visual standpoint, in the hope that even if a possible bipolar model of screening fails to emerge, our understanding of dyslexia may be increased.

The next three sections give a brief overview of relevant research within the fields of working memory, visuospatial attention and implicit learning. A more in-depth overview concerning these topics and the relevant research within the field will be given in the introductions to the individual experimental chapters.

Implicit Learning

It is difficult to give a definitive account of what exactly can or cannot be classified as implicit learning and/or memory, but nearly all accounts agree that implicit learning relates to processes by which the internalisation of environmental regularity is derived from sensory experiences, and that this learning occurs at a level of which we are largely unaware. Implicit memory relates to information that has been acquired from previous experiences. Even though this memory shapes one's performance or ability in a given task, it is often unavailable to conscious recall (Steffler, 2001). In the words of Cleeremans (1993), "*Implicit learning is thought of as an unintentional process by which a system acquires information about the structure of the environment*" (P.14). Importantly, this suggests that one's performance on an implicitly learned task does not depend on an awareness of previous learning but rather can be highlighted by a lack of explicit knowledge which nonetheless is demonstrated by an increased rapidity, effectiveness and/or efficiency

in carrying out the task (Buchner & Wippich, 1998). This contrasts with declarative memory in which representational encoding would be highly affected by attentional and processing factors at the encoding or retrieval stage (Baddeley, 1994).

Muddying the waters a little further is the relationship between implicit learning and implicit knowledge. Beyond being acknowledged as a product of implicit learning, implicit knowledge lacks a clear definition in the research literature (Steffler, 2001). It is suggested that knowledge is implicit if it is in some way inaccessible. Generally this is taken as meaning that while the knowledge leads to more efficient or quickened reactions to environmental stimulation it is extremely difficult to verbalise. From a more extreme viewpoint, implicit knowledge can be taken as a case of simply knowing, but one which is fundamentally non-accessible to description (Perruchet & Vinter, 1998).

If one considers an average two year old, one is struck not only by the speed by which they acquire language but also the accuracy of their grammatical and semantic usage. Interestingly, the fluency with which this task is achieved does not simply relate to diligent parentally driven instruction, but rather for the most part may be accounted for by an implicitly derived understanding on the part of the child of highly abstract rules which govern the language system. The child arrives at this competence through repeated exposures to the linguistic environment (Buchner & Wippich, 1998; Perruchet & Vinter, 1998). In a very real sense this can lead to children knowing how to use a word correctly before they can explicitly define it. This is a similar phenomenon to adults' use of words like 'ironic', which they may be able to use in the correct context while being largely unable to actually define. This implicit structuring of incoming sensory experiences has been demonstrated in novel research paradigms which have asked 7 and 8 year old children to recall sequences of non-words. The findings indicated that English-speaking children recalled non-word sequences better if adjacent phoneme-pairs had a high probability of occurrence in the English language than those with a lower probability of occurrence (Gathercole, Frankish, Pickering, & Peaker, 1999). This suggests that even with overt assessments of memory capacity for abstract items, implicitly derived structure leads to increases in storage and/or retrieval capacity. Another interesting study that further supports the idea that learning effects can occur without any conscious reference to the encoding event was conducted with deeply amnesic patients who were asked to rate the pleasantness of Korean melodies. The research demonstrated that those to which

participants had a previous exposure were rated as more pleasant (Wilson, Green, Teasdale & Beckers, 1996).

Gombert (2003) has suggested that implicitly derived learning plays a central role in the acquisition of not only language but literacy skills as well. She distinguished a number of key stages in which there is a boosting effect of implicitly derived knowledge on literacy ability. At the earliest stage, she points out that, before any direct exposure to text, children have already acquired a degree of implicit knowledge related to their particular linguistic system. This may relate to the types of sound combinations that exist in their linguistic environment, as well as a capacity to categorise events and objects which they encounter in their environment. Secondly, with the child's exposure to text, the language regularities that the child has already internalised become associated with the written word and may move from implicit to explicit understanding, but this understanding also generalises beyond direct pairing of word to visual pattern (orthography) associations. Indeed, research has shown that children as early as six years of age were able to choose between two possible pseudo-words that contained either double consonants or double vowels, and were able to choose those words that did contain language-existent combinations with an 85% accuracy over combinations that do not exist in their language system (Pacton, Perruchet, Fayol, & Cleeremans, 2001). Thus, before children can be expected to be able carry out grapheme phoneme correspondences (GPC), they have acquired an implicit visual knowledge of words that can exist in a language system as opposed to those that do not. Lastly, Gombert points out that once a child is receiving explicit instruction concerning GPC, the child's level of implicit understanding of phoneme segmentation (the ability to perceive speech sounds as a collection of discrete phonemes within words) will dramatically boost their literacy acquisition.

While formal instruction may lead to children acquiring an explicit understanding of particular letter/sound combinations within their linguistic system[1], it has to be acknowledged that beyond the initial stages of literacy development a comprehensive, explicit understanding of linguistic rules would be overwhelming. Indeed, one research study indicated that for a corpus of just 17,000 words an individual would require over 2000 GPC rules to be able to spell all these words correctly (Hanna, Hanna, Hodges, and Rudorf, 1966, as cited in Steffler (2001)).

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[1] For example, 'k' is silent if followed by and 'n' as in 'knave', 'knob' and 'knee.'

While literacy-unimpaired individuals are able to read and spell with a very low degree of error, it is highly unlikely, given the vast array of GPC rules that exist, that if prompted one could explicitly state the rule why a certain word has been spelt or pronounced in that exact fashion. George Bernard Shaw is attributed with having made exactly such a distinction between potential versus actual spelling experiences in the English language, stating that the word 'fish' could just as easily have been spelt 'ghoti'. That is as 'gh' is pronounced as an 'f' in 'laugh', the 'o' as an 'i' which occurs in 'women', and the 'ti' as 'sh' as in the word 'nation'.

The reason we are unlikely to pronounce the word 'ghoti' as 'fish' is likely to relate to an implicitly derived sense of regularity. That is, when exposed to a word, one pronunciation simply feels better than any another, and this sense of better or pleasantness relates to probabilistic exposure (Steffler, 2001). From this account one is reminded of the gestalt principle of figural goodness, which relates to a similarly implicitly-derived sense of structure or regularity in the visual environment. Thus our sense of familiarity or increased goodness of one form over another possibly relates to nothing more than the degree of previous exposure – much like Wilson et al.'s (1996) amnesic patients' increased pleasantness ratings for previously-heard melodies.

One means of operationally measuring implicit learning in individuals involves a serial reaction time task in which stimuli are presented in either random or pseudo-random sequences to which participants are repeatedly exposed. Implicit learning and implicitly derived knowledge of the task is inferred from the reduction in response times (RT) for sequences that follow the pseudo-random pattern compared with those that do not (Mayr, 1996). Critically, while participants perform better on the structured sequences they are unable to explicitly state the actual order of presentation. There has been a number of studies that have assessed dyslexic individuals' functioning on serial reaction time tasks, with mixed results. Some studies have suggested that dyslexic individuals are unimpaired (Kelly, Griffiths, & Frith, 2002), although there may have been a sampling bias in this study as only dyslexics in third-level education were included. In contrast, a second study that sampled dyslexic children's functioning did suggest significant impairments in implicit learning (Vicari, Marotta, Menghini, Molinari, & Petrosini, 2003). Similarly, in tasks that have used a classical conditioning paradigm, a deficit in implicit learning has been demonstrated by the lack of tuning in the conditioned response to the

unconditioned stimulus in dyslexic adults, i.e. an eye blink response immediately before the onset of a corneal airpuff, in response to the conditioned stimulus (Nicolson, Daum, Schugens, Fawcett, & Schulz, 2002).

Beyond serial reaction time tasks, a recent study also assessed dyslexic college students' ability on category-based learning and found that they were slower to pick up the implicit rule and maintained a lower overall accuracy on the implicit task. However, they performed as well as literacy-unimpaired cohorts on a explicit derived categorical sorting task (Sperling, Lu, & Manis, 2004). Additionally, the study found that performance on the implicit learning task was correlated with three separate measures of word reading and phonological decoding ability, suggesting, in line with Gombert's (2003) thesis, that the ability to implicitly derive regularity from one's environment is highly related to the acquisition of literacy skills.

Implicit learning, or the use of implicitly derived understanding, may be of particular relevance to dyslexia-related research, given the suggested role of the cerebellum in implicit learning (Justus & Ivry, 2001) and work by Nicolson and Fawcett that has demonstrated abnormalities in automatising balance, motor co-ordination and time estimation (Nicolson & Fawcett, 1990, 1999), which are all likely to depend on implicitly-derived understanding given that these operations rely on subconscious involuntary mechanisms.

Working Memory

Our daily interactions with the world are littered with innumerable situations in which we are temporally required to maintain and or manipulate information which is held in conscious awareness. If one considers the process of baking a cake, from reading a recipe and holding this information long enough so that we can add ingredients in the correct order and quantity, the mental arithmetic involved in converting quantities from pounds into kilograms or vice versa, even the act of holding a spatial representation of our baked goods, such that we can evenly slice it among an odd number of people, all require a capacity to both flexibly store and manipulate information. The process by which we achieve this flexible temporary storage is known as working memory. Baddeley and Logie (1999) defined working memory as comprising "*those functional components of cognition that allow humans to comprehend and mentally represent their immediate environment, to retain information about their immediate past experience, to support the acquisition of new*

knowledge, to solve problems, and to formulate, relate and act on current goals" (P28-29).

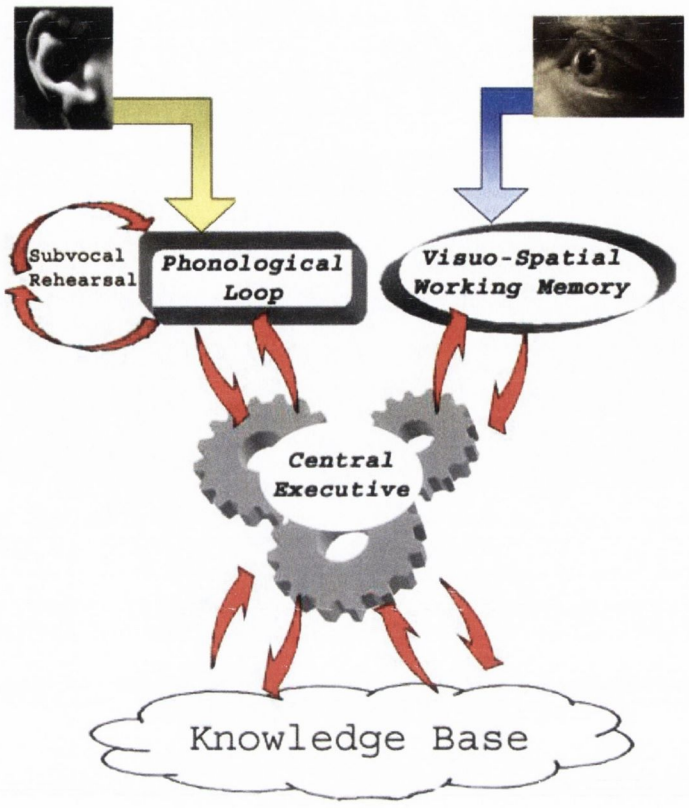

Figure I.1 Baddeley's multi-component model of WM. Sensory stimuli first automatically enter one or other of the two slave subsystems, at which point they can possibly be rehearsed, recoded, processed, manipulated, referenced to LTM representations or simply left to decay.

Baddeley's (1986, 1990) multi-component model of working memory consists of a tripartite system comprising a general central processing mechanism (the central executive or CE), and 2 dedicated subsidiary systems which offer specialised, domain-specific limited storage and rehearsal facilities (see Figure I.1). These are: the phonological loop (PL), which deals with sound or verbal information, and the visuospatial sketchpad (VSSP) subsystem, which deals with visual and spatial stimuli. Both subsystems are hypothesised to be further fractionated between a passive storage mechanism (the phonological store and visual cache) and an active rehearsal system (subvocal rehearsal and the inner scribe) (Logie, 1995, 2003).

The CE is primarily operationalised as serving a regulatory function in attention and control of action, as well as logical reasoning and problem solving. The secondary operations of the CE take the form of the episodic buffer, according to the updated 4-component model (Baddeley, 2000) relate to the co-ordination of the slave

systems and the active integration, manipulation and/or processing of the subsystems contents (Baddeley, 1996). Intrinsic to the model is the idea that short-term memory (STM) is functionally distinct from (though related to) LTM and that the intermediary CE is responsible for both retrieving existing and encoding new representations in LTM.

If sensory experiences are verbal or auditory they gain automatic access to the phonological store. The storage process is very sensitive to temporal decay. If information requires extended storage beyond a couple of seconds a subvocal rehearsal mechanism is initiated in order to avoid informational loss, refreshing the contents of the decaying representations in the phonological store (Baddeley, 1986). The same process of sub-vocal rehearsal can be used to recode non-verbal sensory stimuli (text or objects in the environment) into phonological representations and thereby gain access to the phonological store.

The VSSP serves as a storage facility for visual and spatial information, be it the visual appearance of objects, pathways through space and time, the locations of sounds or the spatial properties which define objects in the environment (Logie, 1995). Rather than all visual and spatial representations entering a single storage facility, at which point the representations can then be allowed to decay or are maintained through a secondary rehearsal mechanism, existing research has indicated that visual and spatial information are stored separately in domain-specific subsystems (Logie & Pearson, 1997). The visual aspects of our experiential world are stored in the 'visual cache', which is argued to be a largely passive mechanism, much like the phonological store, with visually-related sensory stimuli gaining automatic access to the storage facilities while spatial or path-related memory is handled through the 'inner scribe'.

The evidence in support of a separation between the varieties of sensory experience and storage mechanism originally arose from the observation of a selective impairment on visual discrimination tasks when participants were required to look at but ignore task-irrelevant pictures during a retention period, but no impairment was found when participants made task-irrelevant arm movements (Logie, Marchetti, Logie, & Denis, 1991). However, when participants were required

to remember spatial sequences which were tapped out on a Corsi blocks[2] type task, the irrelevant pictures had no effect on capacity for spatial sequences but task-irrelevant arm movements did. Indeed further research has subsequently indicated that there is a developmental fractionation in the speed at which these two processes develop, with the ability to store visual patterns demonstrating a larger and quicker capacity increase with age than memory for spatial patterns (Logie & Pearson, 1997; Pickering, Gathercole, Hall, & Lloyd, 2001).

In contrast to Baddeley's model above, where sensory experience first enters either of the two slave systems, from which point it can then be recoded into another format or referenced to LTM, the current thesis takes Logie's conception of WM, whereby any sensory experience is first pre-filtered through existing LTM representations. This is simply a recognition that when our sensory experiences enter either any of the visual, spatial or phonological storage mechanisms they are pre-packaged in terms of our existing knowledge base. Verbal information that enters the phonological store does not require additional processing to be recognised as words but enters storage already packaged as words (see Figure I.2). This is not to say that one will always get a completely accurate representation through our sensory experiences. If asked to specify the contents of a bowl which is put in front of me, I may need to carry out additional processing relating to the sensory experience to decide if the bowl contains flour or icing sugar. My sensory experience will come pre-packaged as a bowl which contains white powder. Again it is recognised that the nature of the packaging relates to my particular knowledge base. If one was to ask a baker, the specificity of his or her knowledge base might be such that the sensory representation that enters working memory is experienced as a bowl of icing sugar rather than a bowl of white powder. A second critical aspect of Logie's conception of working memory is that all three aspects of working memory are in principle activated and act in concert with one another when we are interacting with the world. If one were to consider the bowl of sugar analogy again, it should be realised that if one were placed in the discrimination task, besides the relative visual appearance and

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[2] The Corsi Blocks task in its original format consists of nine identical square blocks arrayed in a semi-structured pattern on a wooden board. The task involves the experimenter tapping out sequences of varying span lengths on the individual blocks which the participant is required to copy in the order they were presented.

spatial properties one experiences when required to make the judgement, one would also have activated the verbal labels for the sensory stimulation, thus engaging visuospatial and verbal representations. Additionally, we may have carried out a quick mental calculation as to the weight of the bowl or possibly retrieved a recipe from LTM for which we could use that general amount of sugar, all of which would have engaged CE resources.

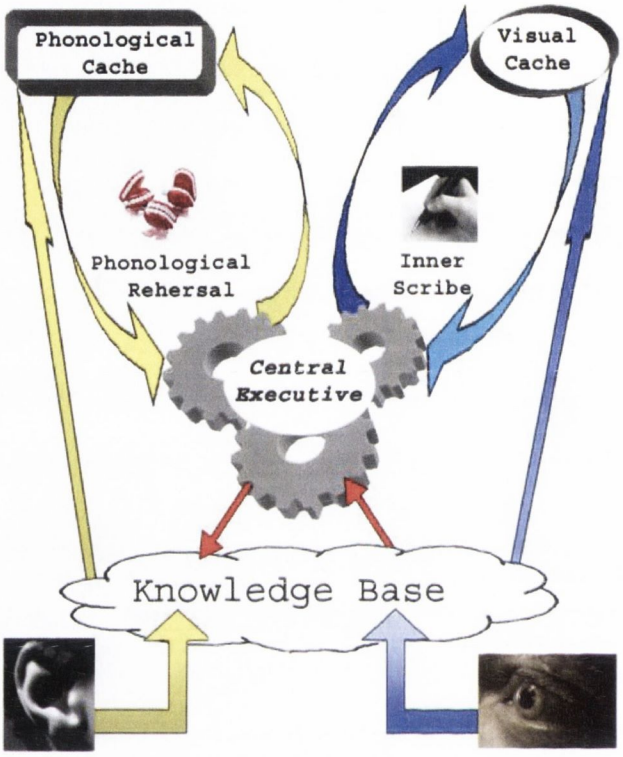

Figure I.2 Graphical depiction of Logie's multi-component model of WM. The representations in WM are derived from pre-filtering sensory experiences through existing representation in LTM.

Logie argues, in line with Paivio's dual coding model of imagery, that information is better retained when it is stored in more than one code simultaneously (Paivio & Clark, 1986). In this respect, most everyday tasks involving representations in WM have considerable redundancy, with all three components storing information and activating representations in LTM, and with the CE allocating additional processing resources as necessitated by task demands. The highly flexible nature of WM leads to a very individuated system, where the nature of the procedures initiated can differ dramatically from individual to individual, due to variation in one's knowledge base, heuristic use and strategic procedures.

The vast majority of research which has addressed WM and dyslexia has focused on the retention of verbal material and many studies have found deficits in

dyslexic children's verbal working memory performance (Ackerman & Dykman, 1993; McDougall & Donohoe, 2002; Pennington et al., 2001; Plaza, Cohen, & Chevrie-Muller, 2002; Roodenrys & Stokes, 2001; A. M. Wilson & Lesaux, 2001). The specificity of a representational code relating to the accuracy of LTM representations has particular relevance to dyslexia research. Given that, at the very least in the phonological domain, dyslexic individuals are suggested to have representations of degraded specificity (Amitay et al., 2002; Tallal, 1980) the deficits experienced by dyslexic individuals in WM may result from these degraded representations rather than a verbal WM deficit per se. However, the deficit found in verbal WM tasks may equally relate to speed of articulation, given that the phonological loop is believed to have a capacity which is constrained by the number of words one can articulate in 1.5 seconds (Baddeley, 1986, 1994) and that dyslexic individuals have a slower articulation rate (Fawcett & Nicolson, 1995). Wolf and Bowers' (1999) research highlighted that lowered speed of articulation in dyslexic children does not necessarily relate to phonological ability. This would suggest there may not be a simple solution to why dyslexic individuals experience verbal WM deficits.

The little research that has addressed dyslexic individuals' functioning on VSWM tasks has found a rather mixed bag of results. Studies indicate normal functioning in dyslexic children on both visual and spatial WM tasks (Jeffries & Everatt, 2004; Kibby et al., 2004); impairments on visual WM tasks, but without an assessment of spatial ability (Reiter et al., 2005); visual WM impairments but impairments in spatial ability only being found in dyslexic children with a mathematic impairment (Helland & Asbjornsen, 2003); and impaired spatial WM in dyslexic adults on tasks that are suggested to require scaffolding from CE resources (Smith-Spark et al., 2003). Due to the high variability in task methodologies across research studies, it is currently impossible to establish if dyslexic children are experiencing a deficit in ability on either spatial or visual WM tasks. One of the primary aims of the current research thesis is to flesh out our understanding of dyslexic children's capacity on both visual and spatial WM tasks. Existing research, particularly in the visual domain, has relied on highly abstract stimuli which largely lack any real world applicability. It is hoped that by using measures which have an increased ecological validity one can not only accurately assess WM capacity, but

that the assessment may actually have applicability to educational and learning environments.

Attention

"*Human learning and behaviour are dependent upon the ability to pay attention to critical features in the environment; retain and retrieve information; and select, deploy, monitor, and control cognitive strategies to learn, remember, and think. Without these abilities, we could not plan, solve problems, or use language. Likewise, being absent of the capacity to attend, remember, and organise and structure data within our world, we would be incapable of modifying our behaviour when confronted with new situations*" (Lyon, 1996, p. 3).

As the quote above suggests, both learning and memory are intricately linked with one's attentional capacity. But what is understood by the term attention? Possibly the most frequent introductory statement to research involving attention alludes to the fact that while anyone may have an intuitive sense of what it means, attention nonetheless remains rather difficult to objectively define or assess. Attention, like WM, is central to our understanding of cognition in general, and while there is no definitive model of the processes and components involved, there is considerable overlap between individual models in terms of how attention is operationalised.

Earlier models of attention focused on a unitary capacity-limitation account, which suggested that due to the finite resources available, once resources were channelled towards one task, a bottleneck was created whereby the unattended stimuli were never subject to cognitive processing (Broadbent, 1958). However, experimental situations like the "cocktail party effect", which demonstrated our capacity to engage in one conversation, and yet simultaneously become aware when one's name was used in an unattended secondary conversation, suggested that Broadbent's theory was fundamentally incomplete. Subsequently, the simplified unitary models have been updated with multi-component frameworks of attentional functioning (Corbetta & Shulman, 2002; Mirsky, Lyon, & Krasnegor, 1996; Posner & Petersen, 1990), which have been far more successful operationally capture attentional functioning.

The suggested differences amongst individual models, however, mostly relate to the relative importance and functionality ascribed to certain anatomical areas over

others, rather than to the componential breakdown of attention per se. Thus attention can be quite comprehensively fractionated into four sub-processes: 1) Attentional orientation, which relates to the ability to direct attention towards particular stimuli; 2) Selective (or focused) attention, while closely related to attentional orientation, encompasses the idea that by selectively attending to one stimulus or location one is purposely excluding others; 3) Divided attention, which is the ability to divide attentional resources across multiple stimulus items; and 4) Sustained attention, which is simply the ability to maintain attention processing for prolonged periods of time (Coull, 1998).

Existing research addressing dyslexic individuals' ability in attentional orientation has suggested that they may experience a prolonged attentional dwell time between the shift from one stimulus to the next (Hari & Renvall, 2001; Hari, Valta, & Uutela, 1999; Visser, Boden, & Giaschi, 2004). For example, in a target detection task, dyslexic children demonstrated significantly slowed reaction times when invalid cues directed attention to the left visual field compared with developmentally normal children (Facoetti, Turatto, Lorusso, & Mascetti, 2001). Dyslexic individuals may also experience a mini-left neglect (Hari et al., 2001). Left mini neglect in adult dyslexics relates to a temporal advantage for stimuli presented to the right visual field over stimuli presented to the left. When shown left and right synchronised stimuli, dyslexics perceive the right stimuli as flashing up first rather than simultaneously. For the left stimuli to be seen first, presentations need to precede the onset of the right stimulus by some 16ms.

Further research has also indicated that dyslexic individuals have a reduced ability to focus attention (Facoetti, Paganoni, & Lorusso, 2000; Facoetti, Paganoni, Turatto et al., 2000). The results suggested that in a target detection task, dyslexic children, unlike control children, did not experience a graded reaction time advantage for stimuli presented at the centre of the fovea relative to more distally presented stimuli. Instead the results indicated that dyslexic children relied on a more distributed spatial focus, possibly related to a visual inhibitory deficit. While the existing research indicates that impaired attentional focus in dyslexic individuals affects the speed of target detection, research is needed to ascertain whether impaired spatial focus may lead to secondary deficits in other cognitive functions.

Possible evidence of a specific deficit in dyslexics related to dividing attention between multiple tasks also exists in the research literature (Nicolson & Fawcett,

1990). Nicolson and Fawcett's seminal work indicated that dyslexic children consistently experience relatively impaired functioning when they are required to dual task. For example, when dyslexic children were asked to simultaneously count backwards and balance with their eyes closed, they experience an impairment in their ability to remain balanced. Counting backwards does not impair balancing ability in literacy-unimpaired children. This suggests that dyslexic children may be experiencing difficulties in adequately allocating attentional resources when dual tasking.

The research related to sustained attention has presented a mixed picture concerning dyslexic individuals' ability to maintain vigilance. Research involving dyslexic adults suggests they experience more breaks in attention than their literacy-unimpaired cohorts (Smith-Spark et al., 2004). Research involving dyslexic teenagers similarly suggests impaired performance on measures of sustained attention but this appears to relate to automatisation deficits in carrying out the task (Moores & Andrade, 2000). In contrast, research involving spatial focus suggests that dyslexic children are unable to sustain spatial focus as long as literacy-unimpaired children (Facoetti, Paganoni, Turatto et al., 2000). Further research is therefore needed to assess if dyslexic children, like their adult literacy-impaired counterparts, do suffer from a deficit in sustaining attention, or if these apparent deficits should be more accurately described as an impairment in operationalising task requirements (Moores & Andrade, 2000).

The success of an attentional operation also relates to arousal level, which can be defined operationally in terms of one's state of physiological reactivity. Arousal can be conceptualised both as a bottom-up physiological arousal system, and a top-down cognitive arousal system, which can actively modulate the former (Broadbent, 1971). Take the example where one is trying to re-read an article but, due to a lack of sleep the night before, one's physiological levels are relatively reduced, leading to a difficulty in sustaining attention. In such a situation one's cognitive system can attempt to increase arousal levels, say by reminding oneself that there is only 32 days before one has to hand in one's PhD thesis, which, at least temporarily, should manage to increase arousal levels so that one's attentional vigil may be successful.

The above example also highlights the interwoven nature of attentional processes. Beyond the requirement to sustain attention, one has to direct attention to the page, selectively focus and shift attention between individual words and sentences

to derive passage meaning, all the while dividing attention between the information imparted in the article and the informational dialogue one is in the process of creating for the purpose of thesis writing.

Computerised Assessment

The current thesis principally uses computer-based assessment (CBA) to measure children's functioning across the VSWM and attentional task measures. CBA has a number of advantages over table-top or pen-and-paper based assessments using human assessors. Firstly, all participants experience an identical procedural instruction and test environment. Secondly, CBA also allows for a greater degree of test precision and timing, as well as allowing for a far more detailed record of individual performance to be taken (Singleton, 2001). Most importantly, existing research has suggested that it may allow for a more accurate measure of ability in individuals with special educational needs. Since such individuals may experience a negative response to conventional assessment with human assessors, the research has suggested that they feel less threatened by, and prefer to be assessed using, CBA (Singleton, 1997). Given that much of dyslexia research has been carried out in research laboratory settings, the use of computerised assessment also allows for assessments to be carried out within schools, which should increase the ecological validity of the overall assessment (Smith-Spark et al., 2004).

Outline of thesis

This thesis aims to examine dyslexic children's functioning across a range of visuospatial WM as well as visual attentional and learning measures. The thesis is an attempt to gain further insights into dyslexic children's skill levels on tasks which are independent of literacy or phonological ability in the hope that these insights in turn may increase our understanding of dyslexia, its possible remediation and the causal models which attempt to quantify it. Chapter 2, Experiment 1.1, examines VSWM ability on a modified Corsi blocks task. In Experiment 1.2, dyslexic children's functioning was assessed when the spatial displays were presented in a parallel (row or column) format rather than a spatial matrix. This is a simple measure of VSWM that also examines the possibility of left mini neglect as well as children's ability to selectively attend to one stimulus source to the exclusion of others. In Experiment 1.3, the same experimental manipulations as Experiment 1.2 are used except that the

children are now required to backwards-recall the presented sequences. In chapter 3, Experiment 2 redresses the assumption made in Experiment 1.2 that spatial tasks presented in a matrix format are easier to recall than those presented in parallel displays. The presentations involve primarily spatial representations as individual stimulus items were visually indistinct. In chapter 4, Experiment 3.1, we assess children's WM capacity for sequential presented visual stimuli. The task involves recalling sequences of 3 stimulus types, which differ from one another in terms of LTM representations. These are presented in a serial fashion so that sequence items do not differ in terms of spatial location. Experiments 3.2 and 3.3 use the same three categories of visual representation, but use parallel and matrix display formats at the presentation stage which are rendered spatially redundant at the recall stage. Chapter 5, Experiment 4.1 explores recall capacity between the three stimulus categories used in Experiment 3.1-.3, but allowing both spatial and visual encoding of sequence representations. In Experiment 4.1, sequences are presented on a parallel display format, while in Experiment 4.2 sequences are presented using a matrix presentation display. In chapter 6, Experiment 5 assesses implicit learning in the form of increased recall capacity on visually indistinct VSWM tasks. In chapter 7, Experiments 6.1-2 examine children's ability to sustain attention on a visual serial response task, using a modified test procedure such that possible differences in attentional dwell time between developmental groups will have a minimal effect on the sustained attention assessment.

In chapter 8, the general discussion, findings from the individual experiments will be considered together, highlighting their particular relevance to existing models of dyslexia. While it will be argued that the findings are most consistent with the modified version of Nicolson and Fawcett's (2001) cerebellar deficit hypothesis, a new explanatory framework will also be tentatively offered. Recommendations for future studies addressing VSWM and attention will be made, as well as possible avenues for dyslexia research in the future.

Chapter 2- Experiments 1.1-1.3

Visuospatial working memory and the role of interference effects in dyslexic children

Introduction

Across the existing models of working memory (WM), the consensus is that WM acts as a workspace where representations from long-term memory (LTM) can be processed, stored and manipulated (1998; Baddeley et al., 1999; Conway & Engle, 1994; Cowan, 1993; Logie, 1995; Richardson, Engle, Hasher, & Logie, 1996). The dominant model of WM advocates that it is best conceived of as a conglomerate of specialised structures (Baddeley, 1986; Baddeley et al., 1999; Hitch & Halliday, 1983; Logie, 1995; Logie et al., 1991) including two slave systems; firstly, the phonological store, which processes/stores language/auditory material, and secondly, the visuo-spatial scratchpad, which stores/processes visual and spatial information. Both components have an associated rehearsal mechanism, and a modality-free central executive, which allocates/integrates information between the slave systems as well as retrieving associated information from LTM (Baddeley, 1986).

Impaired working memory capacity has been suggested as one of the core deficits underlying developmental dyslexia (McLoughlin, Fitzgibbon, & Young, 1994), but while there is a host of research that has addressed the connection between dyslexia and deficits in verbal short-term/working memory (Ackerman & Dykman, 1993; Pennington et al., 2001; Roodenrys & Stokes, 2001; A. M. Wilson & Lesaux, 2001), very little research has addressed dyslexic individuals' functioning on visual spatial working memory (VSWM) tasks. The current chapter outlines 3 foundation experiments which sought to assess dyslexic children's functioning across a number of VSWM tasks.

Experiment 1.1- Introduction

The general dearth of research investigating VSWM ability and dyslexia is likely due to Vellutino's (1979) vehement arguments against dyslexic individuals experiencing any impairment on visuospatial tasks, which he based on a number of experiments carried out in his research laboratory. In opposition to a deficit model,

Swanson's (1984) research found that reading disabled children actually demonstrated a visual advantage for unnameable novel visual stimuli relative to control children, while other studies have indicated a disproportionate number of dyslexics in spatially dominant professions (Winner & Casey, 1992). In line with these findings, Geschwind and Galaburda (1987) proposed a pathology of superiority in explaining the higher ratio of dyslexic individuals in spatially dominant professions such as engineering, art and architecture, suggesting a possible compensatory talent associated with dyslexia within the visual spatial domain. The authors went on to further clarify this position in terms of a testosterone hypothesis; arguing that atypical exposure or sensitivity to testosterone in utero, which may cause left-hemisphere language-related impaired growth/dysfunction, may also result in increased growth in the parallel regions in the right hemispheres. In contrast to this position of compensatory talent, research carried out by Winner et al. (2001) across a wide range of visuospatial measures, found dyslexic performance to be in deficit relative to age-matched controls. However, it must be noted that a high proportion of the visuospatial tasks used in the study required a large degree of verbal instruction and, as the authors themselves pointed out, they may have lacked ecological validity as measures of visuospatial ability. Given the split between models of visuospatial advantage versus deficit models in relation to dyslexia, it is unknown whether dyslexic children will demonstrate an advantage or dysfunction in VSWM tasks relative to age-matched, developmentally normal children.

Method

Participants

Forty seven dyslexic (D) participants were recruited from dyslexic schools and reading units in the greater Dublin region. All participants had been formally diagnosed with dyslexia, and had no documented co-morbid disorders such as ADHD or dyspraxia. The gender breakdown was 29 males and 18 females, aged between 8-11 years with a mean age of 9.26 (SD=.68).

Forty one developmentally normal (DN) children were recruited from schools in the greater Dublin region. Where possible, control children were recruited from the same schools as the dyslexia reading units. Where this was not possible, schools within the same catchment area were used as a means of matching for socio-

economic status. Potential participant children were allocated to the control group if their teacher assessed them as having no learning or behavioural problems. Kenny and Chekaluk (1993) found that teachers could accurately allocate children to an "at risk" category with 91% accuracy for children below the age of 8. They also found that as age and literacy increased, so too did the accuracy of allocation. DN children had a similar gender breakdown to D children: 25 males and 16 females, with same age range 8-11 and a mean age of 9.05 (SD=.74).

Written parental consent was obtained for all children in accordance with the ethical regulations of the School of Psychology, Trinity College Dublin.

Apparatus

VSWM was assessed using a modified version of the Corsi Blocks test (Corsi, 1973), which was part of a larger test battery. Testing involved the copying of spatial sequences on a two-dimensional matrix. The matrix consisted of nine squares placed in a semi-structured layout. Spatial sequences were demonstrated with the experimenter touching squares at a rate of 1 per second. Children were then required to copy the order in which the squares were touched. Figure 1.1 shows the spatial matrix with a possible 3-item sequence. All children were given 2 practice trials to ensure procedural understanding before testing proper started with a 2-item sequence of difficulty. There were 2 test trials for each sequence level, with the maximum possible sequence containing 6 items, as Smyth and Scholey (1992) suggested that visuospatial span in adults consisted of 5 or 6 items. If a child was able to successfully copy at least 1 out of the 2 trials at each sequence level, testing progressed with an extra item to be remembered. Testing ended after 2 consecutive failures in any sequence level or if a child successfully completed the 6-item trials. Every child was assessed on the same set of sequences and spatial positioning was allocated through random assignment without replacement. For a complete view of the item sequences and test instructions see appendix 1. Possible differences in span capacity between the developmental groups was assessed with one-way ANOVA.

Results

There were no significant differences between groups in Age $F(1,86)=1.875$ $p > .05$ or Gender $\chi^2=(1, N=88)=.005$, $p > .05$, nor were there significant differences found between groups on VSWM: $F(1,86)=.351$, $p > .05$. The mean number of

sequences remembered in the D children was 4.36 (SD=.9) versus 4.2 (SD=.740) for the DN children. Six children out of each group got at least 1 trial correct on the 6 item sequence, that is 11% of the D and 12% of the DN children.

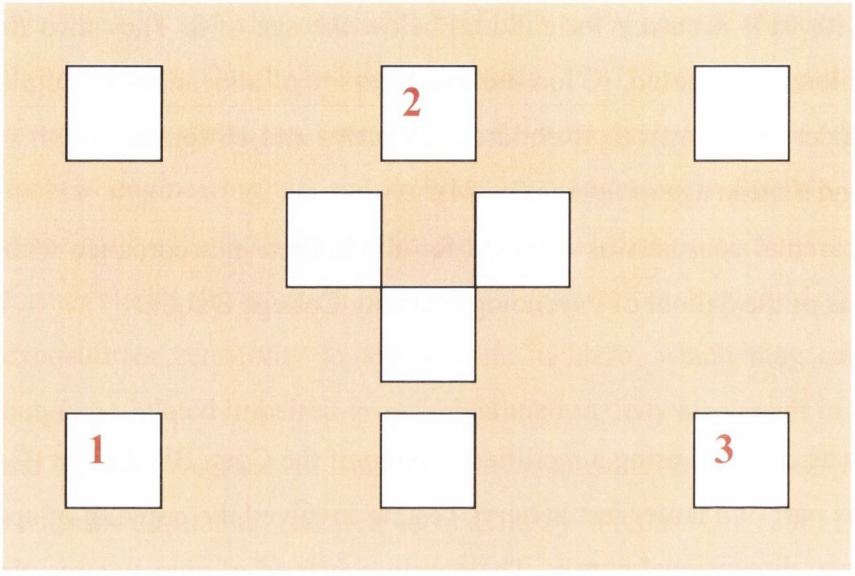

Figure 1.1 Spatial layout of the semi-structured matrix used in the assessment of VSWM, demonstrating a 3-item sequence.

Discussion

While no significant differences were found between developmental groups, a couple of interesting observations were made during the course of testing. Firstly, it was noticed that adding sequence items did not seem to provide the same linear progression in difficulty as one finds in digit span or phonological memory span measures, as the spatial nature of the task seemed to facilitate memory chunking. If one considers the example from Figure 1.1, rather than encoding the sequence as three separate items, it is possible to simply chunk it as one item- a triangle. A similar effect is found in verbal WM tasks for digit sequences of the nature 4, 5, 6 being easier then 8, 2, 5 (Baddeley, 1994; Gathercole & Baddeley, 1993b). It is suggested that accessibility of chunking in certain sequences or the use of a chunking strategy is likely to dramatically distort the measurement of discrete visuospatial capacity. In a paper published after Experiment 1.1 was carried out, it was suggested that children may spontaneously recode visual spatial images into verbal labels, in the form of:

"that pattern of stimuli looks like an A", however the authors argued that this use of strategy would be unlikely for dynamic sequentially presented sequences, akin to those found in the present task (Pickering et al., 2001). However, rather than a simple labelling effect, it is possible that the activated representations in LTM, even for dynamic tasks, are stronger if a sequence does in fact "look like an A". This would be likely to lead to greater recall, whether or not verbal labelling is occurring.

Kemps (1999, 2000, 2001) has suggested that complexity on visual spatial tasks is in fact mediated by 4 distinct but often overlapping factors: 1) number of items in the spatial matrix; 2) the number of items in a sequence; 3) the structure of the sequence path and 4) the structure of the matrix. The non-linear progression between sequence length and difficulty found in the present task may underlie not only the lack of findings in this study but the contradictory findings found in other studies which have sought to assess VSWM ability in dyslexic and developmentally normal children (Pickering & Gathercole, 2004; Simmons & Singleton, 2006; Smith-Spark et al., 2003). In order to accurately assess VSWM function, it is advocated that efforts should be made to constrain sequences in order to remove those that are easily chunk-able.

Secondly, it was believed that there may be differences in the types of mistakes being made between developmental groups. Unfortunately, in Experiment 1.1 individual response accuracy was all that was recorded, and there was no measurement concerning the exact nature of incorrect responses. However, it was the belief of the experimenter that the D children made more errors where the "shape" of a sequence was maintained, although the selected spatial locations deviated from the presented locations, that is, the response sequence, while still in the form of a triangle, was just not the same triangle as the presented sequence. Thirdly, over 10% of each group reached ceiling effects, pointing to yet another methodological impairment in the study. This skewing in the data does, however, have a simple solution. All future studies of VSWM should allow for indefinite increases in sequence length, enabling all children to reach the ceiling of their own ability rather than a predetermined test cut-off point.

Lastly, it was observed that the methodological format used in the present study opens up the possibility for additional levels of encoding, specifically encoding the patterns of motor movements which are used to point out the sequence (Hamilton, Coates, & Heffernan, 2003). Research has shown that memory for patterns of motor

movements is distinct from memory of spatial patterns (Smyth, Pearson, & Pendleton, 1988). Although highly unlikely, the possibility remains that children could simply copy the motor patterns carried out by the experimenter, thus invalidating the Corsi blocks procedure as a strict measure of VSWM. In order to overcome this shortcoming, it was suggested that all future assessments of VSWM should be presented via computer presentation, removing the possibility of additional motor pattern encoding.

Experiment 1.2- Introduction

In an accomplished reader the act of sentence reading is a largely effortless and unconscious process involving rapid phonological decoding of the letter strings. For children who are learning to read the process of decoding individual sounds within words is a conscious, slow and highly effortful undertaking. While children may initially use working memory resources to store the individual sound units that need to be combined to form words (Baddeley, 1986; Gathercole & Baddeley, 1993a, 1993b), these same resources will later be used to enable sentence and passage comprehension (Just & Carpenter, 1992; Just, Carpenter, & Keller, 1996).

Practised readers do not read words as pictorial units, but instead automatically decode the phonological components contained within them, allowing unfamiliar words to be decoded as efficiently as familiar words from sight vocabulary (Adams, 1994). This decoding requires not only the recognition of individual letter/sound relationships but the interrelations and combinations which the letters/sounds can produce. The individual letter/sound correspondences must be maintained in memory in order to allow the collective blending of the individual elements to produce word pronunciation (Adams, 1994). Accurate and automatic reading requires that the secondary activation of LTM representations (in the form of verbal and semantic codes), activate stronger representations and gain an increased allocation of processing resources relative to the initial visual representation, which is then largely suppressed after the recoding takes place (Palmer, 2000c).

Swanson (1989) argued that poor readers have weakened interconnectivity between verbal and visual codes. Skilled readers experience automatic activation of secondary verbal and semantic representations, when faced with easily codable visual stimuli. Dyslexic children on the other hand are unlikely to carry out these additional levels of processing unless necessitated by task demands. There is a large body of

research which suggests that spontaneous recoding of visual stimuli into verbal representations and verbal recall does not occur until around 7 to 8 years of age, with verbal re-encoding suggested to manifest itself with the development of early literacy skills (Hitch, Halliday, Dodd, & Littler, 1989; Hitch, Halliday, Schaafstal, & Schraagen, 1988; Hitch, Woodin, & Baker, 1989).

Pictorial based working memory tasks are one of the closest parallels to sentence reading, but unlike text based stimuli, there is no need for phonological decoding for item recognition to occur. Thus, if dyslexic children show an impairment on verbal but not pictorial WM tasks, the impairment is likely to relate to phonological processing rather than WM capacity per se. In contrast to Swanson's thesis, Palmer's (2000b) WM research, which used picture stimuli, found that 14 year old dyslexic children, like their age-matched cohorts, demonstrated a phonological similarity effect[3], indicating that they were recoding the stimuli into verbal codes. However, in line with Swanson's position, Palmer also found that, unlike their matched cohorts, dyslexic children were still showing a visual similarity effect[4]. This suggests that they were continuing to process the visual aspects of stored information, even when secondary verbal and semantic activation was occurring, suggesting a noisy dual visual-verbal coding strategy in dyslexic children.

Anderson and Johnston (1998) found that unlike reading age and age matched control children, 11 year old dyslexic children did not show word length[5] effects for pictorial stimuli, but were showing a similar word length effect to cohorts with auditory presentation. The authors argued that it was unlikely that dyslexic children

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[3] The phonological similarity effect is demonstrated by reduced recall and/or an increased error rate on sequences presented using phonologically similar stimuli item names (e.g. 'map', 'cap', 'sap') as opposed to sequences using item names which are phonologically dissimilar from one another (e.g. 'door', 'shoe', 'book') (Baddeley, 1994). The implication being that if the phonological similarity effect is demonstrated verbal retrieval is being used.

[4] The visual similarity effect, like the phonological similarity effect, is found when sequences using items which are visually similar to one another show a reduced recall and/or increased error rate relative to items which are visually dissimilar from one another. The implication being that the visual similarity effect is only demonstrated when visual retrieval is being used.

[5] Word length effect relates to the finding that verbal span capacity is roughly constrained by the number of words one can articulate in 1.5 seconds, that is the longer it takes to pronounce a word the shorter our span capacity. An absence of word length effect suggests that the participant is not using phonological encoding and/or retrieval.

failed to verbally encode pictures, as they reported using verbal rehearsal. On the other hand, and in contrast to control children, dyslexic children simply did not retrieve information from the phonological store, but were instead relying on the visual store at recall. Similarly, research involving developmentally normal five year olds demonstrated the same lack of word length effect when pictorial stimuli are used (Johnston, Johnson, & Gray, 1987), suggesting that young children, like dyslexic children, either may not spontaneously convert visual stimuli into verbal form, or they simply don't use the phonological codes when recalling pictorial-based stimuli (Henry, 1991). A second study involving developmentally normal children aged 5 and 10 years of age, indicated that while requiring the 5 year old children to name stimuli at the encoding stage did significantly improve recall, in contrast to the 10 year old children, they continued to show visual similarity effects and failed to show any word length effects. This suggests that they were continuing to use a visually dominant strategy (Hitch et al., 1988).

It is likely then that the research of Palmer or Anderson and Johnston simply relates to a delay in the changeover to verbally dominant encoding and retrieval strategies of easily nameable visually-based stimuli in dyslexic children, possibly related to their lowered exposure to the written word.

The first research hypothesis under investigation concerned whether D children's span capacity on VSWM tasks that are not easily chunked will significantly differ from DN children's. To this end, VSWM was assessed by presenting stimuli in a parallel rather than a matrix format, due to the suggested increased risk of spatial chunking occurring with a matrix type presentation as indicated in Experiment 1.1. Parallel spatial displays reduce the possibility of easily chunkable item paths occurring in sequences trials. Furthermore, displaying stimuli in a parallel presentation is perhaps a more ecologically valid measure of testing VSWM functioning in dyslexic children, given it is a far more analogous setting to reading a line of text than matrix presentation (since the spatial properties are constrained to movements along a singular plane, see Figure 1.2). Existing research has indicated that the prevention of verbal recoding in visual WM tasks can selectively enhance WM performance (Pelizzon, Brandimonte, & Favretto, 1999). As D children have been suggested to be less likely to use verbal recall on a visuospatial task, they may translate to an enhanced recall span in the D children relative to the DN children.

A second aspect which is implicit with the act of sentence reading is the requirement to inhibit information from the surrounding paragraph, which we have either finished reading or are yet to read. Logie (1986) found that the presentation of task-irrelevant pictures, which participants were told to ignore, selectively disrupted retrieval when participants were using a visual mnemonic technique but not when they were instructed to use rote (verbal) rehearsal. This led Logie to suggest that the visual store was a largely passive mechanism, which was susceptible to the visual interference which automatically enters the store (Logie, 1995; Logie et al., 1991).

Quinn and McConnell have argued against Logie's model of visual-spatial processing in which access to the visual store is gained through LTM. They cite their findings that Dynamic Visual Noise (DVN), selectively disrupted performance when pegword imagery was used as an encoding strategy (McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1996). This is despite the fact that the task should have no LTM representations as it is nothing more than visual static. However, research using more ecologically valid measures of visual short term memory found that DVN had no significant disruptive effects (Andrade, Kemps, Werniers, May, & Szmalec, 2002). The authors argued that, as visual WM does not show the same disruptive effects experienced in verbal WM with the presentation of irrelevant background noise, the stores are not functionally analogous and different mechanisms are likely to underlie the separate components. It is worth pointing out that Salamé and Baddeley (1987) found an identical lack of interference for auditory white noise on verbal working memory tasks, finding that only speech-like sounds have a significantly disruptive effect on memory performance. While both random spatial tapping[6] and random interval generation[7] have been shown to selectively disrupt spatial memory but not verbal or visual WM tasks (Pickering et al., 2001; Vandierendonck, De

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[6] Spatial tapping is usually used as a secondary task that requires participants to tap blocks in an established order, e.g. a *Figure* of eight, or counter-clockwise. Thus, it is argued to cause a disruption in spatial processing, but because the order is routinised, it does not draw on additional CE resources. In random spatial tapping, there is an additional draw on CE resources as participants must avoid tapping in a regularised sequence pattern.

[7] In random interval generation, participants are required to irregularly tap the same spot such that the intervals between taps remain "random" and as such is suggested to rely heavily on continued CE processing. By requiring participants to tap the same spot, the task crucially removes the spatial component but maintains the draw on CE processes.

Vooght & Van der Goten, 1998), there has been no research which has investigated whether task irrelevant visual stimuli presented during the encoding stage of VSWM tasks will selectively disruptive performance. Or if possible disruptive effects will differ between literacy impaired and unimpaired children.

Even more so than auditory experiences, our visual system is constantly bombarded with such massive amounts of information from the surrounding environment that it would simply be impossible to process all of it (Broadbent, 1958). Originally known as the attentional spotlight or zoom lens, the mechanism by which processing resources are allocated to a particular area or stimuli (Posner, 1980; Posner & Petersen, 1990) is probably best understood as spatial attention (Cave & Bichot, 1999). Spatial attention is argued to consist of two distinct but interwoven mechanisms, one involving the moving or shifting of attentional focus and the other relating to the adjustment in size of the attentional window in which selectively increased levels of processing will be carried out (LaBerge, 1983). Research suggests that it is inhibitory processes which define the focus of visual attention (Cepeda, Cave, Bichot, & Kim, 1998; Facoetti, 2001; Facoetti & Molteni, 2000). Thus if one's spatial attention is focused away from the source of distractive or interfering stimuli, one should be able to avoid the effects of stimulus intrusion on performance. However, if one's spatial window is such that task-irrelevant stimuli do fall within one's focus, the relative disruptiveness that task-irrelevant stimuli will have is likely to lie in the relative strength of LTM representation. The more enriched or meaningful a representation is, the more of a disruptive effect it will exert over the existing stored material (due to the strength of images produced by interference items). This could explain the lack of disruptive effect by DVN as, like auditory white noise, visual static is not likely to have any meaningful representations in LTM.

Facoetti (2001) suggested that spatial attention acts through a facilitation mechanism which helps to select stimuli at the attended location over stimuli at the unattended location which have been inhibited. It is likely then that if stimuli are sufficiently engaging, even if they are not within the field of attentional focus, they will siphon off some of the storage and processing resources from task-related activity. If stimuli are uniformly similar throughout the visual field, attentional focus should be sufficient to avoid perceptual intrusion. However, if stimuli outside the field of attentional focus are sufficiently captivating, the conjoined processes of stimuli enhancement at the attended location, combined with stimuli suppression at

the unattended location, will be required to counter the occurrence of intrusion errors (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000). Existing research also suggests that the suppression of irrelevant distracting stimuli is related to the level of attentional resources devoted to the target task, with the greater resource allocation leading to more effective suppression (Rees, Frith, & Lavie, 1997).

Nicolson and Fawcett (2000) have suggested that dyslexic individuals suffer from a general deficit in automatising tasks, arguing that while performance may appear to be within normal levels of functioning, this is only achieved through a process of conscious compensation that requires higher demands on processing resources and greater effort on the part of the child. A process is said to become automatic through extensive practice, but once automatic it is no longer limited by WM capacity or attention but instead acts as a fast, inflexible prepotent system which works simultaneously with other processes, and is heavily resistant to suppression and unlearning. In contrast, consciously controlled processes are resource demanding, are limited by the system capacity, are slower, are largely serial in nature, and require conscious monitoring and maintenance. Due to this lack of automaticity, for dyslexic individuals most tasks require at least some consciously controlled scaffolding to achieve adequate performance, and hence the addition of secondary tasks can disproportionately impair their performance.

Existing research has suggested that dyslexic children do have a relative impairment in maintaining focus size over time, the authors suggesting that dyslexic children are forced to move to a distributed rather than a focused attentional style due to an inability to inhibit the surrounding stimuli during testing (Facoetti, Paganoni, Turatto et al., 2000). Supporting this research is a single case study involving SJ, a 40 year old dyslexic professor, who demonstrated a similar inability to inhibit parafoveal letters and words during reading. Interestingly, the research found that reading performance significantly improved when a restrictive window was used to present words (Rayner, Murphy, Henderson, & Pollatsek, 1989).

Stemming from this research, a second experimental manipulation in the current experiment involved the addition of task-irrelevant interference which was placed outside the task-designated field of attentional focus, investigating whether dyslexic individuals reported inhibitory difficulties would lead to impaired VSWM performance. This was tested by flanking the target parallel placement on either side with task-irrelevant interference stimuli, which the participants were instructed to

ignore, see Figure 1.2. It was hypothesised that D children would experience an impaired performance on the interference tasks relative to their performance on standard non-interference presentation tasks, as they are more likely to rely on distributed spatial attention (Facoetti, Paganoni, Turatto et al., 2000). This lack of spatial focus will entail that more task-irrelevant items should gain access to the visual store, and hence impair recall. Coupled with this is the possibility that as D children are unlikely to use verbal retrieval strategies, they may be less able to resist the overwriting effects of the task-irrelevant stimuli.

The final experimental manipulation in the current experiment relates to existing research which has suggested dyslexic individuals may experience a left mini neglect (Hari et al., 2001). This opens up the possibility that dyslexic children will only experience impaired VSWM capacity on tasks that require left spatial orienting. This possibility was accounted for by including both sequence trials that are presented in a central vertical (column) alignment and those that have a horizontal (row) alignment. Vertical stimuli alignments, in contrast to the horizontal (row) presentation displays, do not require any left spatial orientation or bisecting of the visual field. Given the suggested left mini neglect in dyslexic individuals, it was believed they would experience an impairment in span capacity for sequences displayed on the horizontal relative to the vertical alignment. Secondly, this opened up the possibility that if DN children were using spatial encoding, they might experience an enhanced spatial location benefit in recalling horizontal placement displays due to their increased exposure to print. Therefore, it was believed that the vertical placement condition may act as uncontaminated measure of VSWM core ability between groups with an inverse relationship expressed between developmental groups on the horizontal measure. If there is no change observed in span capacity for either developmental group with the shift from horizontal to vertical placements this may suggest that both groups are possibly using verbal retrieval strategies, in opposition to Anderson and Johnston's (1998) research. If both groups are using verbal recall, D children are likely to demonstrate an impaired span capacity relative to DN children on both alignment conditions, in line with existing verbal WM research, but there should be no difference in recall span between the alignment conditions.

In summary, with reference to previous research the following the questions were identified:

i) If there are differences in recall span on simple measures of VSWM between literacy impaired and unimpaired children.

ii) Will D children experience lowered span capacity on the horizontal alignment relative to the vertical alignment due to a left mini neglect.

iii) Will the addition of task-irrelevant interference impair span capacity more in the D children than the DN children due to differences in the ability to spatially focus between these groups.

iv) Will D children's weakened ability to spatially focus and suggested left mini neglect translate to an additional impairment on the horizontal interference condition.

Method

Participants

Forty seven D participants were recruited from dyslexic schools and reading units in the greater Dublin region. All participants had been formally diagnosed with dyslexia by a clinical or educational psychologist, and had no documented co-morbid disorders such as ADHD or dyspraxia. The gender breakdown was 36 males and 11 females aged between 8-12 years with a mean age of 10.5 (1.1). The group had a mean IQ of 98 (6.3), with all participants being within or above the normal range (85-113).

Fifty DN children were recruited from schools in the greater Dublin region. Where possible, control children were recruited from the same schools as the dyslexia reading units. Where this was not possible, schools within the same catchment area were used as a means of matching for socio-economic status. DN children had an identical gender breakdown to the D children- 39 males and 11 females, with the same age range 8-12, with a mean age of 10.4 (1.1). The group had an estimated mean IQ of 100 (10.8) and were all within the normal range or above (85-129).

Prior to computerised testing the control children's IQ was assessed with a WISCIII short form, which consisted of Similarities, Arithmetic, Picture Completion and Block Design, which gives the most reliable estimate of full scale IQ (Kaufman & Kaufman, 1996). Only those children who had an estimated IQ within the normal range were used as control children in this study. Additionally all children were tested

on the Digit Span measure of the WISCIII as a means of assessing verbal WM functioning between developmental groups.

With the information and consent forms, children's parents were asked to fill out a Conner's Global Index-Parent (CGI-P) which is a short 10-item questionnaire which assesses the incidence of hyperactive type behaviour in the child. However, as 16% of DN and 18% of D children's parents did not return the forms filled in, no further analysis was carried out with the Conner's data.

None of the participants who took part in Experiment 1.1 took part in Experiment 1.2. Written parental consent was obtained for all children in accordance with the ethical regulations of the School of Psychology, Trinity College Dublin.

Apparatus

All children were tested in a quiet room within the participating schools. All computerised testing was carried out using a laptop computer, with the test stimuli being presented on a 17" LCD 3000 Series Elo Entuitive touch-screen monitor. In this way, children were never required to look away from the screen during testing, with all responses requiring only the simplest motor coordination. Care was taken so that the rooms were moderately lit and that the computer screen did not face any windows in the room as a means of avoiding screen glare or mirroring. For the same reason a gray screen background was chosen to avoid screen glare/mirroring which can occur with black or excessively dark backgrounds. For the 'flashing' stimulus the object/background ratio was above the 2:1 abrupt luminance ratio change which Theeuwes (1995) found enables exogeneous 'pop out' preattentive detection of stimuli. While existing research has suggested a decreased luminance contrast sensitivity in dyslexic individuals, the luminance contrast ratio used in this study is substantially higher than the 5-10% increases or decreases in luminance contrast where an insensitivity has been found (Graves, Frerichs, & Cook, 1999). Children sat approximately 60cm from the screen although their position was not restrained. As schools are intrinsically noisy places, children wore Sennheiser noise reduction headphones throughout testing as a means of reducing between setting auditory variation, as the level of background noise can vary considerably depending on the time of the day or individual school.

The use of a single semantic category has been shown to enhance recall (Wetherick, 1975). Existing research also suggests that as the ease of predication[8] increases, so too does ease of recall of the encoded stimulus (Jones, 1985). That is, if one can attach three meanings to a stimulus versus a singular meaning, the former will be better recalled. Thus, shape stimuli were chosen as it is difficult to predicate beyond their outward appearance, and hence no one stimulus item should have a greater semantic representation, and hence they should all be of equal difficulty in encoding and retrieving representations from LTM (Jones, 1985).

Procedure:

A repeated measures design was used with two within group and one between group variables, all of which had two levels, which were presentation type (standard or interference conditions) and alignment (horizontal or vertical conditions), with developmental type (D versus DN children) as the between group variable. Across experimental conditions the task was to copy the order in which shapes flashed up on the screen, by touching shapes in the same order they had flashed up on the touch-screen. In this way all children were tested on the four independent conditions with the highest correctly recalled span sequence acting as the dependent measure across tests. As Figure 1.2 demonstrates in both the standard presentation conditions (screenshots A&B) and the interference presentation conditions (screenshots C&D) stimuli were centrally placed either in horizontal (screenshots A&C) or vertical (screenshots B&D) alignment. In the interference conditions children were required to attend and copy only those shapes which flashed-up in the centre line, ignoring the shapes that flashed up in the flanking lines. As highlighted in screenshot C, while the task required children to copy only those shapes that flashed up on the middle line (the green line in the example below), individual shapes did flash up randomly on the other four flanking lines, and it was these flanking stimuli which children had to ignore in order to correctly copy the order of flashes on the centre line.

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[8] The ease of predication effect is the finding that words that can easily be derived into multiple associated meanings or connective links are better recalled than words for which it is difficult to predicate associated meanings. The effect was later subsumed under the terms of concrete versus abstract word recall. That is, it is easier to predicate associated meanings if a word has a concrete rather than an abstract meaning.

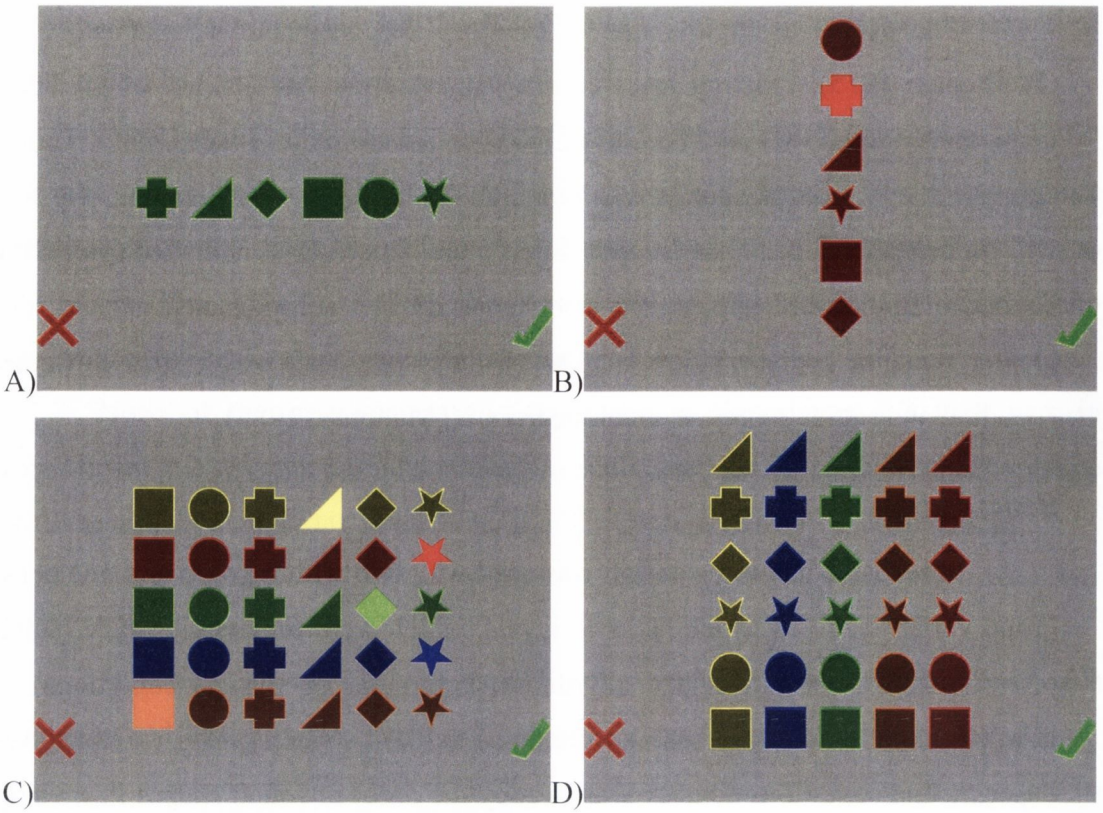

Figure 1.2 Screenshots displaying the four experimental conditions. Screenshot A) displays the standard horizontal condition; screenshot B) displays the standard vertical condition with a red X flashing; screenshot C) displays the interference horizontal condition with stimuli flashing; and screenshot D) displays the interference vertical.

The order in which children completed the test levels was randomised with one constraint. The first test carried out by a child was always a standard presentation test (either with a horizontal or vertical placement) but was never an interference style presentation test. The reasoning behind this constraint was to give children a chance to internalise the standard task instructions before complicating the task demands with the interference condition. In all conditions testing began with a two-item sequence and after each correctly recalled sequence trial an additional item was added with no upper limit imposed. If a child failed a particular sequence trial they were given a second attempt at that sequence level, but after 2 consecutive failures on the same sequence length the test condition was terminated.

The requirements of each condition were explained at the start of each test to children using a computerised graphical demonstration with visual and verbal instructions of the full test procedure (see Appendix I for a complete description). As part of the procedural instructions, children were instructed that if they made a

mistake they could undo it by touching the red X, at which point they would have to copy the sequence out from the beginning again. Once the demonstration was complete children were asked to explain the rules of the game as a means of ensuring procedural understanding.

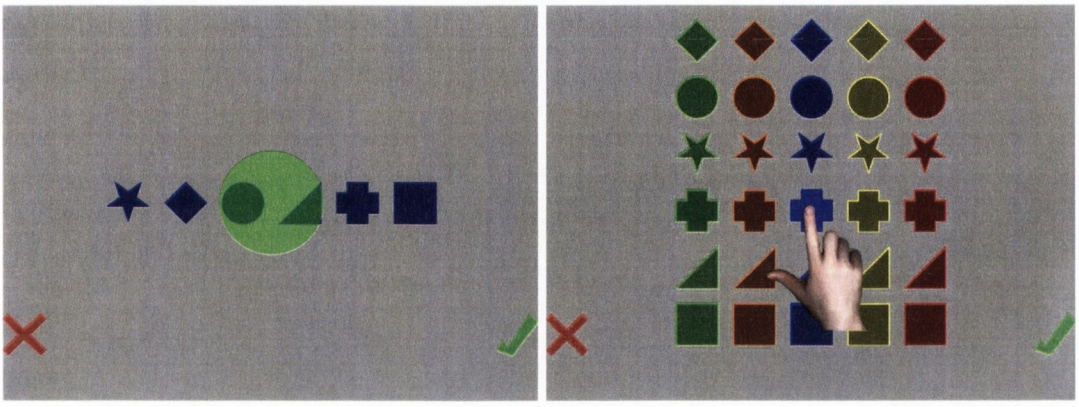

Figure 1.3 The first screenshot displays the green traffic light stimuli on the standard horizontal condition, which was presented at the start of every new trial to fixate gaze, the second screenshot displays the demonstration hand copying out a sequence in the vertical interference task.

Before the start of every sequence trial, a visual fixation circle flashed up in the centre of the screen, changing from red to green like a 'traffic light', see Figure 1.3. The 'traffic light' was a means of priming children to visually fixate at the same point on the screen, with the first stimulus sequence flashing 2000ms after the green circle had disappeared. The span sequences were built up by flashing shape stimuli on the screen one at a time for 500ms with an interval of 1000ms before the next shape flashed up. The end of a sequence presentation was indicated by the presentation of a warning tone, and verbal instructions to copy out the sequences they had just seen. At this point children copied out the sequence by pressing the relevant shapes on the touch screen. To indicate a screen press was being recorded, the shape stimuli changed from the default presentation to the "flash" level of abrupt luminance change. Children signified that they had completed copying a particular sequence trial by touching the green tick. Stimulus size remained constant across presentation type and alignment conditions. If a mistake was made on either the two or three-item sequences children were given automatic computerised feedback in the form of further verbal and graphical instruction, with the sequence being re-presented and the demonstration hand copying out the order correctly (Figure 1.3). For all other trials, children received uniform positive feedback after touching the green tick.

Repeated measures ANOVAs with development as between group factors were carried out on the data, with all secondary pairwise comparisons using Bonferroni statistical significance conversions. In addition to highest recall span, further dependent measures in the form of serial position accuracy (on incorrectly recalled trials) and response times (RT) for both correct and incorrectly recalled sequence trials across the experimental conditions and between developmental groups were analysed.[9]

Experiment 1.2- Results

Grouping variables

The developmental groups were matched for gender, with 36 male and 11 female D children versus 39 male and 11 female DN children $\chi^2=(1,N=97)=.027$, $p > .05$. There were no significant differences between groups on age: D mean=10.5 (SD=1.1) and DN mean=10.4 (SD=1.2), $F(1,95)=.027$, $p > .05$, or on IQ: D mean=98 (SD=6.5) and DN mean=101 (SD=10.8), $F(1,95)=1.591$, $p > .05$. Significant differences were found between groups on Digit Span, with D children having a lower scaled score (mean=8.3, SD=1.9) than DN children (mean=10.8, SD=3.1), $F(1, 95)=22.629$, $p < .001$. Likewise, there were significant differences found between groups for raw scores on both digits forward (D mean=8.3 SD=1.9 vs. DN mean=9.6 SD=2.2) $F(1,95)=9.048$, $p < .005$, and digits backwards (D mean=3.3, SD=1.1 vs. DN mean=4.8, SD=1.8) $F(1,95)=18.217$, $p < .001$.

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[9] Additional data was collected on the types of errors children made when incorrectly recalling a span sequence, as it was believed that such errors may underlie potential shifts in task strategy or learning. Four types of errors were categorised: 1) Missing – the sequence is correct but is missing one element from the overall sequence, 2) Reordering – the items of the sequence are correct, but the item order of the sequence has been mixed up, 3) Displaced – the sequence is correct but part of the sequence has been displaced spatially to one side or the other of the correct sequence, for example in a sequence with the location 5, 1, 3 a response of 6, 1, 3 or 6, 2, 4 etc. would be considered displaced, 4) Other – these are mistakes that do not fall into any of the above categories. As there was no indication of any differences between developmental groups or any significant interactions involving developmental groups across any of the 4 error types, no further mention will be made of the analysis.

Span Capacity

Repeated measures analysis was carried out on presentation type by alignment, with developmental type as a between subjects factor with longest span as the dependent measure. The alignment condition was highly significant $F(1, 95)=36.183$, $p < .001$, indicating that both groups of children performed better on the horizontal alignment (mean=3.60, SE=.091, 95%CI=3.42-3.79) than on vertical alignment (mean=3.01, SE=.101 95%CI=2.80-3.21). Presentation type was significant across groups $F(1, 95)=5.841$, $p < .05$ indicating that children performed better on the standard presentation (mean=3.44, SE=.092 95%CI=3.42-3.79) than the interference condition (mean=3.17, SE=.106, 95%CI=2.96-3.38). However, presentation type was also found to interact significantly with developmental group $F(1, 95)=5.409$, $p < .05$. While Bonferroni comparisons indicated that DN children's span capacity on the standard presentation (mean=3.45, SE=.127, 95%CI=3.19-3.70) did not significantly differ from their performance on the visual interference task (mean=3.44, SE=.141 95%CI=3.15-3.73), D children showed a marked impairment in performance on the interference presentation (mean=2.90, SE=.131, 95%CI=2.60-3.21) relative to the standard presentation (mean=3.43, SE=.146, 95%CI=3.17-3.69) – see Figure 1.4. No significant difference in recall span were indicated between the developmental groups (DN children mean=3.45, SE=.115, 95%CI=3.22-3.67) $F(1, 95)=2.874$ versus D mean=3.17, SE=.119, 95%CI=2.92-3.40, $p > .05$, nor was there a significant interaction between the development and alignment conditions $F(1, 94)=.544$, $p > .05$. As both developmental groups demonstrated an equal decline in recall span with the change from horizontal to vertical placements, DN (horizontal mean=3.73, SE=.127, 95%CI=3.48-3.98 versus vertical mean=3.16, SE=.141, 2.88-3.44), D (horizontal mean=3.48, SE=.131, 95%CI=3.22-3.74 versus vertical mean=2.85, SE=.146, 95%CI=2.56-3.14).

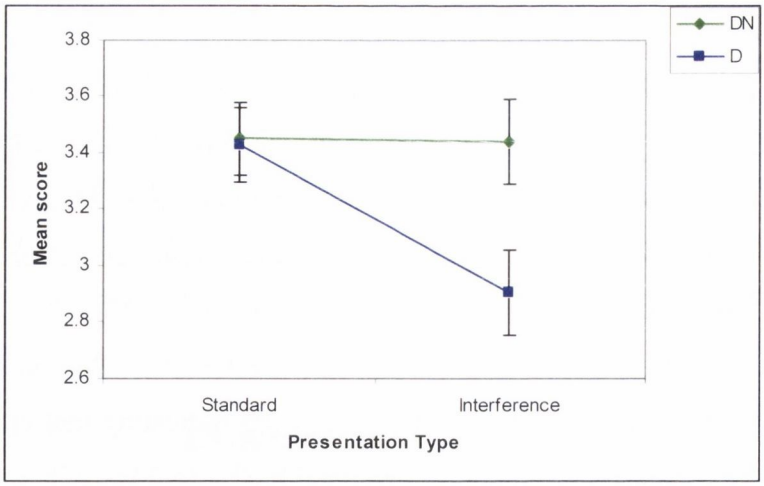

Figure 1.4 Line plot highlighting the interaction between presentation type and developmental status, on the forwards-recall tests.

Interestingly, when the scaled digit span scores were entered into the same repeated measures analysis as above as a covariate, we found that alignment $F(1, 94)=.725$, $p > .05$, (horizontal mean=3.6, SE=.088, 95%CI=3.44-3.78 vs. vertical mean=3.0, SE=.100, 95%CI=2.81-3.21) and presentation conditions $F(1, 94)=.099$, $p > .05$, (standard mean=3.4 SE=.088, 95%CI=3.27-3.62, vs. interference mean=3.2, SE=.105, 95%CI=2.97-3.38) no longer significantly differed between levels, while there remained no significant simple effects between developmental groups $F(1, 94)=.103$, $p > .05$, (DN mean=3.3, SE=.117, 95%CI=3.10-3.57 vs. D mean=3.3, SE=.121, 95%CI=3.04-3.52). In contrast, the interaction between presentation type and development remained significant $F(1, 94)=4.937$, $p < .05$. With scaled digit span entered in as a covariate, D children demonstrated an slightly elevated performance on the standard presentation type tests (mean=3.7, SE=.135, 95%CI=3.3-3.8) relative to DN children performance (mean=3.3, SE=.130, 95%CI=3.1-3.6), however D children continued to show a significant impairment on the interference presentation type tests, even when digit span was co-varied (mean=3.0, SE=1.59, 95%CI=2.7-3.3), while the DN children's performance on the interference presentations (mean=3.4, SE=.154, 95%CI=3.0-3.6) remained highly similar to their performance on the standard presentation tests, see Figure 1.5.

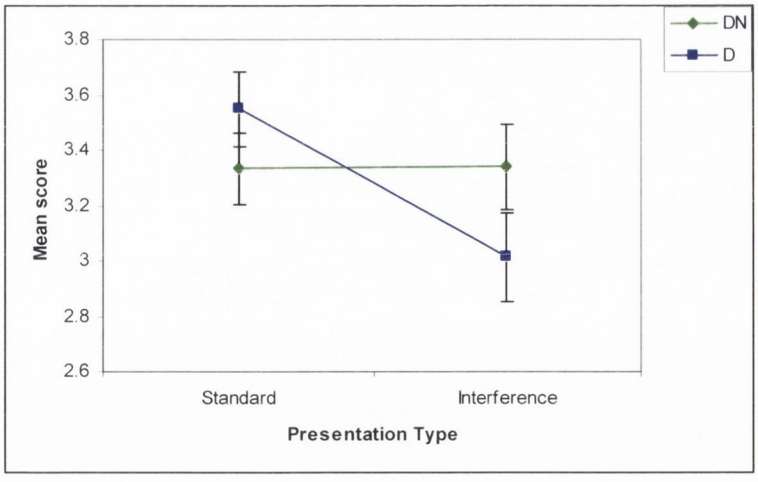

Figure 1.5 Interaction between presentation type and development when Verbal WM has been entered as a covariate, on the forwards-recall tests.

Serial Order Effects

In investigating potential differences in error types between groups, accuracy of item serial order position was assessed (Kerr, Ward, & Avons, 1998; Penney & Godsell, 1999; Smyth & Scholey, 1996b). The last two trials which children failed to copy accurately at the termination point of each test condition were scored in terms of serial position accuracy, e.g. primacy, intermediate and recency effects. Primacy was defined as the first 1 or 2 items that were presented to the child; intermediate was defined as those items presented in the middle section of each sequence; and recency defined as the last 1 or 2 items to be presented to the child. For sequences 3 items long, primacy was the first item to be presented, intermediate the next item, and recency the third item. For sequences of 4 items both primacy and recency were still only one item long, with intermediate taking up the middle 2. For all other items, primacy and recency were the first and last 2 items presented, with intermediate enclosing the rest of the items. The maximum possible score on either primacy or recency elements was 4, which would indicate that a child successfully copied the first and second items on both trials. A repeated measures analysis was carried out, entering in the individual error types across the experimental conditions.

When accuracy on serial position items was assessed across the presentation and alignment and between developmental groups, a highly significant effect was found in respect to serial position accuracy ratios $F(2, 190)=153.452$, $p < .001$, with Bonferroni comparisons indicating that primacy items (mean=2.5, SE=.082, 95%CI=2.4-2.7) had a significantly higher recall accuracy than both intermediate

(mean=1.5, SE=.081, 95%CI=1.4-1.7, $p < .001$) and recency item accuracies (mean=1.0, SE=.044, 95%CI=1.0-1.1, $p < .001$). Intermediate items were recalled more accurately than recency items ($p < .001$). A significant interaction between serial position and developmental groups was also indicated $F(2,190)=3.610$, $p < .05$, see Figure 1.6. Planned comparisons indicated that the interaction was due to a change in accuracy profiles between developmental groups with the shift from primacy to intermediate items $F(1, 95)=7.434$, $p < .001$. That is, D children showed an increased drop in accuracy levels on the intermediate items relative to DN children, but the profile of accuracy change was highly similar between developmental with the shift from primacy to recency items $F(1, 95)=.000$, $p > .05$ (see Table 1.1).

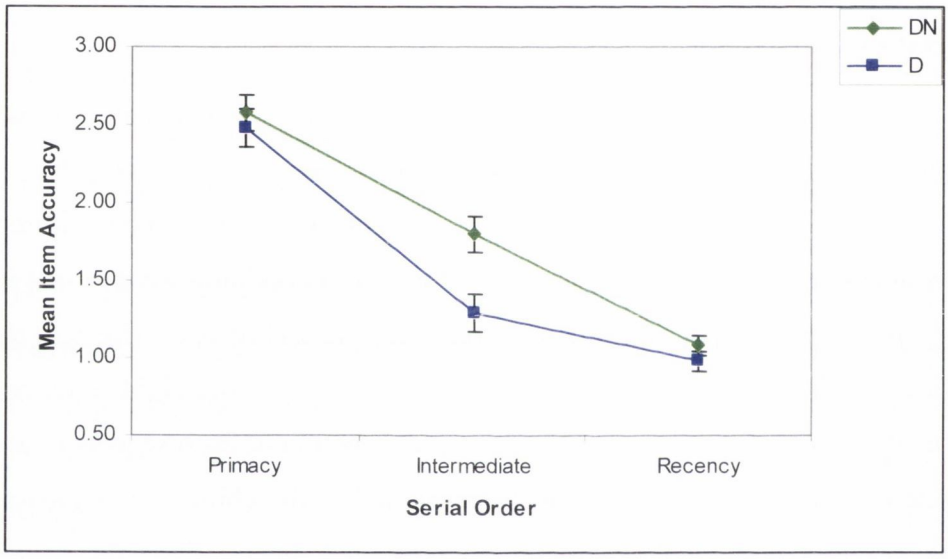

Figure 1.6 Line graph depicting the interaction between serial order positions and developmental groups on the forwards-recall VSWM tests.

Table 1.1 Mean scores and 95%CI across serial order positions between developmental groups, for the forwards-recall tests.

Development	Serial Order	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	2.58	0.114	2.35	2.81
	Intermediate	1.80	0.113	1.57	2.02
	Recency	1.08	0.061	0.95	1.20
D	Primacy	2.48	0.118	2.25	2.71
	Intermediate	1.29	0.117	1.06	1.52
	Recency	0.97	0.063	0.85	1.10

The analysis also indicated significant differences in recall accuracy between the alignment conditions $F(1, 95)=27,280$, $p < .001$, with horizontal placements (mean=1.9, SE=.058, 95%CI=1.7-2.0) having a higher overall accuracy than the vertical placements (mean=1.6, SE=.058, 95%CI=1.4-1.7). Significant effects were

also found between presentation conditions $F(1, 95)=30,331$, $p < .001$, with standard presentations promoting higher item recall accuracies (mean=1.9, SE=.060, 95%CI=1.7-2.0) than interference presentation conditions (mean=1.5, SE=.058 95%CI=1.4-1.6). Additionally a significant interaction between the alignment and presentation conditions was found $F(1, 95)=11.391$, $p = .001$. As Figure 1.7 highlights, while on the vertical alignment tests recall accuracy is equally low on both standard (mean=1.6 SE=.072, 95%CI=1.4-1.7) and interference presentations (mean=1.5, SE=.071, 95%CI=1.4-1.6), children had a significantly higher recall accuracy on the horizontal standard presentations (mean=2.1, SE=.076, 95%CI=2.0-2.3) than the horizontal interference presentations (mean=1.6, SE=.073, 95%CI=1.4-1.7, $p < .001$).

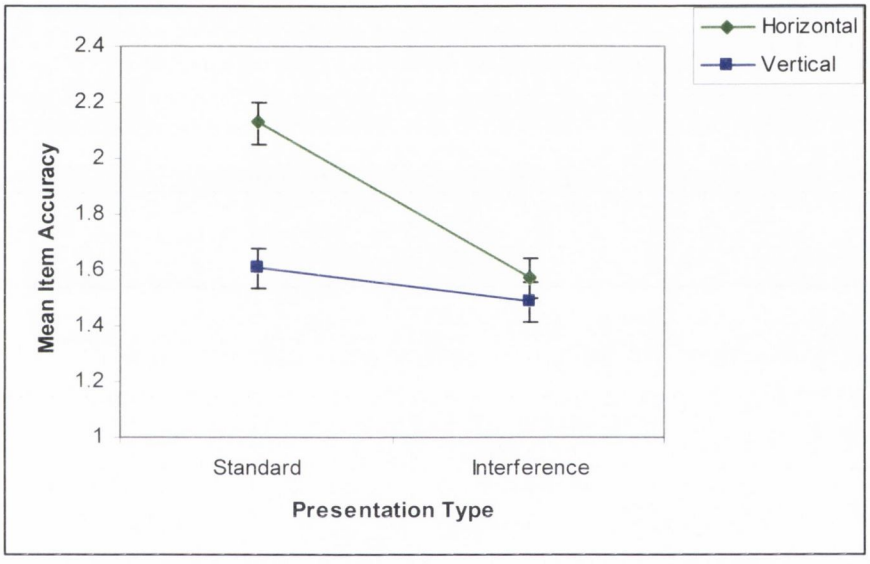

Figure 1.7 Line graph depicting the interaction between alignment and presentation conditions on the forwards-recall VSWM tests

Response Times

A repeated measures analysis was carried out on the RTs for correctly recalled sequences, across alignment, presentation and between developmental groups. The analysis indicated that there were no significant differences in RT between the alignment conditions $F(1, 90)=.675$, $p > .05$, with correctly recalled sequences on the horizontal placements (mean=4569ms, SE=111, 95%CI=4348-4788) being similar to the vertical RTs (mean=4448ms, SE=120, 95%CI=4209-4687). No significant differences or interactions involving developmental groups were found $F(1, 90)=3.447$, $p > .05$, although the trend suggested that D children were responding

more quickly (mean=4341ms, SE=131, 95%CI=4081-4601) than DN children (mean=4674ms, SE=123, 95%CI=4431-4917). This difference was approaching statistical significance (P=.06). The only significant effect was indicated across presentation type (F1,90)=10.614, $p < .005$, indicating that RTs for the standard presentation conditions (mean=4730ms, SE=137, 95% CI=4461-5007) were significantly longer than interference presentation RTs (mean=4280ms, SE=083, 95%CI=4117-4445).

RTs for incorrectly recalled sequences were analysed in a second repeated measures analysis, again across alignment, presentation and between development conditions. Again no significant differences were indicated between the alignment conditions $F(1, 95)=.884$, $p > .05$, with RTs on the horizontal placements (mean=7585ms, SE=253, 95%CI=7083-8087) being highly similar to RTs on the vertical placement (mean=7335, SE=194, 95%CI=6950-7720). The analysis now indicated there were significant differences in RT between developmental groups $F(1,95)=4.562$, $p < .05$, with D children responding more quickly (mean=7071ms, SE=261, 95% CI=6552-7590) than DN children (mean=7849, SE=253, 95% CI=7345-8352). Presentation type RTs again significantly differed $F(1,95)=16.517$, $p < .001$, with the interference RTs (mean=6949ms, SE=198, 95%CI=6556-7.343) being significantly shorter than the standard presentation (mean=7970ms, SE=252, 95%CI=7490-8451).

Discussion

Span length

The analysis indicated that D children's recall span on the standard presentation conditions was not significantly different from the DN children's recall span. In opposition to the theory of left mini neglect (Hari et al., 2001) in D children, in the present study enhanced span length was experienced across groups on the horizontal relative to vertical placement condition. As both developmental groups showed an equal advantage on the horizontal relative to the vertical alignment, it seems unlikely that the advantage relates to a print exposure effect. This is suggested as both groups would have had very different experiences with the written word but show an equal effect across alignments. While it is possible that both groups have simply received sufficient instruction in reading to have developed ceiling ability

levels, it seems plausible that the advantage lies with our day to day experiences in which we are constantly required to spatially locate and scan the environment on the horizontal plane but less so on the vertical.

That both developmental groups experienced a significantly lowered capacity on the vertical alignment condition is a strong indication that both groups were at least to some extent using visuospatial encoding and/or retrieval. Presumably, the alignment of stimulus presentation would have had no effect if children were only using a verbally dominant encoding and/or retrieval strategy. The lack of an interaction between presentation type and development would suggest that both groups were using similar retrieval strategies and have an equal capacity to recall visuospatial presented sequences of this type.

The lack of any impairment in performance on the horizontal presentations in D children due to their proposed left mini neglect (Hari et al., 2001) was unexpected. Existing research has shown that auditorily presented phasic alerts transiently correct spatial bias in left neglect patients (Robertson, Mattingley, Rorden, & Driver, 1998). In line with this research it is possible that the impairment due to left mini neglect was minimised in the current experimental procedure, as a auditory cue and the centrally presented visual 'traffic light' may have acted as phasic alerts, transiently correcting spatial bias during sequence trials. However, it is just as likely that the D children's degree of spatial neglect was not large enough to impair VSWM capacity for sequences that bisect the horizontal and their impairment is so selective that it does not affect performance on tasks of this nature.

The main effect found on the presentation condition related to the D children's selectively impaired performance on the interference condition. As the interaction between development and presentation type indicated, DN children were showing no effect due to the introduction of visual interference, but the D children were showing a significant impairment in performance. This supports existing research indicating that dyslexic children experience a difficulty in maintaining focused attention (Facoetti, Paganoni, Turatto et al., 2000; Rayner et al., 1989) and further supports Logie's thesis that visual stimuli (like auditory stimuli's access to the phonological loop) have automatic access to the visual store. It is suggested here that due to the constant competition for visual processing resources, this automatic access is filtered in such a way only to include stimuli that can fall within or close to the fovea of visual spatial attention. Likewise, unless representations are likely to have

some form of LTM code, they are unlikely to have much of a disruptive effect. Because D children are more likely to use a diffuse spatial window (Facoetti, Paganoni, Turatto et al., 2000) they are more prone to parafoveal interference. This lack of specificity when encoding could also relate to dyslexic individuals' spelling impairments, given that if auditory or visual representations are constantly embedded in an additional noise signal, they are likely to be more changeable and error prone. The interference condition's lack of effect on the DN children may relate to increased development of inhibitory mechanisms relative to the D children, which is suggested to define the focus of visual attention (Cepeda et al., 1998; Eriksen, Pan, & Botella, 1993; Facoetti, 2001).

D children demonstrated no additional impairment on the horizontal alignment interference presentation beyond that found on the vertical alignment. This suggests that the impairment in performance was simply related to weakened spatial focus in D children and that once again there was no additional deficit with the requirement to bisect the horizontal in these children. Interestingly, while task irrelevant information did not impair DN children's recall span, both the D and DN children demonstrated a significant drop in recall span when sequences were presented on a vertical alignment relative to the horizontal presentations. What is suggested is that our memory for spatial location for vertically aligned stimuli may simply not be as developed as that for horizontal placements, resulting in the equal deficit across developmental groups.

Excitation of the magnocellular pathway[10] has been predominantly associated with the capture of visual attention. The lack of differences between developmental groups on the standard presentation would seem to indicate adequate magnocellular functioning in the D children, at least when faced with the abrupt luminance contrast shift ratio of the present study (Graves et al., 1999; Posner & Raichle, 1994; Steinman, Steinman, & Lehmkuhle, 1997). A lack of impairment in magnocellular functioning further supports a recent research study which has suggested that most dyslexic individuals do not suffer from a specific magnocellular deficit, but rather that magnocellular dysfunction occurs in only a small sub-group of dyslexics (Amitay et al., 2002).

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[10] The Magnocellular pathway acts as a relay for achromatic information for stimuli that are low contrast and luminance with high temporal frequencies.

One of the most interesting findings of the study related to the interaction between presentation type and development when scaled digit span was entered as a covariate. The analysis was carried out as a means of ascertaining if differences in recall span were still present, when differences in verbal WM and CE functioning in the form of digit span had been co-varied. The analysis indicated that D children were actually performing significantly better than DN children on the standard version of the test. This supports Swanson's (1984) thesis and suggests that dyslexic children may have a visual-spatial advantage while DN children, in line with Logie's (1995) dual coding of representations theory, were able to efficiently enhance performance in one domain with cooperative representations from a second code (Martein, Kemps, & Vandierendonck, 1999). In opposition to the visual advantage model, even when digit span was entered as a covariate, D children were still performing significantly worse than their DN cohorts on the interference task, suggesting that the interference effects were largely separate from verbal or CE WM capacities as assessed by the digit span measure.

Serial Order Effects

The analysis of the serial order data suggested that there was very little in the way of differences in the types or frequency of errors between developmental groups. D children were found to have poorer recall accuracy on the intermediate items than DN children, perhaps suggesting that D children that they have less resilient representations which are more prone to overwriting. Alternatively D children may simply be experiencing a swifter decay of representations in memory, again possibly due to the lowered strength of representations (Visser et al., 2004). It is important to note that while the developmental groups differed in respect to intermediate items they did not differ in respect to their primacy or recency recall accuracy scores.

The lack of an interaction between presentation type and developmental group would indicate that both developmental groups were experiencing similar impairments to recall from the interference stimuli, at least when their recall span has been exceeded. Likewise, both the standard and interference vertical alignments, and interference horizontal presentations were associated with lowered recall accuracy relative to the standard horizontal presentations, suggesting that across developmental groups, children may have enriched representations for stimuli presented with a horizontal alignment, as long as interference isn't involved.

The little research that has addressed serial position accuracy in visuospatial tasks suggests different profile patterns in the recall accuracy of serial positions from those found in the current experiment. Broadbent and Broadbent's research in the early 80's suggested that for spatial WM recognition tasks, there was a recency effect of only 1 item and no primacy effect (Broadbent & Broadbent, 1981). More recent research studies into serial position recall accuracy have suggested that like verbal WM, there is a recall accuracy bow effect of near perfect recall at either the initial or terminal ends of the sequence with poorest recall accuracy in the medial items (Jones, Farrand, Stuart, & Morris, 1995; Penney & Godsell, 1999; Smyth & Scholey, 1996b). The current experiment did find evidence of a drop-off in accuracy for intermediate versus the primacy items. However, children did not demonstrate significantly improved recall accuracy on the recency items relative to the intermediate, as the traditional bow effect suggests. They instead demonstrated a further drop in item accuracy on the recency items, which may relate to either increased interference effects from subsequent items, or simply quicker item decay in children of this age (Penney & Godsell, 1999).

In opposition to any suggested recency effect, children were found to experience their worst accuracy recall rate on the terminal items of sequences. It is possible that this lack of recency effect relates to the participants' age and the particular methodology of the study. Children were not required to monitor sequence length as a cue to response, as they were cued to the termination of a sequence with the presentation of a tone. It is thus possible that they may simply have started copying the sequence, rather than fixing the last sequence in memory before responding as an adult might do. Supporting this view is existing evidence that suggests that metacognitive planning and strategy use develop with age, and that younger children are less likely to use even overtly obvious strategies or heuristics that may be open to them, unless they are prompted to do so (Kontos & Nicholas, 1986; Miller & Bjorklund, 1990; Schneider & Sodian, 1997). Secondly, it is possible that in children of this age range the act of copying the sequence when prompted actually interferes with the stored memory codes of the terminal items. The significant decline in performance on intermediate item recall experienced by D children is likely to relate to either a quicker item decay (Visser et al., 2004) or to a shorter item capacity (Penney, 1989) in these children. Given that both groups are experiencing the same reduced accuracy levels at the terminal end of the sequence, it

is possible that D children's representations are simply decaying just a little bit more quickly than those of DN children. However, it must be acknowledged that the difference between groups, while significant, was relatively small, and as such limits the extent to which firm conclusions can be drawn from the present analysis.

Response Times

The analysis of the RT data could be viewed as supporting the argument of dual storage, given that verbal memory traces can last for up to a minute while a corresponding visual trace is unlikely to last more than a second (Penney, 1989). Across both correct and incorrect responses, dyslexic children were responding more quickly (though they were only significantly quicker on the latter analysis), perhaps suggesting that they were experiencing a quicker decay of the stored representations in WM in line with the serial position data. Based on anecdotal observations, Pickering (2001) suggested that children who respond more quickly on spatial memory tasks were more likely to recall sequences correctly. While the current RT data between correct and incorrect recalls supports this hypothesis, it does little to explain why dyslexic children are responding more quickly across both domains. As noted earlier, Palmer (2000a, 2000b) suggested that dyslexic teenagers do recode visual stimuli into verbal codes but that they also process the existing visual representation at the same time. This manifests as a noisy dual code where both codes compete against one another. However, in contrast to Palmer's theory, it is possible that non-impaired individuals are simply better at allocating resources to the most efficient code. Rather than this relating to a permanent verbally dominant system, DN children may simply be better at enhancing a specific code, one which can then garner additional support when required from a secondary source. Thus, both developmental groups may continue to maintain information in both visuospatial and verbal stores, but unlike the impairment found in D, DN children do not suffer from an inability to selectively enhance or integrate one store's processing with another.

Summary

Both developmental groups had highly similar recall span on the standard VSWM tasks, while D children demonstrated an impairment to recall span on the interference tasks. It is possible that the differences in the effect of task irrelevant information on recall span may relate to the occurrence of verbal re-coding of the

shape stimuli. If DN children are recoding visual representations into verbal codes, with the subsequent automatic suppression of VSWM representations, by using a task that selectively impairs verbal WM but doesn't impair VSWM, DN children's performance should deteriorate whereas there should be little change in the D children's performance. Backwards-recall of sequence items has been shown to selectively impair performance on verbal working memory tasks relative to forwards-recall (Gardner, 1981). Unlike the simple retrieval of stored information in forwards-recall, backwards-recall places additional demands on the CE. This is because in backwards-recall, the CE is required to access, maintain and manipulate the existing codes into the necessary format (Li & Lewandowsky, 1995; Reynolds, 1997; Schofield & Ashman, 1986). In contrast, VSWM tasks show no significant impairment when order is reversed (Isaacs & Vargha-Khadem, 1989). However, if DN children selectively enhance the most efficient code, we would expect that they will not experience a deficit in performance between forwards and backwards-recall.

Experiment 1.3- Introduction

A planned comparison between forwards and backwards-recall was carried out when developing the current research project for Experiment 1.2 as we found no evidence in the research literature that any research had previously addressed backward visuospatial recall in children or adults with dyslexia. It was believed that the addition of backwards-recall could offer further insight regarding the questions raised in the earlier experiment. Secondly, in line with Palmer's verbal code dominance model, it was hypothesised that if DN children automatically recode the visual stimuli into verbal representations, they will experience a selective deficit in backwards-recall performance relative to forwards span capacity. According to Palmer's noisy dual coding model, the D children are likely to process both the visual and the verbal representations simultaneously, which would in turn lead to a decrease in performance of backwards-recall relative to their forwards-recall. However, it is argued here that as the task does not strictly demand verbal output or encoding. The D children will not process the verbal representations at recall (R. S. Anderson & Johnston, 1998) and hence should not show a deficit in performance between forwards and backwards tasks. It is also possible that DN children may switch to a visual-spatially dominant recall strategy. The impaired performance on the vertical tasks in Experiment 1.2 suggests that DN children were at least partially using

visuospatial encoding and retrieval. If so, it is likely that they similarly will not show any deficits on backwards-recall tasks. It was hypothesised that the additional requirements on CE resources to manipulate sequences for backwards-recall may increase the DN children's vulnerability to intrusive stimuli on the interference condition, as they will have fewer resources to direct towards inhibitory mechanisms.

Method

The same participants who took part in Experiment 1.2 took part in Experiment 1.3. The design materials and procedure were identical to Experiment 1.2, except that children were now required use backwards-recall in the copying of sequences. Again, children were given a graphical demonstration at the start of testing, with procedural understanding being assessed before testing started. All children were tested 1-3 weeks after Experiment 1.2, as part of a planned assessment of visual spatial reverse recall.

Results

Span Capacity

In line with the earlier tests, a repeated measures analysis was carried out across alignment and presentation conditions as within group factors, and development type as a between subjects factor, with longest span as the dependent measure. Consistent with the findings of Experiment 1.2, significant differences were again found between the experimental levels on the alignment condition $F(1, 95)=12.114$, $p < .001$. Again, the significant effects were due to a higher recall accuracy on the horizontal task (mean=3.0, SE=.078, 95%CI=2.9-3.1) relative to the vertical task (mean=2.7, SE=.089, 95%CI=2.5-2.9). There was no suggested interaction involving alignment and development $F(1, 95)=1.098$, $p > .05$ (see Table 1.2), or between alignment and presentation type $F(1, 95)=.043$, $p > .05$ (see Table 1.3).

Table 1.2 Recall span mean scores, standard error and 95% confidence intervals across presentation and between development conditions, when backwards recall is required

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Standard	3.2	0.12	2.9	3.4
	Interference	2.9	0.12	2.7	3.1
D	Standard	2.7	0.13	2.5	3.0

	Interference	2.6	0.12	2.3	2.8

Table 1.3 Recall span mean scores, standard error and 95% confidence intervals across alignment and presentation conditions, when backwards recall is required

Alignment	Presentation	Mean	Std. Error	95% Confidence Interval	
Horizontal	Standard	3.08	0.100	2.88	3.28
	Interference	2.89	0.094	2.71	3.08
Vertical	Standard	2.81	0.106	2.60	3.02
	Interference	2.59	0.114	2.36	2.82

The analysis indicated significant differences in relation to the presentation condition $F(1, 95)=4.499$, $p < .05$, again consistent with the earlier analysis, with enhanced performance being found on the standard presentation type (mean=2.9, SE=.087, 95%CI=2.8-3.1) relative to the interference presentation type (mean=2.7, SE=.086, 95%CI=2.6-2.9). In contrast to the analysis of Experiment 1.2, no significant interaction was found between development and presentation type $F(1, 95)=.182$, $p > .05$, see Table 1.4. The analysis indicated that significant differences existed across conditions between developmental groups $F(1, 95)=6.662$, $p < .01$, indicating that D children were again demonstrating an impaired span capacity (mean=2.7, SE=.105, 95%CI=2.4-2.9) relative to the DN children (mean=3.0, SE=.101, 95%CI=2.8-3.2).

Table 1.4 Recall span mean scores, standard error and 95% confidence intervals across presentation and between development conditions, when backwards recall is required

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Standard	3.15	0.121	2.91	3.39
	Interference	2.91	0.120	2.67	3.15
D	Standard	2.73	0.125	2.49	2.98
	Interference	2.57	0.124	2.33	2.82

A second repeated measures analysis was carried out across the alignment, presentation and between development conditions this time with scaled digit span scores entered into the analysis as a covariate, again with longest span as the dependent measure. No significant differences were indicated between the presentation levels $F(1,94)=1.049$, $p > .05$, or the alignment types $F(1,94)=2.530$, $p > .05$, when digit span was co-varied. Neither were significant differences found between developmental groups $F(1, 94)=1.584$, $p > .05$, with DN (mean=2.94, SE=.104, 95%CI=2.74-3.15) and D (mean=2.75, SE=.108, 95%CI=2.53-296) children's recall span being largely similar, nor did the analysis indicate that the

interaction between development and presentation for backwards-recall was significant, $F(1, 94)=.357$, $p > .05$, see Table 1.5.

Table 1.5 Recall span mean scores, standard error and 95% confidence intervals across presentation and between development conditions, when backwards recall is required, and digit span is co-varied

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Standard	3.07	0.127	2.82	3.33
	Interference	2.81	0.123	2.57	3.06
D	Standard	2.81	0.131	2.55	3.07
	Interference	2.68	0.128	2.42	2.93

Serial Order Effects

The effect of serial order on the accuracy of recall was again assessed using the same method as Experiment 1.2, to determine item serial position allocation. The repeated measures ANOVA was run across alignment, presentation, serial order and between development conditions, with item accuracy ratios as the dependent measure. The analysis indicated that there were significant differences in the accuracy of recall across the alignment conditions $F(1, 95)=8.046$, $p < .01$, with children recalling horizontal presentations (mean=.95, SE=.031, 95%CI=.88-1.0) significantly better than vertical presentations (mean=.82, SE=.031, 95%CI=.76-.88). There were no significant differences in the accuracy of recall between the presentation conditions $F(1, 95)=1.047$, $p >.05$, with standard presentations (mean=.86, SE=.027, 95%CI=.81-.92) being recalled similarly to the interference presentations (mean=.90, SE=.030, 95%CI=.84-.96). The analysis of serial order position across experimental conditions again indicated highly significant differences in the accuracy of item recall between serial positions $F(2, 190)=274.144$, $p < .001$. Bonferroni comparisons indicated that once again children were recalling primacy items (mean=1.40, SE=.038, 95%CI=1.33-1.38) better than both intermediate (mean=.78, SE=.031, 95%CI=.70-.82, $p < .001$) and recency items (mean=.48, SE=.025, 95%CI=.43-.53, $p < .001$). Additionally, once again children were recalling intermediate items significantly better than recency items ($p < .001$). No significant differences were suggested in the accuracy of recall between the developmental groups $F(1, 95)=.623$, $p > .05$, with DN children's accuracy ratios (mean=.90, SE=.030, 95%CI=.84-.96) being similar to D children's (mean=.87, SE=.031, 95%CI=.81-.93). In contrast to the analysis in Experiment 1.2, no significant interaction between serial position and developmental groups was indicated $F(2,190)=.660$, $p > .05$, see Table 1.6.

Table 1.6 Displays the mean, standard error and 95% confidence intervals for DN and D children's recall span across serial position items.

	Serial Order	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	1.43	0.053	1.32	1.53
	Intermediate	0.77	0.043	0.69	0.86
	Recency	0.50	0.035	0.43	0.57
D	Primacy	1.39	0.055	1.28	1.49
	Intermediate	0.75	0.044	0.67	0.84
	Recency	0.46	0.036	0.39	0.53

Response Times

A repeated measures analysis was carried out on the RT data for correctly recalled sequences across alignment, presentation and between developmental groups (DN n=50, D n=44). There were no significant effects between alignment condition $F(1, 92)=.011$, $p > .05$, as RTs for horizontal placements (mean=4428ms, SE=109, 95%CI=4211-4644) were highly similar to RTs on the vertical placements (mean=4413ms, SE=118, 95%CI=4179-4547). Significant differences were found on the presentation condition $F(1,92)=7.796$, $p < .01$, indicating that slower RTs were occurring with the standard presentation (mean=4579ms, SE=116, 95%CI=4350-4809) than with the interference condition (mean=4262ms, SE=96, 95%CI=4071-4452). A significant main effect was found across development $F(1,92)=4.359$, $p < .05$, indicating that this time the trend did reach statistical significance with DN children responding significantly more slowly (mean=4579ms, SE=123, 95%CI=4359-4847) across conditions than the D children (mean=4238ms SE=131, 95%CI=3978-4498ms).

A second analysis was carried out on the RT data for when a wrong response was made across alignment, presentation and between developmental groups (DN n=50, D n=47). Again there were no significant effects or interactions involving the alignment condition $F(1, 95)=.193$, $p > .05$, with RTs on both horizontal (mean=6944ms, SE=210, 95%CI=6527-7362) and vertical placements (mean=7053ms, SE=252, 95%ci=6553-7554) not significantly differing. Significant effects were once more found across presentation types $F(1,95)=5.608$, $p < .05$, indicating that RTs on the standard presentation were significantly slower (mean=7228ms, SE=215, 95%CI=6802-7654) than on the interference presentation

condition (mean=6770ms, SE=223, 95%CI=6328-7654). Significant effects were found between development types $F(1,95)=13.784$, $p < .001$, suggesting once more that DN children were responding significantly more slowly (mean=7727ms, SE=273, 95%CI=7185-8269) across conditions than the D children (mean=6271ms, SE=282, 95%CI=5712-6830).

Direction of Recall Analysis

Span Capacity

The forwards and backwards-recall conditions were entered into a repeated measures analysis across the alignment, presentation and between developmental groups, with longest span as the dependent measure. Significant differences were found between levels on the alignment condition $F(1,95)=37.950$, $p < .001$, indicating that across order conditions children demonstrated significantly higher span capacity on the horizontal aligned trials (mean=3.3, SE=074, 95%CI=3.2-3.4) than the vertically aligned trials (mean=2.9, SE=.078, 95%CI=2.6-3.0). Significant effects were again found between levels on the presentation condition $F(1,95)=10.496$, $p < .005$, with span length on the standard condition being significantly higher (mean=3.2, SE=.071, 95%CI=3.1-3.3) than recall on the interference condition (mean=3.0, SE=.082, 95%CI=2.8-3.1). Significant effects were also found across the order condition $F(1, 95)=37.422$, $p < .001$, with forwards-recall showing a significantly enhanced recall (mean=3.3, SE=.083, 95%CI=3.1-3.5) relative to backwards-recall (mean=2.8, SE=.073, 95%CI=2.7-3.0). Significant differences in recall span were found between developmental groups $F(1, 95)=5.807$, $p < .05$, with the DN children having significantly higher recall overall (mean=3.2, SE=.095, 95%CI=3.1-3.4) than the DN children (mean=2.9, SE=.098, 95%CI=2.7-3.1).

The analysis also revealed a significant interaction between alignment and order conditions $F(1, 95)=6.699$ $p < .05$. As Figure 1.8 highlights, children demonstrated an increased impairment on the horizontal placements with the requirement to shift from forwards (mean=3.6, SE=.91, 95%CI=3.4-3.8) to backward recall (mean=3.0, SE=101, 95%CI=2.8-3.1), than was demonstrated on the vertical alignment trials with the same shift from forwards (mean=3.0, SE=.078, 95%CI=2.8-3.2) to backward trials (mean=2.7, SE=089, 95%CI=2.5-2.9).

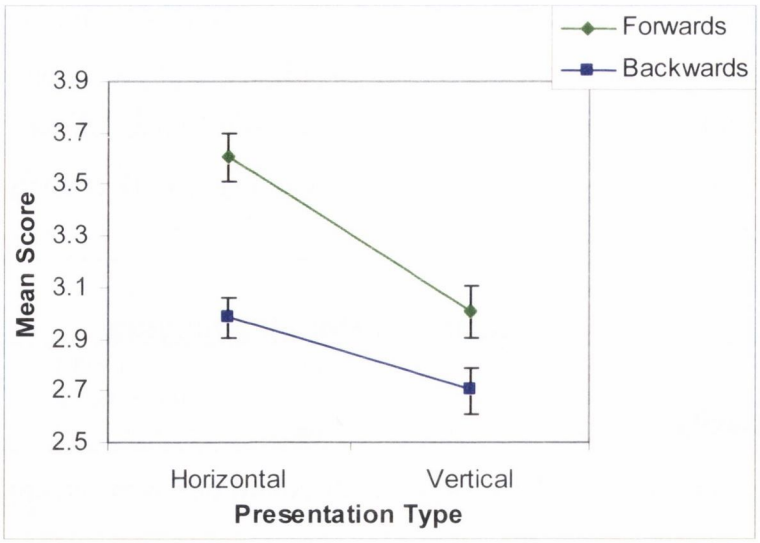

Figure 1.8 Line graph displaying the interaction between the alignment and order conditions.

A 3-way interaction was indicated between the presentation, order and development conditions $F(1, 95)=4.144$, $p < .05$ (see Figure 1.9). The data from Table 1.7 demonstrate that the interaction was due to a change in profile patterns between developmental groups as they moved from forwards to backwards-recall. DN children demonstrated no impairment due to interference stimuli on the forwards-recall, but were significantly impaired with the addition of interference when backwards-recall was required. In contrast to the DN children's profile, D children's performance was significantly impaired on the interference presentation relative to the standard presentation type on forwards-recall, but did not demonstrate significantly changed capacity between presentation levels when backwards-recall was required.

Table 1.7 Summary table with means scores, Standard Error and 95%CI for the 3-way interaction between presentation, order and developmental conditions.

Development	Presentation	Order	Mean	Std. Error	95% Confidence Interval	
DN	Standard	Forwards	3.45	0.127	3.20	3.70
		Backwards	3.15	0.121	2.91	3.39
	Interference	Forwards	3.44	0.148	3.15	3.73
		Backwards	2.91	0.120	2.67	3.15
D	Standard	Forwards	3.43	0.131	3.16	3.69
		Backwards	2.73	0.125	2.49	2.98
	Interference	Forwards	2.90	0.153	2.60	3.21
		Backwards	2.57	0.124	2.33	2.82

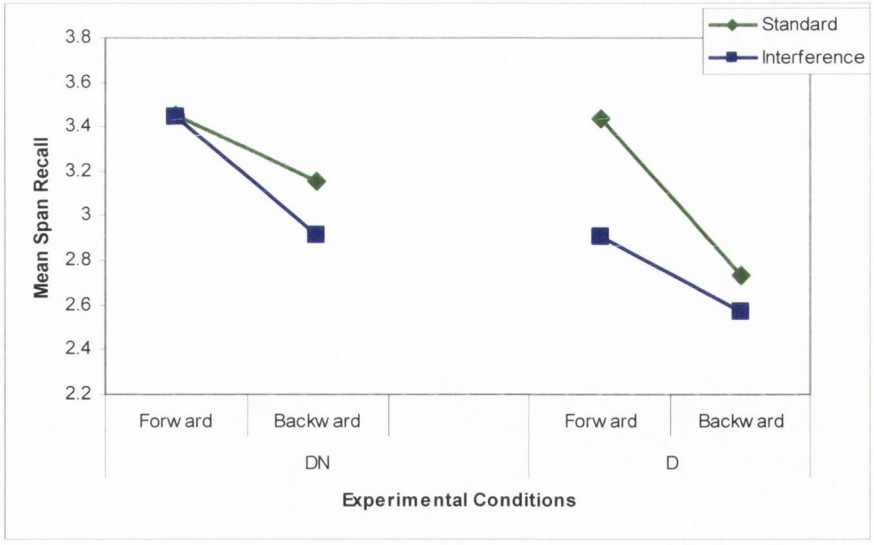

Figure 1.9 Line graph of the 3-way interaction between the presentation, order and development conditions.

When digit span scaled scores are entered as covariates into the same analysis as above, the only effect that remains significant is the 3-way interaction between development, presentation and order $F(1,94)=4.283$, $p < .05$. As the summary data in Table 1.8 demonstrate, when differences in verbal WM are accounted for, the D children show a significant impairment in performance under the forward interference and the backward standard recall conditions. The DN children do not show any significant impairment as a result of forward interference. In contrast, while D children do not have a significantly different performance between presentation levels in the backwards-recall condition, the DN children are significantly impaired by the addition of interference stimuli. So while D children's recall across the presentation levels becomes more similar when asked to reverse recall, the DN children show the exact opposite profile (see Figure 1.10).

Table 1.8 Summary table of confidence interval data and mean scores for the interaction between the development, presentation and order conditions when scaled digit span scores are entered in as covariates.

Development	Presentation	Order	Mean	Std. Error	95% Confidence Interval	
DN	Standard	Forwards	3.33	0.130	3.08	3.59
		Backwards	3.07	0.127	2.82	3.33
	Interference	Forwards	3.34	0.154	3.03	3.65
		Backwards	2.81	0.123	2.57	3.06
D	Standard	Forwards	3.55	0.135	3.28	3.82
		Backwards	2.81	0.131	2.55	3.07
	Interference	Forwards	3.01	0.159	2.69	3.33
		Backwards	2.68	0.128	2.42	2.93

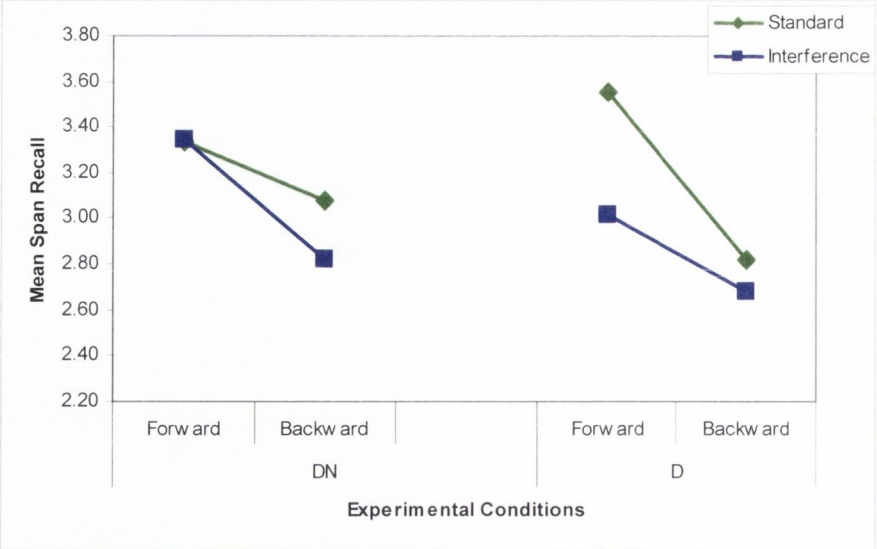

Figure 1.10 Line graph depicting the 3-way interaction between development, presentation and order conditions when digit span scaled scores are entered into the analysis as a covariate.

Response Times

The RTs for correctly recalled trials across forwards and backwards retrieval conditions were entered into a repeated measures analysis across the alignment, presentation and between developmental groups (DN n=49, D n=42). No significant differences were indicated between alignment conditions $F(1, 89)=.223$, $p > .05$, with RTs on horizontal trials (mean=4473ms, SE=88, 95%CI=4299-4647) being highly similar to RTs on vertical trials (mean=4420ms, SE=88, 95%CI=4245-4595). Significant effects were indicated between presentation type $F(1, 89)=14.909$, $p < .001$, again, children had significantly slower RTs in the standard presentation condition (mean=4633ms, SE=96, 95%CI=4442-4823) relative to the interference condition (mean=4260ms, SE=70, 95%CI=4122-4399). In keeping with the established profile, DN children (mean=4647ms, SE=93, 95%CI=4462-4832) continued to have significantly slower RTs than the D children (mean=4246ms, SE=101, 95%CI4046-4446) across tests $F(1, 89)=8.573$, $p < .005$. No significant differences in RT were indicated between order conditions $F(1, 89)=1.253$, $p > .05$, with forwards recall trial RTs (mean=4509ms, SE=91, 95%CI=4328-4687) being very similar to backward recall trial RTs (mean=4384ms, SE=86, 95%CI=4214-4554).

A second analysis was carried out on the RTs for incorrectly recalled trials in a second repeated measures analysis across the order, alignment, presentation and between developmental conditions (DN n=50, D n=47. Again no significant differences were indicated between alignment conditions F1, 95)=.125, $p > .05$, as horizontal RTs (mean=7264ms, SE=193, 95%CI=6881-7648) were almost identical to vertical trial RTs (mean=7194ms, SE=191, 95%CI=6815-7573). Significant effects were indicated between presentation conditions $F(1,95)=23.881$, $p < 001$, with slower RTs found on the standard presentations (mean=7599ms, SE=186, 95%CI=7229-7969) than the interference presentation trials (mean=6859ms, SE=175, 95%CI=6513-7206). Significant differences were indicated between developmental groups $F(1,95)=11.610$, P=.001, with DN children (mean=7788ms, SE=228, 95%CI=7335-8241) responding significantly more slowly than the D children (mean=6671ms, SE=235, 95%CI=6204-7138). Additionally, the order condition was also found to generate significant differences $F(1,95)=5.946$, $p < .05$, with RTs on the forwards condition (mean=7460ms, SE=196, 95%CI=7098-7821) being significantly slower than RTs on the backwards-recall conditions (mean=6999ms, SE=182, 95%CI=6609-7388).

Discussion

Span Capacity

Unlike the forward retrieval trials, when backwards recall was required the analysis now indicated that across conditions the D children were demonstrating a significantly lower recall capacity than DN children. While the analysis indicated that standard presentations were better recalled than interference presentations, interestingly, unlike Experiment 1.2, no significant interaction between development and presentation type was found, suggesting that with backwards recall both developmental groups were equally affected by the addition of interference.

In line with the findings of Experiment 1.2, the horizontal alignment condition was associated with better recall than the vertical alignment condition, with no suggested interaction with development. Nicolson and Fawcett's (2000) square root rule posits that however long it takes to acquire a skill for a developmentally normal child, it will take longer by a factor of 'the square root' of the time for a dyslexic child to acquire it. This could explain the lack of effects found across the horizontal

placement condition, with the argument being that both groups have reached a ceiling level of ability in their capacity to shift attention across the horizontal, given the differences in the degree of print exposure between these children. This however offers a poor explanation for why both groups demonstrate equal impairments on sequences presented vertically, as it seems highly unlikely that the ability to shift attention vertically rather than horizontally would have a lower maximal ability, and that both developmental groups simply reached these ceiling levels of ability. Instead, it is suggested that both groups are developing the ability to spatially shift attention at much the same rate and hence the equal impairment on the vertical placement. This implies that not all skills reveal an automatisation deficit in dyslexic children. The lack of an interaction between alignment and the interference condition would indicate that, rather than relating to impaired spatial focus for vertical alignments, the performance decrement may relate to a less developed spatial location mechanism for vertical alignments in both developmental groups.

Serial Order Effects

The lowered item accuracy ratio on both the interference and vertical alignment presentations would support the position that a weakening of representational codes due to interference or lowered LTM supportive representations reduces span capacity on these conditions. The lack of differences between developmental groups on the recall accuracy items suggests that when an error occurs, the accuracy profile is largely similar between D and DN children. This indicates that there are no differences between groups in the emphasis placed on individual items. Between Experiment 1.2 and 1.3 there was a consistent profile for serial position and item accuracy, with the highest recall accuracy occurring on the initial items, relatively lowered recall accuracy occurring on the medial items, and the lowest item recall accuracy occurring on the terminal items.

In verbal recall tasks, enhanced recall is frequently found on the initial and terminal items (Brown & Brown, 1982). This is known as a bow effect. The consistent lack of a traditional bow effect in serial position accuracy suggests that children may have been using visuospatial rather than verbal codes at the retrieval stage. Supporting this conclusion is the finding that across Experiments 1.2 and 1.3 the primacy effects were relatively weaker than has been suggested by previous research. This earlier research has indicated near perfect recall accuracy on the initial

items, while in the present study we found a primacy accuracy of only 62%. This finding, coupled with the lack of a traditional bow effect in recall accuracy (D. Jones et al., 1995; Penney & Godsell, 1999; Smyth & Scholey, 1996b), suggests that children were simply not fixing the initial or terminal items in memory as has been found in research with adult participants. Whether this finding relates to the age of the children or the present test methodology is a question for future research. In the current study, the stimuli remained visible throughout testing, so that children could use the visual display as a foundation for recall.

Response Times

In keeping with the results for RT in Experiment 1.2, significant effects were found for the presentation condition. Again, children responded significantly more quickly on the interference condition than on the standard presentation condition. RTs between developmental groups were significantly different for correct recall, suggesting that, in line with the trend suggested in Experiment 1.2, D children were responding significantly more quickly than DN children. This may relate to a speedier decay in visual representations on the part of D children (Visser et al., 2004). RT for incorrect recall followed an identical profile to correct recall. D children responded significantly more quickly than DN children, and overall children responded faster on the interference condition than for the standard presentation. Quicker RT for correct recall compared with wrong responses is consistent with Pickering's (2001) hypothesis that the quicker the response the higher likelihood of a correct recall. The finding that dyslexic children are responding more quickly across tests and response types may relate to an increased awareness on the part of D children that their ability to store information is more susceptible to overwriting or decay. This suggestion also ties in with the consistent finding that the interference presentation type had significantly quicker RTs across tests and response styles, and in both the developmental groups. The children were perhaps avoiding item intrusions by responding while the codes were still active in memory. Unlike DN children, however, D children experience degraded item representations even on the standard presentations, without the addition of task-irrelevant interferences.

Direction of Recall Analysis

Span Capacity

The analysis of span length across the three experimental conditions revealed significant differences between developmental groups. D children demonstrated a significantly lower span length than DN children overall, giving little apparent support for the idea of a visuospatial advantage in D children (Swanson, 1984; Winner et al., 2001). Existing research has suggested that there should be no significant difference in span length between forwards and backwards-recall on visuospatial tasks (Isaacs & Vargha-Khadem, 1989). In contrast, the repeated measures analysis indicated that span length was impaired by the requirement to reverse recall. One interpretation of this is that both groups could have been retrieving sequence information with a verbal recall strategy. While it was believed DN children were more likely to spontaneously recode the picture stimuli into verbal codes (Hitch, Halliday et al., 1989; Hitch et al., 1988; Hitch, Woodin et al., 1989), existing research suggested that D children were unlikely to use verbal mechanisms at recall (R. S. Anderson & Johnston, 1998). It must be acknowledged that, in the course of testing, individual children from both developmental groups were observed articulating the individual item names as item sequences were presented to them. However, Anderson and Johnston (1998) observed a similar degree of apparent articulatory rehearsal in their study, but found little evidence of verbal retrieval strategies in dyslexic children. What is suggested is that, while it is possible the deficit in span length for backwards-recall may be due to children verbally encoding/retrieving information, it is equally possible that the impaired backwards recall is due to relatively undeveloped fluency in this process.

Supportive evidence for this view comes from the three-way interaction between the development, presentation and order conditions. In the backwards-recall task, DN children show a significant impairment in span length when interference stimuli are present. Indeed, existing research has suggested that in verbal tasks the influence of interference stimuli decreases as task difficulty increases while for visuospatial tasks, intrusion errors increase as task complexity increases (Palladino, Mammarella, & Vecchi, 2003). Perhaps, then, both developmental groups were relying on visual spatial retrieval at the recall stage. As suggested earlier, allocation of spatial attention is mediated by inhibitory mechanisms (Cepeda et al., 1998;

Facoetti, 2001; Facoetti & Molteni, 2000). Thus, it seems logical that if attentional resources, in the form of the CE functioning, are diverted towards processing and reversing spatial sequences, the rate of intrusion errors should increase. Simply put, in backwards-recall, as sequence length increases, the requirement for CE resources proportionately increases. This in turn reduces the availability of attentional resources which can be directed towards inhibitory processes. As task requirements increase, the demands on CE resources increases the likelihood of inhibitory failure occurring.

On the backwards-recall task the analysis of interference effects followed the same profile as the earlier analysis, with higher span occurring on the standard presentation type. Unlike the earlier analysis, the data didn't reveal a significant interaction between development and presentation type. This suggests that with the requirement to reverse recall, the additional drain on CE resources impaired DN children's ability to inhibit task-irrelevant interference stimuli. Thus both groups demonstrated an equal impairment due to the addition of interference stimuli. This similarity in the effectiveness of interference stimuli between developmental groups (when CE resources and processing are diverted elsewhere) would suggest that the impaired recall capacity demonstrated by D children on the forwards-recall interference presentations related to impaired inhibitory function rather than the preferential access of stimuli presented on the right side of the visual field (Hari et al., 2001). Looking at the recall ability across test conditions, D children yet again were found to have a lower span capacity than DN children. But when scaled digit span, which acted as a measure of verbal and CE capacity in these children, was entered into the analysis, none of the conditions or interactions remained significant.

Nicolson and Fawcett (2000) suggested dyslexic individuals often experience a deficit in automatising tasks, but that through a process of conscious compensation their functioning can appear to be within normal levels. This lack of automaticity usually only becomes apparent when dyslexic children are required to perform a simultaneous secondary task, or if tasks are particularly complex or unusual. In the forwards condition, there was a significant effect of interference for the D children, but none for the DN children. Why might this be? In line with Nicolson and Fawcett's model of conscious compensation, D children may have used CE resources to scaffold VSWM in the standard presentation forwards-recall task. Support for this model comes from the finding that when scaled digit span scores were entered into the analysis as a covariate, D children's span scores on the standard forwards-recall

task were actually elevated above DN children's recall levels, although this difference didn't reach significance. The significantly lowered span length under interference conditions may relate to an inability to continue to scaffold VSWM with CE resources (as such resources are now required to inhibit the interference stimuli). A second, but highly related, suggestion is that the maintenance of CE scaffolding removes or limits the capacity to inhibit interference stimuli. While both options are possible, it seems likely that given there was no difference in the error types between developmental groups, the impairment was due to a reduction in CE scaffolding.

The increased task difficulty in the backwards-recall condition may similarly have made it difficult for D children to employ CE scaffolding. The lack of any significant difference between standard and interference presentation types in backwards-recall in this group may be because span length is close to floor levels. It is possible that if the methodology had allowed for a more sensitive measure of span length, an effect due to the interference condition on backward span length might also have been found.

Response Times

In the Experiments 1.2 and 1.3, D children have consistently responded more quickly than DN children. The most obvious conclusion to be drawn from these findings would be to suggest that these differences simply relate to the shorter span length of D children, as shorter span lengths simply require less time to copy out the relevant sequence of items. There is, however, little support for such an interpretation. While span length was consistently affected by alignment condition, there was no significant alignment effect for RT. Furthermore, span length for backwards-recall was significantly lower than for forwards-recall, yet the analysis of RT for correct recalls again found no significant differences between these conditions in relation to speed of responding. In contrast, both RTs in the interference condition across all the analyses were significantly quicker than RTs for the standard presentation condition. In line with the effects found between standard and interference levels on the presentation condition, it is suggested that tasks that contain interference selectively disrupt representations in storage, perhaps leading to either a degraded signal or simply a faster decay of representation, necessitating quicker recall in order to ensure representations are not over-written or lost (Penney & Godsell, 1999). Existing research suggests that dyslexics do have a difficulty in

inhibiting information which surrounds the target of attentional focus (Facoetti, Paganoni, Turatto et al., 2000; Rayner et al., 1989). Thus, D children may partially encode interference stimuli. This adds additional noise to the representation signal, which is likely to lead to quicker decay as there is a lower capacity for redintegration. The quicker RTs across test conditions may represent a means of counteracting this problem for D children.

General Discussion

The significant differences found between DN and D children across the various measures suggest that, in contrast to Vellutino's (1979) position, the assessment of dyslexic performance on VSWM tasks are indeed worthy of further investigation. The finding that significant differences remained, even after verbal working memory capacity was taken into account, suggests that not only do measures of visuospatial ability have a diagnostic potential, but that such tasks may also offer a further means by which to increase our understanding of dyslexia on a global and on an individual level.

Through the course of the testing, it was realised that the present test methodology largely constrained the sensitivity by which span length was assessed. The test procedure was such that if a child got the first sequence correct on a particular level they advanced onto the next level, while those that got a sequence incorrect were given a second chance at that level, with testing being terminated with 2 consecutive failures. The reasoning behind using such a methodology was to cut down on testing time, as even with the shortened procedure each testing session for the forwards and backwards-recall took between 30 and 45 minutes per child. While some children correctly recalled all sequences bar the two trials that terminated testing, other children made errors on every level they attempted in the test procedure. The problem with the scoring method is that both kinds of children may have achieved the same span length and this raises the question as to whether they should be considered as equivalent in visuospatial skill. On the one hand, they may have both successfully recalled sequences of the same length. The problem is that one child appears to be more error prone. Can we assume that this child would have got a further sequence on the relevant level correct? The honest answer is no, we can't. While considerable effort was placed on constraining sequence item placements so that all sequences of a particular level could be considered comparatively equivalent

in difficulty (by removing particular sequence types such as consecutive or mirror sequences etc) some sequences may still have been slightly easier to recall than others. As a means of overcoming this problem, the suggested best practice would involve testing children on at least 3 trials for each sequence length. This would necessitate a much longer test procedure but would allow for a far more reliable estimate of span performance. Using such a procedure would also allow for other scoring methods, such as total number of sequence items correctly recalled, or the total number of trials correctly recalled, rather than falling back on the longest span achieved as the only measure of capacity. It is possible that, through the use of such procedures and a more fine-grained and holistic scoring method, we may gain a further window into our understanding of the differences between D and DN children on visuospatial WM tasks.

As noted earlier, the significant differences between horizontal and vertical placement conditions would strongly indicate that both developmental groups were using visuospatial encoding and/or retrieval strategies. While individual children in each of the developmental groups were observed to articulate items as they flashed up on the screen, it is suggested that most children used visuospatial retrieval strategies and that the deficit in vertical performance related to a less developed spatial location capacity on the vertical domain. Unless a task specifically requires children at this age range to use verbal codes, they are likely to fall back on their earlier preference for visuospatial codes. However, it is possible that the ability to verbalise stimuli may strengthen memory representation through a process of dual representation, even if the secondary representation is not used at retrieval stage. Such an argument is in line with the findings of enhanced recall in 5 year olds who were required to name stimuli in a visually presented task, even though they demonstrated no signs of verbal retrieval or processing i.e. no word length or phonological similarity effects (Hitch et al., 1988).

A second aspect of this study relates to the nature of the particular representation used. As mentioned earlier, shape stimuli were chosen as a means of equating the level of predication between stimuli (Jones, 1985) and thus the strength of semantic and LTM representations between items. A shortcoming of this assumption was observed through the course of testing as children used signifiers which were not the expected shape names. For example, one child said "hospital" when the "cross" shape flashed up on the screen, another child was heard saying

"Christmas" in response to the star stimulus, a third child uttered "pyramid" in response to triangle shape presentation. While such responses were highly infrequent, it is possible that some of the children used signifiers which may have vastly different representations in LTM. This in turn could possibly affect recall accuracy. Future research into visuospatial WM needs to control for this degree of variation. One procedure would be to make sure all children use the same signifiers for particular stimuli, or to use the stimuli which are novel in terms of LTM representations and are unnameable by children.

Findings from a paper involving university students, published shortly after the completion of the current study, suggested that the requirement to backwards-recall does in fact impair span capacity on visuospatial tasks. The authors suggest that this impairment in span length is removed with practice, however, as it was only the initial assessment of backwards-recall that demonstrated an impaired performance relative to forwards-recall (Vandierendonck, Kemps, Fastame & Szmalec, 2004). It seems likely then that the earlier argument that children are simply slower at automatising the processes involved with backwards-recall was not far off the mark, and that this learning curve is experienced by both adults and children alike. Vandierendonck and colleagues also found that the requirement of random interval generation, but not fixed interval responding[11], was found to consistently impair span length on visuospatial tasks. This suggests that support from the CE is required in all visuospatial WM tasks. In a second experiment in the same paper, Vandierendonck and colleagues suggested that phonological coding might act as an additional backup mechanism when visuospatial storage capacities are exceeded in backwards-recall tasks. The suggestion was based on the finding that while articulatory suppression had no effects on the forwards-recall tasks, the addition of articulatory suppression was seen to significantly impair backwards-recall on the longer sequence items. However, it must be noted that a third experiment failed to replicate these findings, as the analysis did not indicate any effect of articulatory suppression on backwards-recall tasks, even ones at the extreme of span length. The authors argue that due to the

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[11] Random interval generation is suggested to rely heavily on continued CE processing for the intervals to remain "random" between taps. In contrast, interval responding once established, while requiring the same level of motor response as random interval generation, requires little in the way of executive monitoring to maintain it.

possibility that backwards-recall tasks may require simultaneous coding into both visuospatial and verbal stores, it should not be used as a measure of visuospatial WM, particularly in clinical populations.

Summary of findings

The current round of experiments indicated that D children do not demonstrate significantly different VSWM span capacities to DN children when standard forwards-recall is required. These findings however require further investigation before any firm conclusions can be established, due to the potential confound of using easily nameable stimuli for test presentations. Given that DN children may have enhanced their span capacity with the use of verbal WM scaffolding, the possibility remains that, on measures of strict VSWM, D children may still demonstrate a VS advantage. This possibility will be addressed in chapters 3-5. However the consistently impaired span capacity for sequences displayed on a vertical relative to the horizontal alignment presentations suggests both groups were, at least in part, relying on spatial retrieval during the recall phase. The lack of an interaction between alignment and development group indicated that if dyslexic children are experiencing a left mini neglect it was not sufficiently detrimental to their spatial processing to impair recall capacity.

D children did, however, demonstrate a significantly lower span capacity on the interference presentation conditions, while DN children's span capacity was not affected by the addition of task-irrelevant stimuli on the forwards-recall tasks. This would suggest that D children's weakened ability to maintain spatial focus can generalise to impaired functioning in other tasks, beyond the simple reaction time decrements found in other research. That D children will experience impaired functioning on simple memory tasks, due solely to the addition of task irrelevant stimuli, has potentially serious repercussions related to the manner in which these children are educated. These results suggest that beyond any difficulty associated with decoding phonological form, D children (at least at this age range) will also experience greater processing demands when required to read a sentence in a standard paragraph format, compared with sentences which are presented in isolation.

On reverse recall sequence presentations D children again demonstrated a significantly lowered recall capacity relative to DN children. This lowered capacity could relate to the suggested requirement for phonological scaffolding in backward

spatial recall tasks, although this seems unlikely given that significant differences remain between development groups even when digit span scores were co-varied in the analysis. More likely, the lowered capacity on the backwards-recall tasks relates to either a lowered capacity to adequately direct CE processing resources, or D children have fewer processing resources with which to work.

DN children also experienced significantly lowered recall capacity due to task-irrelevant interference when backwards-recall was required, relative to the standard reverse recall task. This finding suggests that spatial focus or inhibitory function is taxed by the requirement to manipulate sequence order. While D children did experience a slightly lower recall capacity on the interference tasks relative to the standard backwards-recall tasks, the capacity shift remained non-significant. Rather than suggesting this relates to a lack of interference effects on backwards-recall tasks, it is likely to be due to floor effects.

Chapter 3- Experiment 2

Spatial working memory capacity in dyslexic children, variations in recall capacity according to spatial presentation.

Experiment 2 Introduction

In the interim between the completion of Experiments 1.2 and 1.3 and the start of testing for the current study Experiment 2, a number of publications appeared that suggested, in opposition to the findings of Experiments 1.2 and 1.3, that dyslexic children have normal functioning on VSWM tasks (Jeffries & Everatt, 2004; Kibby et al., 2004; Pickering & Gathercole, 2004). On a closer analysis of these studies, we noticed a possible methodological flaw inherent in the assessments. That is, none of the studies had expressly taken steps to systematically manipulate task difficulty. Smirni, Villardita and Zappala (1983) demonstrated that if measures are not taken to equate sequence length with task difficulty, 58% of participants will succeed in correctly copying longer spatial sequences after apparently exceeding capacity limits on shorter sequences, thus leading to a highly unreliable assessment of VSWM ability. The methodology used in Experiments 1.2 and 1.3 left open the possibility of a similarly valid criticism being levelled. That is, even though there was evidence that spatial encoding was occurring, the stimuli used did not preclude the possibility of verbal encoding taking place, and this may have led to D children's impairment on the tasks. Hamilton, Coates and Heffernan (2003) suggested that in order to identify the extent to which component processes are contributing to developmental changes in ability, research must be tailored to the specific functionality of the individual VSWM subcomponents. It was for this reason that the current investigation was directed towards assessing functioning on measures which primarily tax spatial WM. A WM task which is primarily spatial in nature can be roughly defined as a task using items that, while incorporating geometric relationships between items in the form of movements from one item to another in a spatial array, they contain no visually distinguishing features bar the items' relative geometric positioning in the spatial array (Logie, 1995).

A second research question was directed towards redressing an assumption made in Experiment 1.2, which suggested that there was an increased ecological validity in assessing VSWM through the use of parallel presentation of stimuli over matrix presentations types. The claim was made as it was believed that matrix presentation types incurred an increased probability of participants chunking sequence paths, giving a less reliable estimate of VSWM capacity. In a review of the research literature, the researcher found no evidence that any investigation had sought to compare matrix and parallel placement conditions. For this reason, it was decided to test the assumption that visuospatial span length is lower on parallel than matrix style tasks. We wished to investigate whether, on tasks of pure spatial WM, there was any evidence that D children experienced a deficit in span capacity relative to DN and Reading Age matched developmentally normal literacy unimpaired (RA) children, particularly if the scoring methodology allowed for a far more detailed investigation of response profile.

The measurement of VSWM task difficulty is often related solely to an increase in the number of sequence items to be remembered. There does, however, exist a long-standing line of research which has assessed how elements such as display types and spatial configurations modify task complexity in VSWM. Chipman (1977) suggested that complexity could be best understood in terms not only of quantitative elements but structural aspects as well. In Experiment 1.1 we suggested that there may not have been a linear progression in trial difficulty with the addition of subsequent items to sequences. The argument suggested that while the later sequences contained more items, they may also have enabled a much more structured representation of the sequences path, which could lead to enhanced recall on these trials over lower item sequence trials. In line with this position, Kemps (1999) suggested that due to the nature of VSWM, tasks such as a the Corsi blocks task elicit two kinds of structural complexity, the structure of the to-be-remembered span path, and the display structure, which relates to the manner in which stimuli are positioned in the spatial array. Path complexity is built up by the order in which items flash up on the screen, while the display structure relates to the relative degree of symmetry or interrelations between items in the display with complexity increasing as asymmetry increases.

Berlyne (1960) suggested that it is the degree of variation in a stimulus that defines complexity. If we relate his position to VSWM tasks we can see that as the

number of items in a display increases so too should complexity. In contrast, the degree to which display items may be perceived as a continuous entity will decrease complexity. Kemps (1999) found evidence for both of these positions, finding that sequence trials of the same length are better recalled on a 9 item display than a 16 or 25 item display. Likewise, sequences displayed on a 3x3 or a 4x4 matrix are easier to recall than trials displayed on 9- or 16-item randomly positioned display. The research also indicated, however, that there was no difference between structured and unstructured 25 item displays, supporting Logie and colleagues' earlier thesis which proposed that VSWM is limited by the complexity of visuospatial material (Logie, Zucco, & Baddeley, 1990). The increase in span lengths for structured display types is suggested to lie with an enhanced LTM representation in these tasks over unstructured displays, similar to the findings of enhanced recall for real words versus non-words in phonological WM tasks (Multhaup, Balota, & Cowan, 1996).

Kemps (1999) linked these findings to the Gestalt principle of "figural goodness", whereby the relative degree of symmetry, continuation, simplicity, closure and proximity, amongst other forms of regularity, all play a part in reducing complexity and thereby increasing figural goodness. While Smyth and Scholey (1994), using a computerised version of the Corsi blocks task, found that neither varying the size of the blocks or the distance between blocks affected recall ability, there is strong empirical support that the other elements of figural goodness do shape the accuracy of VSWM recall. Kemps (2001) further clarified this position by suggesting that good continuation and symmetry serve to increase the degree of structural redundancy in the spatial array, that is, the ease by which individual elements within a display are integrated into the overall display or can be predicted through reference to the other elements. Like structural complexity, Kemps found sequence path complexity followed much the same principles with redundancy reducing task difficulty and hence enhancing span length. One's sense of "figural goodness", or perceived redundancy in a path's sequence, is related to the degree of similarity between the pattern of path and LTM representations. Supporting this position, Kemps' (2001) research indicated that span capacity was still better for structured paths over complex ones even when participants were required to carry out spatial suppression techniques. This suggests that if paths contain aspects of either symmetry, continuation and/or repetition they are easier to redintegrate, due to

interrelatedness between elements in the sequence, as these paths are less likely to be encoded as separate items but rather as a continuous whole.

In a second study in the same paper, Kemps (2001) found that there was little difference in span accuracy between structured and complex paths at item lengths of three or four items, indicating that VSWM has at least a three or four item capacity in adults, and that increased span lengths likely relate to a increased ability to chunk sequence items relative to LTM representations. Research addressing visual binding in short term memory has suggested a similar capacity limitation of 3 or 4 feature items which can be attended to simultaneously (Wheeler & Treisman, 2002). Kemps, in a third and fourth study in the same paper, investigated whether recall of complex path sequences could be increased through repetitive exposure. The evidence suggested that through training on individual complex path sequences (eight exposures on the same sequence) span length could be elevated to a capacity level similar to structured sequences, but that this enhancement did not transfer to other complex paths. In a fifth study, she found evidence that a single exposure to a particular sequence was enough to improve subsequent recall although not nearly to the same level of recall experienced with structured paths. Again no improvement transferred to new complex sequences, suggesting that learning was specific to the particular sequence, supporting Logie's (1995) thesis that representations in WM are filtered through LTM representations.

Research by Logie and Pearson (1997) assessing children in 3 separate age brackets (5-6, 8-9, and 11-12 years of age) on both a visual patterns task and a Corsi block type task, suggested that there was a much steeper capacity increase with age on the visual patterns task than the Corsi blocks task, indicating that the individual subcomponents of the WM system have distinct developmental patterns. A similar pattern of divergent developmental increases between the spatial and visual components of WM was also found between 5, 8 and 10 year old children (Pickering et al., 2001). Although the authors addressed this question in terms of the static or dynamic nature of tasks, it is probably best viewed in terms of dual coding, where spatial encoding occurs in both tasks but to a lesser extent in the static tasks, with visual encoding remaining relatively constant, as demonstrated by the finding that both tasks were impaired by the secondary requirement of spatial tapping. A third study in the same paper, however, found that spatial tapping did not disrupt performance on the static task with adult participants, suggesting perhaps that unlike

the children in the study, adults have perhaps acquired an enhanced visual encoding mechanism which no longer requires spatial scaffolding, and that this enhancement may be due to enriched visual LTM representations.

In Experiments 1.2 and 1.3, six item parallel displays were used. A review of the research addressing visuospatial functioning with measures such as the Corsi blocks task found that the vast majority of research (37 out of 38 reviewed studies) had used a nine item display (Berch, Krikorian, & Huha, 1998), with the other study using a ten item layout. While changing to a nine item format will increase the validity of comparison between this and existing research, it more importantly entails a relative increase in task complexity without dramatically altering the task requirements. It is possible then that the relative deficit in D children's performance suggested in Experiments 1.2 and 1.3 may have related to less developed LTM spatial representations and hence they would have experienced sequences as less structured than DN children. While the D children did not show an impaired recall capacity on the standard forward recall tasks in chapter 2, it is believed that the move to a nine item display may warrant enough of an additional challenge for these children to highlight differences in spatial encoding.

Pickering and Gathercole's (2004) research, while not specifically directed towards assessing dyslexic children's ability, given that the study only contained 3 diagnosed dyslexic children, did subgroup these children as part of a low literacy special educational needs (SEN) group. The study suggested that not only did low literacy children not show a specific impairment on VSWM measures, but in opposition to existing research (de Jong, 1998), they were not impaired on any working memory measures including CE and verbal WM. They further suggested that WM impairments were only found either in children with language difficulties who were experiencing difficulties in CE and verbal WM tasks, or children with general learning problems (that is difficulties in English/literacy and mathematics) who were experiencing difficulties on all three subcomponents of WM. The study contained two potential methodological shortcomings. Firstly, there was no evidence that the authors had attempted to homogenise or systematically manipulate trial difficulty, and secondly, and perhaps more critically, the individual SEN groups were not matched in terms of age. The youngest group, the language impaired group, had a mean age of just 7 years, while the oldest group, the literacy impaired SEN children, had a mean age of 9.6 years. This deviation in age ranges is of particular importance given that

there is rapid developmental growth on the individual WM subcomponents functioning in this age range (Logie & Pearson, 1997; Pickering, 2001; Pickering et al., 2001). While the individual groups' ability ranges were assessed with respect to age matched cohorts, it is possible that, if the particular SEN groups were assessed at different age ranges, they may have demonstrated different levels of ability, showing deficits at one point and normal functioning at later or earlier stages. This change in functioning with age rather than in relation to a strict developmental improvement in capacity in the individual subcomponents, has been suggested to actually reflect the way in which the individual subcomponents interact and support each other (Hamilton et al., 2003).

Jeffries and Everatt (2004), using the same VSWM measures as the Pickering and Gathercole study (which were taken from the Working Memory Test Battery for Children (WMTB-C), Pickering & Gathercole, 2001), compared both dyslexic children and a catch-all group of SEN children (which included children with dyspraxia, emotional/behavioural problems as well as attention deficits), with developmentally normal children. In contrast to Pickering and Gathercole's results, dyslexic children now demonstrated an impaired performance on the verbal WM measures. Findings suggested mixed results across the CE measures, in that they demonstrated a significant impairment in some but not all tasks, with no significant impairment indicated on either of the two VSWM measures, block recall and maze memory. Kibby et al.'s (2004) research, which addressed dyslexic children's ability on VSWM tasks, suggested no significant differences between dyslexic and control children. However, it must be noted that while the researchers again made no reference to the need to homogenise task difficulty between trials, the reliability of the assessment was also seriously constrained by floor effects. While the assessment procedure entailed testing children at sequence lengths of 3, 5 and 7 items, the majority of children in both developmental groups failed to copy any of the 5 or 7 items sequences correctly, necessitating that the comparison in ability was in effect only related to the 3 item sequences. Thus the study had little hope of uncovering differences in VSWM functioning between dyslexic and developmentally normal children, as the measures were simply too crude. Supporting this argument was the finding that their study also suggested there were no differences in VSWM ability between ADHD and developmentally normal children either, in contradiction to existing research (Westerberg, Hirvikoski, Forssberg, & Klingberg, 2004).

In keeping with Pickering and Gathercole's suggestions that deviations from normal functioning in visuospatial ability may go hand in hand with deficits in mathematical ability, Helland and Asbjornsen (2003) suggested that while both mathematically normal and mathematically impaired dyslexic children had lower visual WM span capacity than developmentally normal age matched children, on measures of visuospatial organisational ability, only the mathematically impaired dyslexic children showed a significantly lower ability than control children. While the findings from the study suggested there was little evidence for a specific subgrouping of dyslexic children whose difficulties were particular to VS impairment, the evidence did suggest that individual subgroups within the dyslexic spectrum do experience VSWM impairments beyond the traditional verbal WM deficits. Further research has supported these findings that dyslexic children are impaired on visual WM tasks (Reiter et al., 2005). Unfortunately, as the study did not control for mathematical ability, or assess VSWM ability, it is impossible to ascertain if spatial WM impairments exist irrespective of mathematical ability.

A recent study involving dyslexic adults has indicated a lowered ability on VSWM tasks if there is a high memory updating load, i.e. when sequences are at the limit of span capacity (Smith-Spark et al., 2003). Given the polarised research findings in respect to possible VSWM impairments in dyslexic children, it is believed that further research is needed to clarify how and where these possible deficits in VSWM are manifesting themselves in dyslexic children. As the findings from Experiments 1.2 and 1.3 are open to the criticism that dyslexic children's deficits in ability may have related to the verbalisable nature of the stimuli used, we decided to reassess dyslexic children's functioning on measures where verbalisation of test stimuli was not possible, that is, visually indistinct measures of spatial WM ability.

Method

Participants

Forty seven dyslexic participants were recruited from dyslexic schools and reading units in the greater Dublin region. All participants had been formally diagnosed with dyslexia, and had no documented co-morbid disorders such as ADHD or Dyspraxia. However, eight of dyslexic participants when assessed on Neale Analysis of Reading Ability second edition (NARAII) and the Wide Range

Achievement test, third revision (WRAT-III) were found to be reading and spelling at or above the average range and so were removed from all subsequent analysis, leaving a sample size of 39 dyslexic children. The gender breakdown was 27 males and 12 females aged between 9-11 years with a mean age of 10.5 (1.1). The mean NARAII reading age was 7.1 (SD=.83) with a comprehension age of 7.6 (SD=1.1), and a WRAT-III spelling ability of 79 (SD=5.5).

Thirty nine developmentally normal (DN) children were recruited from schools in the greater Dublin region. Where possible, control children were recruited from the same schools as the dyslexia reading units. Where this was not possible, schools within the same catchment area were used as a means of matching for socio-economic status. DN children had a similar gender breakdown to the D children: 26 males and 12 females[12], with same age range (9-11) and a mean age of 10.5 (SD=.8). The DN children had a NARA reading age of 11.3 (SD=1), a comprehension age of 10.8 (SD=1.4), and their WRAT spelling ability was 107 (SD=9.0).

Thirty five developmentally normal literacy unimpaired children, who had been matched with the D children on reading age (RA), were recruited in the same fashion as the chronological age-matched children. RA children had a gender breakdown of 24 males and 11 females, with an age range of 6-9 years and a mean age of 7.2 (SD=.9). The RA children had a NARA reading age of 7.3 (SD=1), a comprehension age of 7.4 (SD=1.1) and a mean WRAT spelling ability of 108 (SD=12.1).

The Conner's Parent Rating Scale-Revised short form (CPRS-R:S) was used to assess general ADD or ADHD type symptoms in all children in the sample. The scale is further sub-divided into 4 factors: Oppositional, Cognitive problems/inattentive, Hyperactivity and ADHD Index. Due to the difficulties with returned blank forms in a previous round of assessments, teachers were asked to draw particular emphasis to the form when giving the information sheets to parents. Teachers agreed to go through the form with any parents who had learning difficulties. In this round of testing there was a 100% form fill-in rate. Dyslexic children whose profiles fell into the 'at risk' sections, that is T-scores above 60 (Ghelani, Sidhu, Jain, & Tannock, 2004), on any of the above factors, were analysed

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[12] One female child was removed from the DN group because of an 'at risk' of ADD/ADHD profile as indicated by the Conner's parent rating scale.

as a separate 'dyslexia at risk' group. In this way the dyslexic children were split between a low risk of ADD/ADHD group the "D" group (n=26), and a high risk of ADD/ADHD group the 'dyslexic at risk' (DAR) group (n=13). One child in the DN group had a profile in the 'at risk' range and he was removed from all future analysis. It is interesting to note that all of the eight children who were removed from further testing because their literacy assessment indicated they were functioning at average or above average ability, were categorised as 'at risk' profile according to the CPRS-R:S, perhaps suggesting a misdiagnosis of dyslexia in these children.

An additional 35 children, who received parental consent to be included as control children in the study, were not assessed on the computerised tests measures as their NARAII and WRAT-III scores had indicated they were not within the average range of ability for their age group. This was because the majority of these children scored in the gifted range on the test measures. These children were not assessed further as it was believed they would unfairly bias the comparison groups.

Mathematical ability as assessed by the Wechsler Objective Numerical Dimensions (WOND) was collected from a convenience subpopulation of 28 of the 39 dyslexic children, which allowed for a secondary analysis to further test Helland and Asbjørnsen's (2003) hypothesis that VSWM deficits were particular to dyslexic children with an additional mathematical impairment. While we initially collected data from 14 children in each of the D and DAR groups, however three of these children were those from the DAR group that had been removed as they were no longer demonstrating literacy impairment. This left 11 children in the below average mathematical ability group (BAM), which was defined as having a WOND score at least 1 SD or more below their expected age related ability (4 of which were from the DAR group).There were 14 children in the average and above average mathematical ability (ABA) group (7 of which were from the DAR group), allocation to the group was defined as having a WOND score within 1 SD or above expected age related mathematical ability.

All children's verbal WM was assessed with the digit span measure of the WISC-III.

Written parental consent was obtained for all children in accordance with the ethical regulations of the School of Psychology, Trinity College Dublin.

Apparatus

As with Experiments 1.2 and 1.3, all children were tested individually, in a quiet room in the participating schools. All computerised testing was carried out using a laptop computer, with the test stimuli being presented on a 17" LCD Elo touch screen monitor. Care was taken so that the rooms were moderately lit and that the computer screen did not face any windows in the room to avoid screen reflections. Children sat approximately 60cm from the screen although their position was not restrained. As schools are intrinsically noisy places children wore Sennheiser noise reduction headphones throughout testing as a means of reducing between-setting variation.

Procedure

The matrix and parallel spatial WM tests were given as part of a larger test battery of VSWM tasks. The battery was spilt into 3 separate subtests which were administered on three separate days. The order in which children carried out particular subtests and the order of tests within subtests was randomised. All parallel presented trials used a horizontal placement in Experiments 2-4, and across Experiments 2-5 children were only required to carryout forward recall of the test sequences. Further explanation of the individual elements within and across subtests will be detailed in chapters 4, 5 and 6.

There was one constraint on the random ordering of tests which entailed that children were always tested on the matrix spatial presentation in the first session and the parallel spatial presentation on the second testing session. The procedural layout for the tests was much the same as the setup in Experiments 1.2 and 1.3, with stimuli flashing one at a time for 500ms with a 1000ms between-item interval before the next item flashed up. The task again required children copy the order in which the items flashed-up on the screen (visually identical blue squares for both matrix and parallel spatial presentations), by touching them in the same order they flashed up on the touch-screen. Again graphical instructions and demonstrations were given to children before the start of each test, and children were asked to explain the task to ensure procedural understanding. Unlike the earlier experiments, children were given practice attempts at the task as an additional means of ensuring that they understood task requirements, with the testing proper starting after the first correctly copied sequence. Again the same traffic light-like stimuli were used at the start of each trial

to fixate gaze, with the sounding of a tone at the end of each sequence indicating it was time to start copying the order items flashed up on the screen.

Unlike Experiment 1.2 and 1.3, after a sequence had finished flashing up on the screen, the response screen on which children copied out the sequence was visually distinct and now contained an answer box. The answer box comprised of a lighter shaded box which appeared once a sequence had finished flashing up. If a child touched an item on the response screen it would appear in the answer box. The answer box, as such acted not only as an additional response cue, but more importantly this allowed for immediate visual feedback on the sequences children were copying out, as the copied (touched) sequence would remain present in the answer box till children touched the green tick. As children could now ascertain exactly what they had copied out so far, the delete function on the red 'X' now deleted only one item from the answer box at a time, rather than the entire sequence. For a complete overview of the test procedure, see Appendix 2.

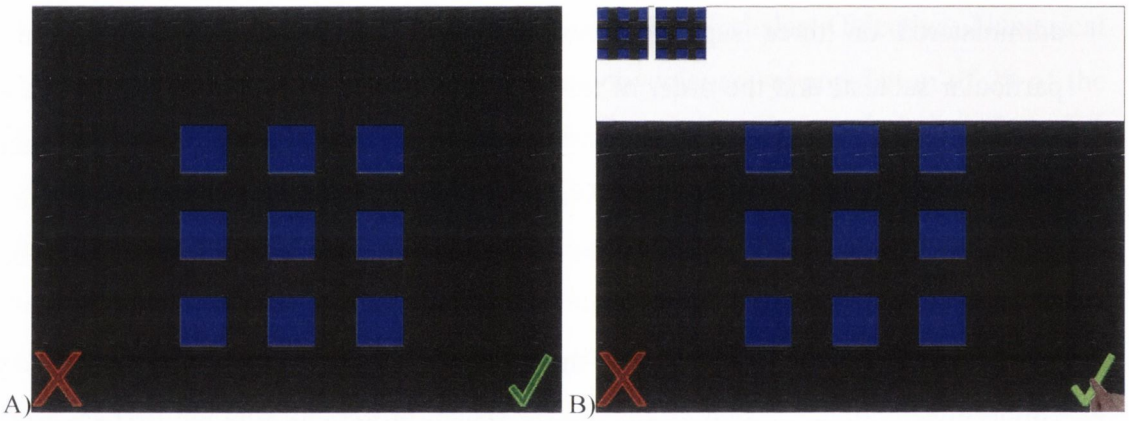

Figure 2.1 Screenshot (A) displays the matrix style presentation test, while screenshot (B) displays the matrix presentation response screen, with the answer box containing a two item response.

On each sequence length children attempted three trials, with an additional item being added to the sequence length only if the child had managed to correctly recall at least one trial of the previous length. Testing was terminated if a child was unable to correctly copy any of the 3 trial sequences at a given sequence length. 2 measures of span ability were taken: 1) the traditional longest sequence correctly recalled "longest span"; 2) the total number of correctly recalled sequence trials

"CRT".[13] The CRT scoring method was included as it was believed that it may act as more sensitive measure of span ability, giving a more complete picture of overall ability.

Numerical signifiers have been superimposed on the screenshots in Figure 2.2 to clarify for the reader the types of sequences that were removed from the testing environment, with a view to homogenising task difficulty. Possible sequence item combinations were constrained on the two presentation types such that none of the sequences were mirrored or contained mirrored items, that is sequences of the nature 3, 5, 3, or 8, 2, 6, 2, etc. were not possible. While items were chosen with replacement, an item could not be re-presented without an interval of at least 2 other items. Consecutive sequences of three or more items were removed from possible test sequences as well. Thus on the parallel test, sequences such as 8, 7, 6, or 2, 3, 4, were not possible, whereas on the matrix test sequences of the type 9, 8, 7, or 3, 6, 9, or 7, 5, 3 were not included in testing.

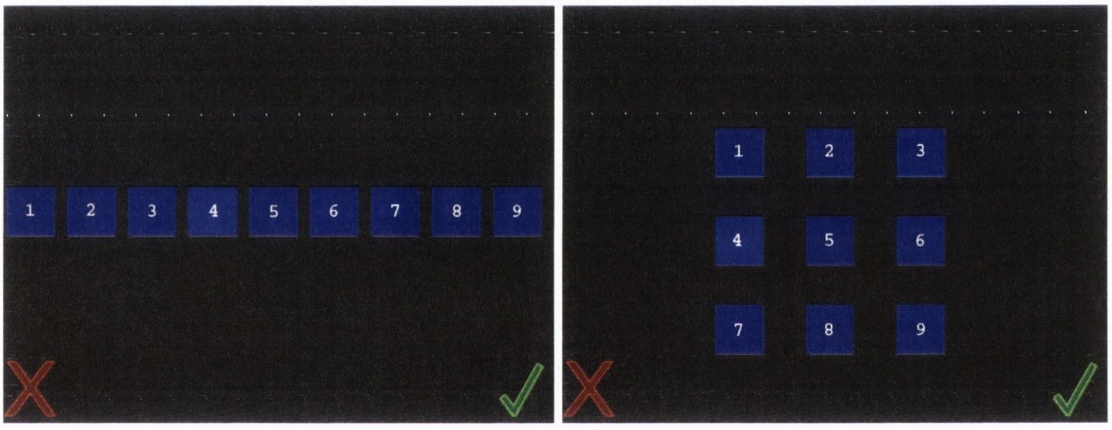

Figure 2.2 Screenshots of both parallel and matrix placement conditions which have both been superimposed with numerical signifiers.

Individual repeated measures ANOVAs were carried out across the two spatial conditions (parallel versus matrix) and between the four developmental groups (D, DN, RA and DAR children) on the separate scoring measures of longest span and CRT. All pairwise comparisons used Bonferroni conversions to adjust P-values. Additionally, once more a secondary analysis of RT and serial order effects was

[13] Two other scoring measures were additionally assessed, which were the total number of correctly recalled items within sequences trials "IWS", and composite score "CS". The CS was derived by summing the top three longest correctly recalled sequence trial levels and dividing this score by three. As the findings form both the IWS and CS methods were highly correlated with the findings from the CRT method, only the CRT was included in the analysis as a contrast to longest span scoring method.

carried out across test conditions and developmental groups. One-way ANOVAs were carried out on the grouping variables to demonstrate the extent of matched comparability between developmental groups. A separate repeated measures ANOVA also assessed possible differences in recall span across the spatial presentations between BAM and AMA children as the between groups conditions.

Results

Grouping Variables

In order to ensure the reliability of comparison between the four developmental groups, a number of one-way ANOVAs was carried out with individual grouping variables as the dependent measure. Significant differences in age were found across developmental groups $F(3, 108)=124.660$, $p < .001$. Bonferroni comparisons indicating that RA children were significantly younger (mean=7.2, SD=.91, 95%CI=6.8-7.5) than D (mean=10.63, SD=.86, 95%CI=10.27-10.97, $p < .001$), DN (mean=10.51, SD=.80, 95%CI=10.24-10.77, $p < .001$) and DAR children (mean=10.35, SD=.69, 95%CI=9.94-10.77, $p < .001$) with none of the other groups differing in age. Significant differences were also found in respect to reading age between groups $F(3, 108)=131.546$, $p < .001$. Pairwise comparisons indicated that DN children (mean=11.37, SD=1.22, 95%CI=10.97-11.77) were reading at a significantly older age level than the D (mean=7.02, SD=.77, 95%CI=6.70-7.33 $p < .001$), DAR (mean=7.11, SD=.99, 95%CI=6.51-7.71 $p < .001$), and RA children (mean=7.33, SD=1.08, 95%CI=6.97-7.71, $p < .001$), with no significant differences existing between the other groups. The groups again significantly differed in respect to reading comprehension age $F(3,108)=55.721$, $p < .001$, with pairwise comparisons indicating that the DN children (mean=10.79, SD=1.42, 95%CI=10.32-11.26) were comprehending text to a significantly older age level than the D (mean=7.75, SD=1.15, 95%CI=7.28-8.21, $p < .001$), DAR (mean=7.57, SD=1.29, 95%CI=6.79-8.35, $p < .001$) and RA children (mean=7.44, SD=1.11, 95%CI=7.05-7.82, $p < .001$), with no significant differences existing between the other groups. Significant differences between groups was also found in respect to spelling ability $F(3,108)=82.630$, $p < .001$. Planned comparisons indicated that both D (mean=80.19, SD=5.6, 95%CI=77.92-82.47) and DAR children (mean=77.38, SD=5.0, 95%CI=74.37-80.40) had significantly lower ($p < .001$) age

appropriate spelling levels than either DN (mean=107.81, SD=9.1, 95%CI=104.81-110.82) and RA children (mean=108.14, SD=11.1, 95%CI=103.98-112.30).

Significant differences were found between groups on digit span ability $F(3,107)=11.858$, $p < .001$, with pairwise tests indicating that both D (mean=8.69, SD=2.9, 95%CI=7.53-9.86, $p < .001$) and DAR children (mean=9.0, SD=2.5, 95%CI=7.48-10.52, $p < .01$) had significantly lower age appropriate span levels than either DN (mean=11.92, SD=2.5, 95%CI=11.08-12.98) and RA children (mean=12.03, SD=2.8, 95%CI=11.08-12.98).

Span Capacity

As was stated in the procedure, two separate methods of quantifying recall span were collected in the current experiment, longest span and the CRT. Separate repeated analyses were carried out using either the longest span or CRT scoring method as the dependent variable. As it was believed that CRT, may act as a more sensitive measure of recall span.

Table 2.1 Longest span mean scores, standard error and 95%CI across developmental groups and spatial presentations types.

Development	Spatial	Mean	Std. Error	95% Confidence Interval	
DN	Matrix	5.43	0.150	5.13	5.73
	Parallel	4.57	0.144	4.28	4.85
D	Matrix	5.12	0.179	4.76	5.47
	Parallel	3.81	0.172	3.47	4.15
DAR	Matrix	4.62	0.253	4.11	5.12
	Parallel	3.31	0.243	2.83	3.79
RA	Matrix	4.43	0.154	4.12	4.73
	Parallel	3.57	0.148	3.28	3.87

The first repeated measures analysis was carried out with longest span as the dependent measure across the 2 spatial (parallel and matrix) presentation and between the 4 development conditions. The analysis found that matrix presentation types (mean=4.90, SE=.094 95%CI=4.71-5.09) had significantly longer span lengths $F(3, 107)=108.091$, $p < .001$ than recall on the parallel presentation types (mean=3.81, SE=.091, 95%CI=3.63-3.99). There was no significant interaction between presentation type and development $F(3, 107)=1.652$, $p > .05$ (see Table 2.1), but as Figure 2.3 demonstrates there was a very slightly modified trend between literacy impaired and unimpaired children. Significant differences in respect to span length were indicated between developmental groups $F(3, 107)=12.984$, $p < .001$, with pairwise tests finding that DN children had significantly longer span lengths

(mean=5.00, SE=.122, 95%CI=4.76-5.24) than D (mean=4.46, SE=.145, 95%CI=4.17-4.75, $p < .05$), DAR (mean=3.96, SE=.205, 95%CI=3.554-4.37, $p < .001$) and RA children (mean=4.00, SE=.125, 95%CI=3.75-4.25, $p < .001$) with none of the other groups significantly differing from one another.

As a means of offering a direct comparison with the findings of Experiment 1.2, a planned one way ANOVA was carried out on matrix and parallel tasks individually between DN and D children. The analysis suggested that while DN (mean=5.42, SD=.919, 95%CI=5.12-5.72) children did not significantly differ from D children (mean=5.12, SD=.909, 95%CI=4.75-5.48) on the matrix tasks $F(1,62)=1.722$ $p > .05$, DN children (mean=4.57, SD=.929, 95%CI=4.26-4.88) had significantly higher span lengths than D children (mean=3.81, SD=.742, 95%CI=3.50-4.11) on the parallel presentations $F(1,61)=11.920$, P=.01.

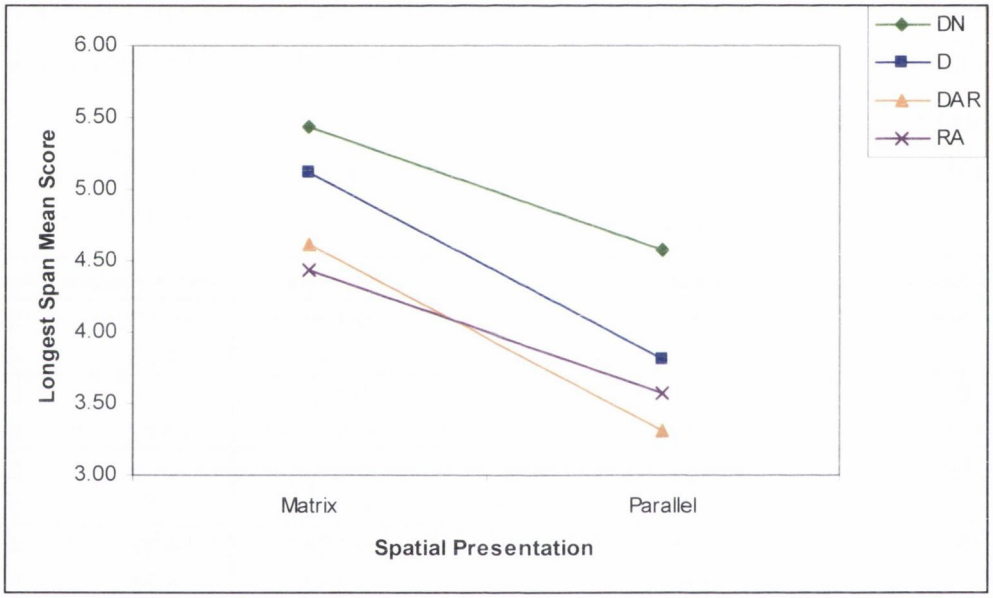

Figure 2.3 Line graph highlighting the change in scores between developmental groups with the move from matrix to parallel tests with longest span the dependent measure. No significant interaction was suggested

A second repeated measures analysis was conducted with the total number of correctly recalled trials (CRT) entered in as the dependent variable across spatial and between developmental conditions. For the matrix presentation condition (mean=9.10, SE=.253, 95%CI=8.60-9.60) children were found to have a significantly higher number of correctly recalled sequences $F(1,107)=117.866$, $p < .001$, than they experienced on the parallel condition (mean=5.942,SE=.203, 95%CI=5.538-6.345). There was no significant interaction between development and presentation $F(3,$

107)=1.543, $p > .05$, (see Table 2.2), but within developmental groups there were significant differences $F(3,107)=16.741$, $p < .001$. Pairwise analysis again indicated that DN children were demonstrating a significantly higher number of CRTs (mean=9.324, SE=.313, 95%CI=8.704-9.944) than D (mean=7.731, SE=.373 95%CI=6.991-8.470, $p < .01$), DAR (mean=6.769, SE=.523, 95%CI=5.723-7.815, $p < .001$) and RA children (mean=6.769, SE=.322, 95%CI=5.620-6.895, $p < .001$). Additionally, D children were now found to have a significantly higher number of CRTs than RA children, $p < .05$.

Table 2.2 CRT mean scores and 95% CI across developmental groups and presentation types.

Development	Spatial	Mean	Std. Error	95% Confidence Interval	
DN	Matrix	10.89	0.402	10.09	11.69
	Parallel	7.76	0.323	7.12	8.40
D	Matrix	9.65	0.480	8.70	10.61
	Parallel	5.81	0.386	5.04	6.57
DAR	Matrix	8.31	0.679	6.96	9.65
	Parallel	5.23	0.546	4.15	6.31
RA	Matrix	7.54	0.414	6.72	8.36
	Parallel	4.97	0.333	4.31	5.63

D and DN children were again assessed across the individual spatial presentation types when CRT was the dependent variable, as a comparative analysis to Experiment 1.2. With CRT as the dependent variable the analysis now indicated that DN children (mean=10.84, SD=2.25, 95%CI=10.10-11.58) were correctly recalling more trials than D children (mean=9.65 SD=2.40, 95%CI=8.68-10.62) on matrix presentations $F(1,62)=4.084$ $p < .05$ and once again DN children (mean=7.76, SD=2.09, 95%CI=7.06-8.45) were demonstrating higher recall span on the parallel tests $F(1,62)=16.782$, $p < .001$, than D children (mean=5.81, SD=1.47, 95%CI=5.21-6.40).

Co-varying Digit Span

The repeated measures analysis was re-run on longest span capacity as the dependent variable with scaled digit span scores entered into the analysis as a covariate. While span length was no longer found to be significantly different between presentation types $F(1,105)=.386$, $p > .05$, significant differences remained between developmental groups $F(3, 105)=13.222$, $p < .001$, with DN children (mean=4.941, SE=.124, 95%CI=4.696-5.187) still demonstrating significantly longer span capacity than either DAR (mean=4.085, SE=.207, 95%CI=3.675-4.494, $p < .005$) and RA children (mean=3.922, SE=.126, 95%CI=3.672-4.172 $p < .001$), and D

children (mean=4.605, SE=.153 95%CI=4.302-4.908) having significantly longer span lengths the RA children while ($p < .01$), but the analysis now indicated no significant differences between D and DN children. Interestingly, there was now a suggested interaction between development and presentation type $F(1,105)=3.179$, $p < .05$ (see Table 2.3). As Figure 2.4 highlights, the effect of moving from a matrix to a parallel presentation type was more detrimental to literacy impaired groups (D and DAR children) than to the non-literacy impaired DN and RA children.

Table 2.3 Longest span mean scores and 95% CI across developmental groups and presentation types when digit span is entered as a covariate in the analysis.

Development	Spatial	Mean	Std. Error	95% Confidence Interval	
DN	Matrix	5.33	0.150	5.03	5.62
	Parallel	4.55	0.151	4.26	4.85
D	Matrix	5.35	0.185	4.98	5.71
	Parallel	3.86	0.186	3.50	4.23
DAR	Matrix	4.81	0.250	4.32	5.31
	Parallel	3.36	0.252	2.86	3.85
RA	Matrix	4.30	0.152	4.00	4.61
	Parallel	3.54	0.154	3.24	3.85

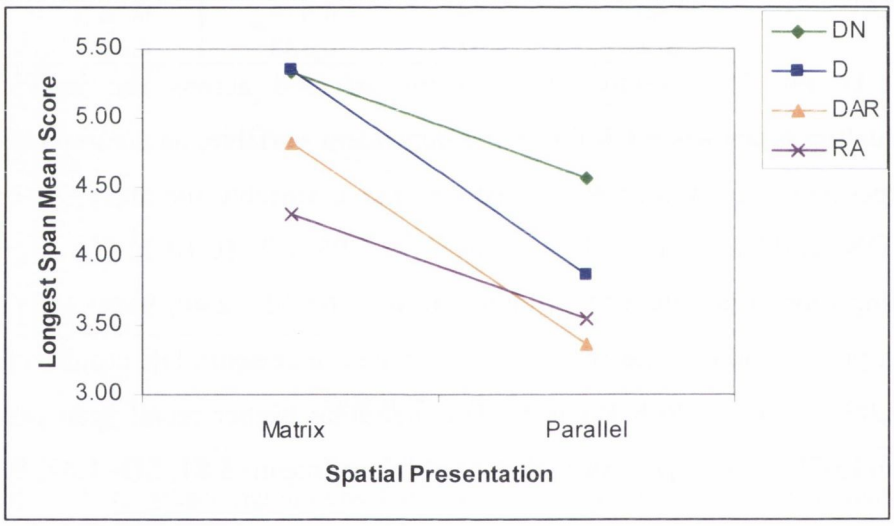

Figure 2.4 Line graph highlighting the interaction between presentation type and developmental group, when highest correctly recalled span length is the dependent measure and digit span is entered as a covariate.

A second repeated measures analysis was carried out with digit span entered into the analysis as a covariate, this time with CRT as the dependent measure. In keeping with the findings above, the analysis indicated that the spatial presentation conditions no longer significantly differed from one another $F(1,105)=1.337$, $p > .05$. Development type still contained significant differences between groups $F(1,105)=18.250$, $p < .001$, and there was again a significant interaction between

development and presentation type $F(3, 105)=3.177$, $p < .05$. The profile of differences among developmental groups was identical to that found when longest span length was used as the dependent measure, with DN children (mean=9.084, SE=.311, 95%CI=8.467-9.701) recalling significantly more trials correctly than both DAR (mean=7.194, SE=.518, 95%CI=6.166-8.222, $p < .05$) and RA children (mean=5.984, SE=.317, 95%CI=5.361-6.616, $p < .001$), and D children (mean=8.225, SE=.383, 95%CI=7.465-8.980) correctly recalling significantly more trials than RA children ($p < .001$), but no significant differences indicated between D and DN children. As highlighted in Figure 2.5, the significant interaction between development and presentation was again due to an increased impairment in performance with the shift from matrix to parallel presentation displays in the literacy impaired relative to literacy unimpaired children (see Table 2.4).

Table 2.4 A summary table of CRT mean, standard error and 95% CI across spatial presentation and between development groups, when scaled digit span scores are co-varied.

Development	Spatial	Mean	Std. Error	95% Confidence Interval	
DN	Matrix	10.53	0.394	9.75	11.31
	Parallel	7.64	0.335	6.98	8.30
D	Matrix	10.37	0.486	9.41	11.33
	Parallel	6.08	0.413	5.26	6.90
DAR	Matrix	8.92	0.657	7.62	10.22
	Parallel	5.46	0.558	4.36	6.57
RA	Matrix	7.15	0.401	6.36	7.95
	Parallel	4.82	0.341	4.15	5.50

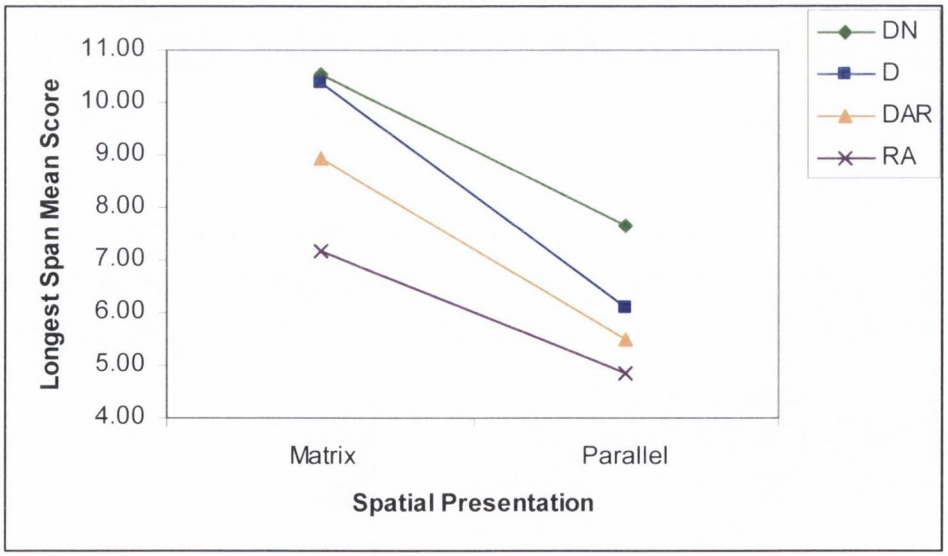

Figure 2.5 Line graph highlighting the interaction between presentation type and developmental group, when total number of correctly recalled trials is the dependent measure.

Mathematical Ability

Additional repeated measures analysis were run across the spatial presentation conditions and between the dyslexic children who had been sub-sampled according to their mathematical ability (average and above average mathematics ability 'ABA' and the below average mathematics ability 'BAM' children).

The repeated measures analysis with longest span as the dependent variable indicated no significant differences in recall span $F(1, 23)=1.599$, $p > .05$, between groups according to mathematical ability, with AMA children (mean=4.22, SE=.163, 95%CI=3.88-4.56) have a similar recall span to BAM children (mean=4.21, SE=.262, 95%CI=3.67-4.76), Nor was there a significant interaction between mathematics ability and spatial conditions $F(1, 23)=.001$, $p > .05$, see Table 2.5.

Table 2.5 Summary table with mean scores, standard error and 95%CI, for both the longest span and CRT scoring measure, across spatial presentation conditions and between mathematical ability conditions

Scoring Method	Mathematics Ability	Spatial	Mean	Std. Error	95% Confidence Interval	
Longest	AMA	Matrix	4.83	0.227	4.36	5.30
		Parallel	3.61	0.195	3.21	4.01
	BAM	Matrix	5.14	0.364	4.39	5.90
		Parallel	3.29	0.312	2.64	3.93
CRT	AMA	Matrix	9.00	0.563	7.83	10.17
		Parallel	5.39	0.417	4.53	6.25
	BAM	Matrix	8.71	0.904	6.85	10.58
		Parallel	4.43	0.669	3.05	5.81

A second repeated measures analysis was carried out this time using the CRT scoring method as the dependent measure. The analysis indicated in line with the analysis above that there were no significant differences in recall span between the groups split according to mathematical ability $F(1, 23)=.700$, $p > .05$, with AMA (mean=7.19, SE=.394, 95%CI=6.38-8.01) children's recall span being similar to BAM (mean=6.57, SE=.632, 95%CI=5.26-7.88) children. The interaction between spatial conditions and mathematical ability once again was non-significant $F(1, 23)=.352$, $p > .05$, see Table 2.5.

Serial Order Effects

Serial position item accuracy was again assessed using the procedure set out in Experiment 1.2, with sequence items split between primacy, intermediate and recency conditions. A repeated measures analysis was carried out across spatial

presentation type and serial position and between developmental groups. The analysis indicated that spatial presentation condition did not contain significant differences $F(1,108)=.430$, $p > .05$, as matrix (mean=.396, SE=.016, 95%CI=.365-.428) presentations were recalled with a similar accuracy ratio to parallel (mean=.410, SE=.016, 95%CI=.379-.441) presentations. Developmental groups were found to differ significantly in terms of item accuracy $F(3, 108)=3.361$ $p < .05$, with pairwise comparisons indicating that DN children (mean=.448 SE=.019, 95%CI=411-485) recalled a significantly higher proportion of items accurately than RA children (mean=.365, SE=.020, 95%CI=.326-403, $p < .05$), but that neither D (mean=.389, SE=.023, 95%CI=.344-434) nor DAR children (mean=.409, SE=.032, 95%CI=.346-.473) significantly differed from the other groups. Significant differences were found across the serial position condition $F(2, 216)=55.286$, $p < .001$, with Bonferroni comparisons suggesting that recall on primacy items (mean=.547, SE=.023, 95%CI=.506-.589) had a significantly higher proportion of accurate recalls than both the intermediate item recall (mean=.381, SE=.018, 95%CI=.344-.417 $p < .001$) and recency item recall (mean=.280, SE=.018, 95%CI=.245-.316 $p < .001$), with intermediate items having significantly higher recall accuracy than recency items ($p < .001$).

Response Times

A repeated measures analysis was carried out across spatial presentation types and between developmental groups with RT for correct recalls as the dependent variable. The analysis indicated that there were no significant differences across spatial presentation types $F(1,105)=1.600$, $p > .05$, as RTs for matrix (mean=4574ms, SE=164, 95%CI=4247-4901) presentations were similar to parallel (mean=4173ms, SE=149, 95%CI=3877-4469) presentations. Nor was there a significant interaction between development and spatial presentation conditions $F(3,105)=.507$, $p > .05$. Response times did however differ between developmental groups $F(1,105)=3.478$, $p < .05$, with pairwise tests suggesting that D children (mean=4030ms, SE=224, 95%CI=3585-4475) had significantly quicker RTs than RA children (mean=4893ms, SE=185, 95%CI=4525-5261, $p < .05$), but that neither DN (mean=4258ms, SE=178, 95%CI=3904-4612) nor DAR children (mean=4313ms, SE=317, 95%CI=3684-4943) significantly differed from the other groups (see Figure 2.6).

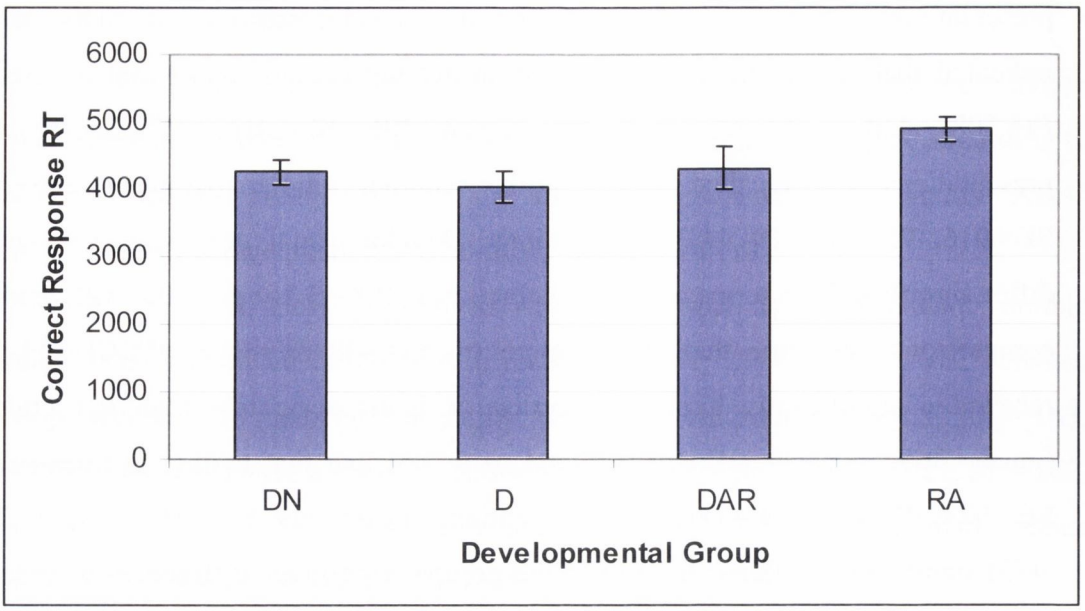

Figure 2.6 Mean RT across developmental groups for correctly recalled sequence trials.

RTs for incorrectly recalled sequence trials were entered into a second repeated measures analysis. Again no significant differences were suggested between spatial presentation conditions $F(1,108)=2.562$, $p > .05$, as matrix RTs (mean=7781ms, SE=318, 95%CI=7149-8412) were very similar to parallel presentation RTs (mean=7186ms, SE=283, 95%CI=6625-7747). Similarly, the interaction between development and presentation type was non-significant $F(3,108)=1.523$, $p > .05$. Significant differences were indicated between development groups $F(3,108)=4.027$, $p < .01$, with Bonferroni comparisons suggesting that D children (mean=6785ms, SE=451, 95%CI=5890-7679) were responding to sequences trials significantly more quickly than DN children (mean=8417ms, SE=373, 95%CI=7678-9157, $p < .05$), but that neither DAR (mean=6591ms,SE=638, 95%CI=5326-7855) nor RA children (mean=8141ms, SE=338, 95%CI=7370-8912) significantly differed from any of the other groups.

Discussion

Span capacity

Consistently across both scoring methods and across all the individual developmental groups, recall of sequence trials on matrix tasks was superior to recall for sequences presented on parallel displays. In line with Kemps' research (1999, 2000, 2001), it is suggested the parallel tasks simply have less interconnectivity between spatial locations and in the path patterning within sequence trials, making

them harder to recall. The nature of parallel display presentations would suggest that encoding is more likely to involve individual items rather than chunking of sequences into strings of items. From Logie's (1995) perspective, all visuospatial information entering WM stores is first filtered through LTM. In the parallel tests there is unlikely to be as much of a scaffolding effect to recall span due to specific LTM representations as matrix presentations. For this reason it is believed that parallel presentations may act as a more genuine measure of spatial and visuospatial WM, as there is less likely to be applicable representations which would enhance coding or chunking of sequence strings.

Repeated measures analysis suggested that the findings across the scoring methods were largely consistent with one another, indicating that that they are acting as reliable measures of VSWM. On both the scoring methods when performance was assessed across both matrix and parallel tests, when digit span was not entered as a covariate, DN children were found to be outperforming D, DAR and RA children. The significant enhancement in ability in DN relative to the RA children is in line with existing research which has found a developmental increase in ability across the assessed age ranges, suggesting that dyslexic children may be experiencing a relative delay in VSWM functioning (Logie & Pearson, 1997; Pickering, 2001; Pickering et al., 2001). Interestingly, the analysis on the CRT method indicated that D children were actually completing significantly more trials correctly or reaching a higher composite score than the RA children, suggesting that while they are experiencing a developmental delay in spatial WM in respect to DN children it is not as severe as the delay experienced on reading related measures. In the DAR children, however, the delay in spatial WM was largely equivalent to their literacy development.

Of particular note were the findings from the oneway ANOVA which suggested that, depending on which of the separate scoring methods was used, one could find both supportive and non-supportive evidence for the position that dyslexic children suffer from a VSWM impairment (Jeffries & Everatt, 2004; Kibby et al., 2004; Pickering & Gathercole, 2004). When the analysis was run on the longest span length, in line with previous findings, D and DN did not significantly differ on the matrix presentation tasks, but D children were found to be performing worse on the parallel presentation type. Given that all the earlier studies had assessed VSWM using a matrix style task and had either used a longest span length or averaged highest span as the scoring method, the evidence does suggest that, using such methods and

scoring practices, D children will not demonstrate a deficit in functioning. In contrast, the CRT scoring method seemed to be a far more sensitive scoring method, as not only did it support the findings of significant differences in recall span between D and DN children on the parallel measures, but the findings also indicated that DN children were performing significantly better than D children on the matrix tasks as well.

Interestingly, in contrast to Helland and Asbjørnsen's (2003) research, the dyslexic children with below average mathematical ability did not demonstrate a deficit in spatial WM ability, relative to dyslexic children with average and above mathematical ability. However, it must be noted that the group of dyslexic children with below average ability in mathematics was relatively small, and thus may not be a representative sample of dyslexic children with a co-occurring mathematical impairment. Furthermore, although non-significant, the difference between the below average and the average and above groups on the parallel task were in the expected direction.[14]

The repeated measures analysis when digit span was entered as a covariate indicated a highly similar profile of findings across the separate scoring measures. In all scoring types, significant differences between presentation types were no longer found, while significant differences between developmental groups remained. Unlike the earlier analysis, once digit span was co-varied, D children across both scoring methods outperformed RA children. Similarly, significant overall differences were no longer found between D and DN children, with the significantly enhanced functioning of the DN children relative to both DAR and RA children remaining constant. Smith-Spark et al. (2003) suggested that the impairments found in dyslexic adults on high memory load VSWM tasks likely relate to impaired CE functioning. Given that the digit span scores are derived partially from backwards verbal recall, a task which is suggested to rely heavily on CE resources, one possibility is that the differences demonstrated in recall span between matrix and parallel displays at least partially relates to additional scaffolding from CE resources. Of particular note to this position are the findings from Tables 2.3 & 2.4 which indicate that even when digit

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[14] In the experiments of chapters 4, 5 and 6, similar analyses were run assessing the relationship between mathematical ability and recall span. In keeping with the analysis above, none of the analyses indicated significant differences in recall span between AMA and BAM groups and will not be detailed in the main body of the thesis but can be found in Appendix IV.

span is co-varied, D children continue to have significantly lower recall span than DN children on the parallel tasks. The lowered reliance on CE resources in the parallel displays could be due to linear presentation of stimuli items, as there is likely to be less of a capacity to support the encoding of sequence paths with representations from LTM. The findings on the parallel tasks, in contrast to Smith-Spark et al.'s (2003) position, suggest that D children are experiencing impairments to VSWM ability that are not derived from impaired CE functioning in these children. However, in support of Smith-Spark et al.'s position is the finding of no significant differences between D and DN children on the matrix presentations, once digit span is co-varied. An immediate question from this finding is of course drawn to mind. That is, if there are meaningful differences in VSWM ability, which are not best explained as a side effect of CE impairment between groups, why are there no longer significant differences between groups on the matrix presentations when digit span is co-varied? The lack of meaningful differences between groups, it is suggested, relates to the additional noise in the matrix presentation type tasks, which relates to an increased level of individual differences between children on their ability to pair sequence paths with existing LTM representations. That is, besides the ability to use CE resources to support sequence paths with existing LTM representations, there are likely to be considerable differences between individual children in the degree of LTM representations with which they are to be able to usefully scaffold performance (Baddeley & Andrade, 2000).

This position was further supported by the significant interaction between presentation and development type, when digit span was co-varied. The interaction indicated that there was a deviation in profile between the literacy impaired and the non-literacy impaired groups, with the literacy impaired groups showing a much stronger impairment in functioning with the shift from matrix to parallel tasks. While the interaction was consistently found across the both scoring methods, the profile was less pronounced in CRT measures. In line with the argument in the paragraph above it is suggested that the interaction may possibly relate to matrix tasks being more likely to benefit from CE scaffolding. That is, when digit span is controlled for, the literacy impaired children's performance is proportionately increased on the matrix tasks, which in turn increases the deviation in functioning between matrix and parallel tasks. That matrix tasks may experience a disproportionate benefit from CE resources relative to parallel tasks is a question that needs to be answered with further

research, perhaps using a dual task methodology or assessing the covariance across a number of CE measures.

Serial Order Effects

In line with the previous chapter, there was no evidence from the analysis of serial positioning that literacy impaired children differ from DN children in respect to recall accuracy when children have exceeded their span capacity. The only significant difference indicated between developmental groups was found between DN and RA children, with RA children experiencing lower accuracy scores across serial positions than DN children. Like the findings for Experiment 1.2 and 1.3, there was no evidence of a bow effect whereby accuracy is greater in the primacy and recency positions than the intermediate items, but instead accuracy decreased gradually across serial positions, with the primacy items experiencing the best recall, the next best recall was on the intermediate items and least accurate performance was on the recency items. In line with the argument put forth in chapter 2, it is believed that children unlike adults are less likely to fix the last items in memory before attempting recall and hence the general decrease in accuracy toward the end of sequences (Smyth & Scholey, 1996b).

Response Times

The analysis of RT for correctly recalled sequences suggested that D children were responding significantly more quickly than RA children, but in contrast to the findings from the previous chapter, D and DN children did not significantly differ, with DAR children not significantly differing from any of the other developmental groups. No significant differences were found between presentation types in RT, nor was there any interaction between presentation and development type. The analysis of RT related to incorrect recalls followed a similar profile with no differences between developmental groups or any interactions between development and presentation type. D children, in keeping with the findings of the earlier chapter, were once again found to respond significantly more quickly than DN children in respect to RTs related to incorrect responses, with none of the other groups significantly differing. It is possible that the D children's quicker RTs relate to the increased awareness of the rate of decay they experience in stored representations with time, as previous research

has suggested that dyslexic individuals do experience quicker rates of decay (Visser et al., 2004).

General Summary

The results of Experiment 2 are in a unique position given that they both supported and at the same time contradicted the findings of earlier research studies which suggested dyslexic children do not suffer from a VSWM impairment. The lack of evidence in support of differences between developmental groups found in previous studies are suggested to be twofold; first, on account of the scoring methods utilized and second, the assessment of VSWM through matrix style presentation displays. It must be noted that the current research can really only be generalised to spatially dominant assessments, as there was little or no requirement to encode and/or retrieve representations visually in the current experiment. As such it is possible that dyslexic children may only demonstrate an impairment on VSWM tasks which are predominantly spatial in nature. While our previous research, Experiments 1.1-1.3, had suggested that dyslexic children were impaired on both backwards recall tasks and tasks with visual interference, there was little evidence that dyslexic children had impaired capacity on the simple forwards recall tasks. The earlier lack of findings may possibly relate to the scoring method used, the possibility of verbalisation or the spatially simpler task requirements, given that there were only 6 rather than 9 items in the parallel array. However, it is also possible that in tasks that enable visual encoding and or retrieval, dyslexic children may not experience a deficit in functioning relative to developmentally normal children. The relative interplay between visual and spatial elements and how they interact to effect sequential recall, as well as the role of CE and LTM representations, are issues for further research and shall be addressed in chapters 4 and 5. The findings of the present study suggest that matrix presentation displays may indeed depend on CE resources to a greater degree than parallel presentation displays. Additionally, it is believed that in line with Kemps' (1999, 2001) research, matrix style tasks receive an additional benefit from LTM representations, both in encoding the spatial location of items and the path of the sequence presentation, relative to parallel tasks. Notably, it is believed that this scaffolding from both the CE and LTM representations increases the noise between individuals, such that changes in span capacity on matrix tasks may not be best understood from a VSWM ability standpoint. For this reason it is believed that

parallel presentation displays offer a cleaner measure of VSWM as they are less likely to depend on secondary modalities.

Chapter 4- Experiments 3.1-3.3

Visual working memory ability in dyslexic children: the implications of long term memory representations and task redundant spatial encoding

The current chapter presents 3 experiments, which focus on visual WM capacity between literacy impaired and unimpaired children. In Experiment 3.1 sequences were presented using serial displays, while Experiment 3.2 used spatially redundant parallel displays, with Experiment 3.3 using spatially redundant matrix displays. As such Experiment 3.1 assessed recall span on clean measures of visual WM, with Experiments 3.2 and 3.3 assessing the effect of task irrelevant information on tasks that only allow for visual WM retrieval.

Experiment 3.1 Introduction

The divergent rates at which visual and spatial WM systems individually develop may be an underlying factor in the lack of significant differences between D and DN children found in other studies. Given that the majority of the research has predominantly focused on tasks that have allowed for both visual and spatial encoding, though dyslexic children may be selectively impaired in one capacity, through compensatory use of the other code they may appear to have normal functioning. Logie and Pearson (1997) argued that memory for visual patterns developed at a much faster rate than memory related to spatial sequential tasks. Research using pattern matrices stimuli found that even patterns that are sequential in nature yet strongly resemble existing LTM visual representations may be recoded in an analogous fashion to these existing representations (Pickering et al., 2001). Simply put, if one pattern resembles a LTM visual representation, for example the letter A, or the shape of a triangle, it is likely to be better recalled than a pattern which doesn't elicit LTM representations. Kemps (1999, 2001) likened this phenomenon to the gestalt principle of figural goodness, indicating that sequence patterns and displays which are more familiar structurally were significantly better recalled than sequences or displays with low levels of figural goodness. This suggests that even in tasks that

are predominantly spatial in nature, such as the Corsi blocks task, individuals may be able to chunk or bind spatial sequences in terms of visual LTM representations.

The findings of Experiment 2 indicated that dyslexic children were experiencing significantly lower spatial span lengths than their developmentally normal cohorts when sequence trials were constrained in such a way as to remove highly codable sequences. Thus, it seems plausible that the lack of significant findings suggested in earlier studies relate to the ease of visual chunking on these tasks. For this reason, the present set of experiments set to assess dyslexic children's functioning on clean measures of visual WM ability where spatial representations have been rendered redundant. That is by using a serial presentation style which presents stimuli one at a time in the same central spatial location, it is not possible to spatially encode the sequence trials. If dyslexic children are found to have normal functioning on the visual WM tasks, the division in the research over suggested impairments may relate to the degree of visual encoding possible in the individual experimental measures used in the research studies.

Existing research has suggested that discrete neurological areas become activated during object/visual WM tasks as opposed to WM tasks with specifically location/spatial requirements (Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998). Courtney et al.'s research has indicated that the inferior prefrontal cortex is activated by object/visual WM tasks, while the superior frontal sulcus is activated by location/spatial WM tasks.

The magnocellular theory of dyslexia posits that dyslexic children's developmental impairments relate to a specific deficit in magnocellular system functioning (Stein, 2001; Stein, Talcott, & Walsh, 2000; Stein & Walsh, 1997). Given that the magnocellular system is said to deal with determining "where" a stimulus is, while the unimpaired parvocellular system determines "what" a stimulus is (Slaghuis, Twell, & Kingston, 1996), there is further support for the position that dyslexic children's deficits in VSWM tasks should only be specific to spatial tasks. Likewise, the findings from Experiment 1.2 showing dyslexic children to have normal recall capacities in the forward recall task, may relate to the possibility that they were encoding the stimuli visually rather than spatially and not, as suggested in Experiment 2, to a lack of sensitivity in the scoring method. Nonetheless, the possibility remains that the indication of normal functionality in Experiment 1.2 may have been linked with the methodology of the task. That is, the requirement to process sequences

across six spatial locations was simply not sufficiently demanding to tax spatial processes in either D or DN children, which is why deficits in spatial processing were only found when participants were required to process sequences across nine spatially distinct locations as in Experiment 2. This possibility will be further clarified in the experiments of chapter 5.

In developing the current round of testing, it was recognised that while the majority of verbal working memory tasks involve (linguistic) LTM representations, the assessment of visual WM is almost entirely based on recalling stimuli that lack any LTM representations. This is because if the visual stimuli used do have LTM representations, they are more likely to be verbalised, thereby creating doubt as to which storage facility is being used. While the ecological validity of testing visual WM with novel stimuli, which by design lack experiential applicability, may be questioned, the contrived nature of assessment stimuli used in many visual WM tasks opens up an interesting possibility as to why such a long line of well-replicated findings suggests that dyslexic children experience deficiencies on verbal WM tasks (Ackerman & Dykman, 1993; Pennington et al., 2001; A. M. Wilson & Lesaux, 2001), and why there exists such conflicting findings related to dyslexic VSWM ability levels (Helland & Asbjornsen, 2003; Kibby et al., 2004; Pickering & Gathercole, 2004; Smith-Spark et al., 2003). The addition of the episodic buffer as a fourth component to Baddeley's (2000) WM model may offer a tantalising connective thread between the polarised research findings. That is to say, the deficits found in dyslexic individuals' WM ability may actually relate to their capacity to combine sensory stimuli with LTM representations to form limited unitary short term episodic representations. This requirement to link sensory input with LTM representations is inherent in all verbal WM tasks, but is mostly absent in visual tasks. For this reason we decided to test dyslexic children's visual WM capacity across three representation groupings that differ from one another in the level of LTM representations associated with each.

Experiment 3.1 was developed to systematically test if dyslexic children demonstrate impaired functioning on tasks that require accessing existing LTM representations or if they are impaired in the ability to establish new connections between sensory stimulation and LTM representations. By comparing the recall span profile between the literacy impaired and unimpaired children, it should be possible to assess if dyslexic children are demonstrating an impairment in functioning, if this

impairment relates to increased difficulties in accessing established representations, or establishing new representations, or if they simply have a lowered overall capacity.

The age of acquisition (AOA) theory states that the speed at which a word or stimulus can be named/accessed from LTM is related to the age at which it is acquired. Thus, the earlier a word is assimilated into one's lexicon, the more quickly it can be accessed (Barry, Morrison, & Ellis, 1997). Rapid naming for animal based stimuli follows a somewhat unique pattern, given that even animal names which are acquired later in adolescence are retrieved with the same rapidity as names acquired in very early childhood. This suggests that animal names are simply more accessible than other nameable stimuli (Funnell, 2005). Thus, when children integrate animal images and names into LTM representations, they seem to be uniformly accessible regardless of their AOA. For this reason, we decided to use animal stimuli as a measure of strong, invariant LTM representations.

The use of animal stimuli unfortunately opens up the possibility that verbal encoding or verbal scaffolding of the visual representations may take place, so these tasks could not be considered a pure measure of visual WM capacity but rather a potentially visuo-verbal measure. Thus, we needed a second set of stimuli that could draw on LTM representations but do not have readily accessible verbal labels, so offering a more valid assessment of visual WM capacity. The use of unfamiliar face stimuli in WM tasks has been argued to have an number of key advantages over random non-nameable spatial arrays or matrix patterns (Kerr et al., 1998). It is suggested that unrecognised faces are equally if not more difficult to assign verbal labels to than random matrices patterns. At the same time, unlike pattern or abstract stimuli, their use lends an increased ecological validity, given that on a daily basis we are required to encode, process and retrieve face representations from LTM. Face stimuli were therefore used as the second measure of visual representations.

Lastly we wished to test if dyslexic children would experience normal visual WM functioning using stimuli that shouldn't have established LTM representations, are visually distinct, are not verbalisable, but are less complex than face stimuli. We decided to use Chinese characters as existing research has demonstrated that participants show visual similarity effects when required to recall presentations using such stimuli, indicating that they are unlikely to be verbalised and that visual encoding/retrieval is occurring (Andrade et al., 2002). By requiring children pre-testing to state if the individual symbol or face stimuli reminded them of anything,

and only using stimuli with which they were not familiar, we were able to ensure that all children had an equal lack of LTM representations for the specific stimuli.

For both face and symbol stimuli, children were required to establish new links with representations in LTM, in order to successfully recall sequence presentations, a function which is argued to rely on the episodic buffer (Baddeley, 2000). If the literacy impaired children were experiencing a deficit specific to episodic buffer functioning, it was believed they would experience the greatest impairments to recall capacity on the unfamiliar face stimuli. This is because face recognition requires configurational encoding (Baenninger, 1994), which could entail greater interconnectivity between the sensory input and LTM representations before individual faces can be accurately encoded and remembered. Secondly, the literacy impaired children should experience impaired functioning on the symbol stimuli as they are likely to require the establishment of new figural codes or at least their pairings with existing LTM representations. Lastly they should experience least difficulty on the animal stimuli given their existing LTM representations and the established ease of access to these stimuli (Funnell, 2005).

Swanson (1989) suggested that poor readers show a visual dominance in encoding and processing due to weaker interconnectivity between visual and verbal systems. However, when items are difficult to encode verbally (e.g. face and symbol stimuli), developmentally normal children should switch to a visually dominant strategy. If dyslexic WM deficits are specific to only spatial and verbal codes, both groups should show an equal performance on these visually dominant tasks. In line with this McDougall, Hulme, Ellis and Monk (1994) found that poor readers had equivalent visual memory spans to normal readers when abstract visual shapes where used and the test procedure did not allow for spatial encoding. However, there is a possibility that these findings may have related to floor effects given that both groups had an average span capacity of less than 3 items. This may suggest that the stimuli used were simply too complex for children in the 7-9 age range to successfully encode visually. Alternatively, in line with an episodic buffer hypothesis, the stimuli may simply have been too novel and complex to have allowed memory facilitation through LTM scaffolding.

Given that earlier research has suggested that dyslexic children are less likely to use verbal retrieval strategies at recall (R. S. Anderson & Johnston, 1998), we would expect the D children to demonstrate less of a shift in performance between the

verbalisable stimuli and non-verbalisable stimuli than DN children. However, we would expect a similar profile between RA and D children, given that they should be using similar recall strategies (R. S. Anderson & Johnston, 1998). If dyslexic children's deficits are specifically related to episodic buffer functioning, we would expect that there would be a difference in performance between the literacy and non-literacy impaired children, but that this effect would differ across representation types. As RA and dyslexic children should be using the same retrieval strategies, if the dyslexic children are impaired on episodic buffer functioning we would expect that they should show a different profile from RA children in respect to the symbol and face stimuli, but this should be less pronounced on the animal stimuli. That is, the dyslexic children may have a difficulty in establishing new connective links between sensory stimulation and LTM representations. As such, dyslexic children would demonstrate similar recall span to RA children on the animal stimuli, (due to the established strong LTM representations) but an impaired ability on the face stimuli (as discrimination entails referencing configurational differences between faces, which requires accessing in-depth facial LTM representations). With recall span on the symbol stimuli falling somewhere between the other two stimuli types, as symbol stimuli should not require as much in-depth referencing to LTM representations as face stimuli, since item discrimination is likely to be figural rather than configurational in nature (Baenninger, 1994). It was believed that the profile between the literacy impaired and DN children would be very similar to the one detailed above in respect to RA children. However, a more pronounced difference should occur on the animal stimuli given the likelihood that DN children will scaffold performance with additional verbal processing. If dyslexic children are not suffering an impairment specific to the episodic buffer, we assumed that they would perform similarly (even if showing lower capacity levels) between visual representation conditions to the non-literacy impaired children, with the exception that DN children would demonstrate enhanced span capacity relative to the animal stimuli for the reasons suggested above.

Method

Participants

The same participants who took part in Experiment 2 were used in Experiments 3.1-3.3. That is, 38 developmental normal chronological age matched control children (DN), 26 dyslexic (D) children with a low risk of ADHD/ADD, 13 dyslexic children with a high risk of ADHD/ADD (DAR), and 35 developmentally normal reading age matched (RA) children.

Apparatus

The setting was identical to Experiment 2, for Experiments 3.1-3.3 with children being tested individually on the computerised VSWM tasks using a touch-screen, in moderately lit rooms, wearing noise reduction headphones throughout testing.

Procedure

As mentioned in Experiment 2, assessments were split into 3 separate test sessions, with the order of tests and order of individual subtests within tests being randomised. The three test sessions were split according to the visual representation of the stimuli used: e.g. one session presented sequences using animal stimuli, another session presented sequences using Chinese symbol stimuli and the other used face stimuli to present sequences. Additionally, the individual visual representation stimuli were presented on five separate presentation types; serial (Experiment 3.1), spatially redundant parallel (Experiment 3.2), spatially redundant matrix (Experiment 3.3), spatially and visually relevant parallel presentations, spatially and visually relevant matrix presentations. In the first three presentation types mentioned above, either spatial information is absent at the encoding stage (serial tests) or it is rendered redundant at the retrieval stage. By rendering spatial information redundant in this way all three presentation types are dependent on visual encoding and retrieval and as such can be considered pure measures of visual WM. The spatially and visually relevant parallel and matrix presentation types were not used in the current experiment but form the basis of the experimental manipulation under investigation in chapter 5, as they allowed for both visuo-spatial encoding and retrieval.

The test procedure was identical to that discussed in Experiment 2, with children receiving a graphical demonstration of procedural instructions, and then being required to explain task requirements to ensure procedural understanding. Again stimuli items flashed up one at a time for 500ms with an interval of 1000ms before the next item flashed up. Children were given 3 trials at each sequence length, starting with 2 item trials. If the child successfully copied at least 1 out the three trials of a sequence length, an additional item was added to the length of the sequence, with children having 3 trials at that sequence length. The individual subtests terminated once a child failed to correctly recall any of the 3 trials at a given sequence length. Again children were only required to use forward recall that is touching the relevant stimuli items on the touch screen in the same order they were presented.

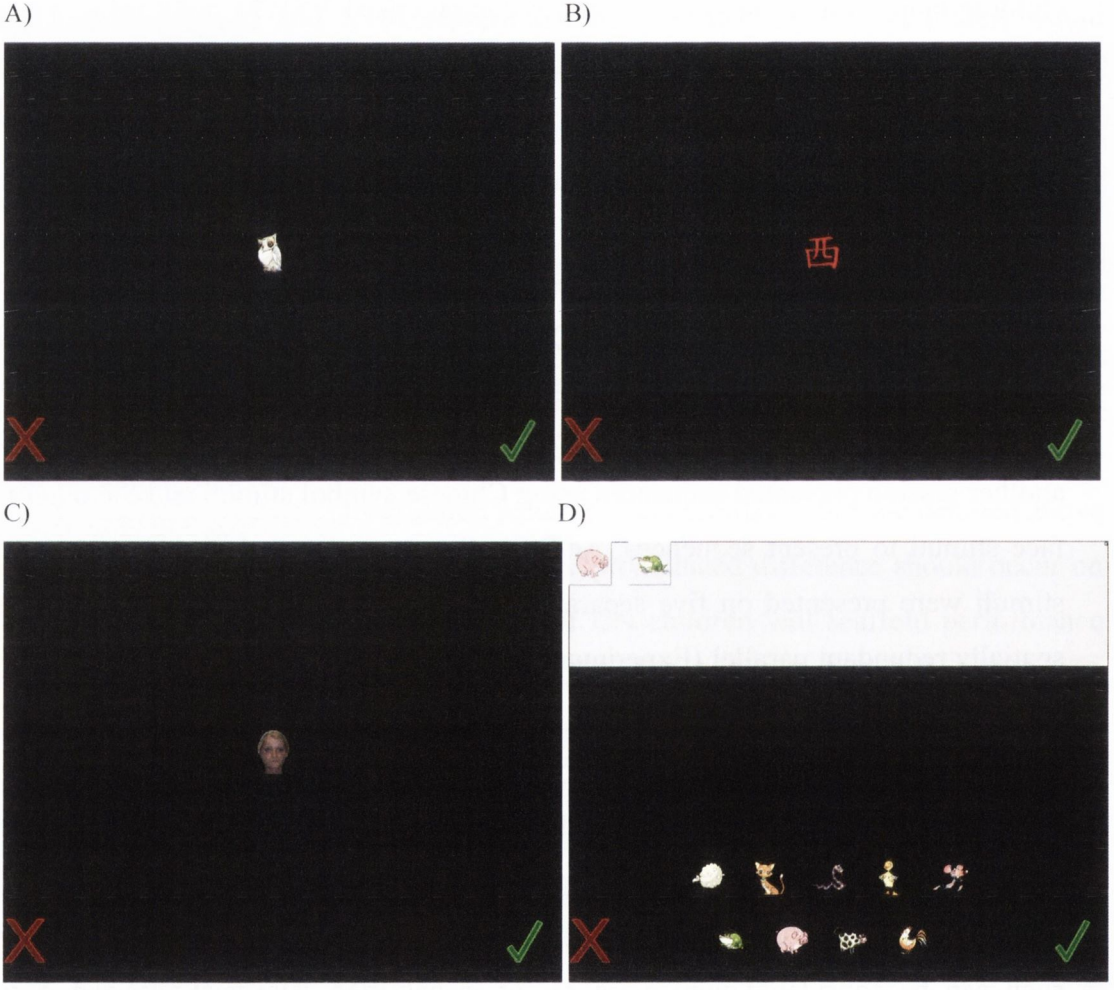

Figure 3.1 Screen-shots of the serial presentation types across the three visual representation types and response screen: A) Animal stimuli, B) Symbol stimuli, C) Face stimuli, and D) the response screen for animal stimuli, indicating that a 2 item sequence has been copied e.g. pig then frog.

Like Experiments 1.2 and 2, the serial presentation trials involved items flashing up one at a time on the screen. However, unlike the earlier experiments, individual trial items were now presented in the same central spatial location. This ensured that there were no spatially distinguishing features between individual items as they were all presented in the same position, and therefore children had to use visual encoding and retrieval when copying sequence trials (see Figure 3.1). For Experiments 3.2 and 3.3, the spatially redundant parallel and matrix presentations, spatial redundancy was achieved by using a separate response screen to the display used to present the stimuli, which shared no spatial correlates with the presentation display.

Following the observation in Experiments 1.2 and 1.3 that children may not use the same signifiers to represent stimuli and that this may adversely affect encoding and retrieval processes, children were required to name animal stimuli in a pre-test before VSWM assessment took place. In respect to the animal stimuli the pre-test consisted of asking children to "say the name out loud if you know what the animal is called, but say you don't know if you are unsure." Nineteen different animals were presented one at a time to the children. Particular animal stimuli were accepted as test stimuli if the child used the acknowledged signifier (see appendix III), and only if it was not prefixed or suffixed by an additional signifier, e.g. if children said "doggie" or "puppy" for the dog stimulus it was not included in testing. To avoid possible word length effects, animals with names of no more than one syllable were used. Additionally, an animal stimulus was only used as a test stimulus if it was immediately recognised, i.e. if a child took longer than 2 seconds to retrieve the animal's name even if it was the correct signifier, it was not included in the test stimuli. All children correctly named at least nine of the nineteen stimuli which enabled testing to continue.

The pre-test procedure was somewhat different for the symbol and face stimuli from the one discussed above for the animal stimuli. Given that the assessment wished to assess the influence of long-term memory representations across developmental groups, children were once again asked to indicate if they recognised each stimulus or if it reminded them of anything (or anyone in the case of face stimuli). A representation was only included if the child indicated that they did not recognise it and that it did not remind them of anything, by saying, "don't know". All children failed to recognise at least 9 of the 20 possible symbol stimuli, and 9 of

the 21 face stimuli. (See appendix III for the complete set of testing stimuli). To discourage verbal coding of the face stimuli all stimuli were of female faces, taken from participants aged 18-25, facial expression was neutral in all stimuli and hair style was standardised between faces using imaging software.

The analysis in the results section focuses on the total number of correctly recalled trials (CRT) measure of span capacity, as it was believed to be the most sensitive of the scoring methods. Although for comparative purposes the analysis of the longest span measure of recall span is included. Repeated measures analyses were carried out across the 3 visual representation stimuli (animal, symbol and face) between the 4 developmental groups (DN, D, DAR, and RA children) individually on the CRT and longest span dependent measures. Additional, analyses were also carried out with item serial order accuracies, RTs for correct and incorrectly recalled sequence trials as the dependent measures. All pairwise comparisons used Bonferroni conversions to adjust the relevant P-values.

Results

Span Capacity

A repeated measures analysis was carried out across the three visual representation conditions and between developmental groups, with CRT as the dependent measure. The analysis indicated that significant differences existed between visual representation conditions $F(2,212)=61.167$, $p < .001$. Bonferroni comparisons indicated that animal stimuli (mean=5.97, SE=.193, 95%CI=5.59-6.36) were recalled significantly better than both symbol (mean=4.09, SE=.205, 95%=3.68-4.50 $p < .001$) and face stimuli (mean=3.37, SE=.191, 95%CI=2.98-3.74 $p < .001$). In addition, symbol stimuli were recalled significantly better than face stimuli ($p < .05$) (see Figure 3.2). Significant differences were found between developmental groups, $F(2, 212)=61.167$, $p < .001$, with DN children's recall span (mean=6.20, SE=.218, 95%CI=5.77-6.63) being significantly higher than D (mean=4.24, SE=.265, 95%CI=3.72-4.77, $p < .001$), DAR (mean=3.69, SE=.235, 95%CI=2.97-4.42, $p < .001$) and RA children (mean=3.76, SE=.224, 95%CI=2.97-4.42, $p < .001$), and none of the other developmental groups significantly differing from one another. No significant interaction between development and visual representation condition was indicated $F(6, 212)=.398$, $p > .05$, see Table 3.1

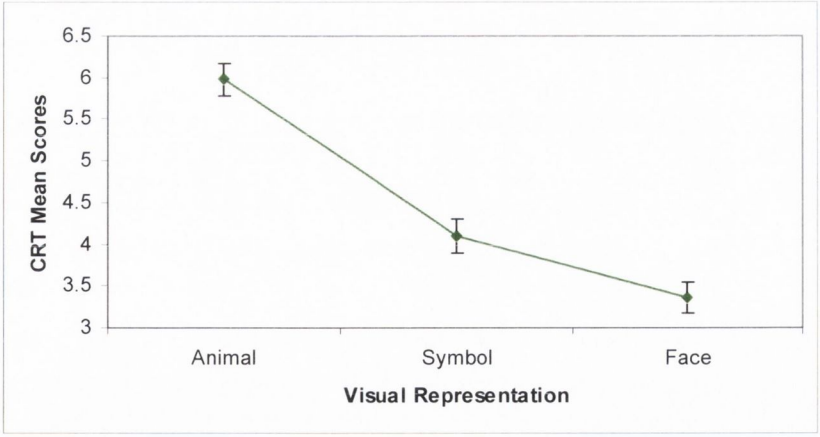

Figure 3.2 Line graph representing mean CRT scores across the three visual representation conditions, when stimuli are displayed using the serial presentation type.

Table 3.1 Summary table with CRT mean scores, standard error and 95% CI across developmental groups and visual representation stimuli when sequences are displayed using serial presentation

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	7.86	0.306	7.26	8.47
	Symbol	5.86	0.325	5.22	6.51
	Face	4.86	0.302	4.27	5.46
D	Animal	5.64	0.372	4.90	6.38
	Symbol	3.80	0.396	3.02	4.58
	Face	3.28	0.368	2.55	4.01
DAR	Animal	4.92	0.517	3.90	5.95
	Symbol	3.38	0.549	2.30	4.47
	Face	2.77	0.510	1.76	3.78
RA	Animal	5.46	0.315	4.83	6.08
	Symbol	3.31	0.334	2.65	3.98
	Face	2.51	0.311	1.90	3.13

When the analysis was rerun on the longest span as the dependent measures the profile of findings was largely consistent with the analysis above. Significant differences were again indicated between the 3 visual representation stimuli $F(3, 212)=28.700$, $p < .001$, indicting once again that animal stimuli (mean=3.79, SE=.084, 95%CI=3.63-3.96) were recalled better than both symbol (mean=3.16, SE=.098, 95%CI=2.97-3.35, $p < .001$) or face stimuli (mean=2.91, SE=.098, 95%CI=2.72-3.11, $p < .001$). However, unlike the CRT analysis, the analysis did not indicate that symbol stimuli were recalled better than face stimuli ($p > .05$). Significant differences were indicated between the developmental groups $F(3, 106)=18.749$, $p < .001$, with DN children (mean=3.97 SE=.099, 95%CI=3.78-4.17) demonstrating significantly higher recall span than D (mean=3.11, SE=120,

95%CI=2.87-3.35, $p < .001$), DAR (mean=3.03, SE=.167, 95%CI=2.70-3.36, $p < .001$) and RA (mean=3.05, SE=.102, 95%CI=2.85-3.25, $p < .001$, with none of the other groups significantly differing from one another. No significant interaction between development and visual representation was indicated $F(6, 212)=.319$, $p > .05$, see Table 3.2.

Table 3.2 Summary table with longest span mean scores, standard error and 95% CI across developmental groups and visual representation stimuli when sequences are displayed using serial presentation

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	4.49	0.133	4.22	4.75
	Symbol	3.89	0.155	3.58	4.20
	Face	3.54	0.155	3.23	3.85
D	Animal	3.52	0.161	3.20	3.84
	Symbol	2.96	0.188	2.59	3.33
	Face	2.84	0.188	2.47	3.21
DAR	Animal	3.54	0.224	3.10	3.98
	Symbol	2.85	0.261	2.33	3.36
	Face	2.69	0.261	2.17	3.21
RA	Animal	3.63	0.136	3.36	3.90
	Symbol	2.94	0.159	2.63	3.26
	Face	2.57	0.159	2.26	2.89

Serial Order Effects

A repeated measures analysis was carried out across the three serial position items (primacy, intermediate and recency items), the three visual representation conditions and between developmental groups, with item recall accuracy as the dependent measure. The analysis indicated that there were no significant differences in accuracy levels between stimulus types on the visual representations condition $F(2,214)=.319$, $p > .05$, with animal (mean=.366, SE=.019, 95%CI=.328-.403), symbol (mean=.353, SE=.018, 95%CI=.318-389) and face (mean=.347, SE=.017, 95%CI=.312-.381) stimuli having highly similar accuracy ratios. Significant effects were suggested between serial position categories $F(2,214)=83.207$, $p < .001$. Bonferroni comparisons indicated that primacy items (mean=.507, SE=.020, 95%CI=.467-547) were recalled significantly better than both the intermediate (mean=.295, SE=.014, 95%CI=.267-.323 $p < .001$) and recency items (mean=.264, SE=.015, 95%CI=2.35-2.93 $p < .001$), with intermediate and recency items not significantly differing from one another. Development, as in the previous chapter, was found to have significant main effect $F(3,107)=3.150$, $p < .05$, with Bonferroni comparisons indicating once again that DN children had a higher ratio of correctly

recalled items across serial positions (mean=.407, SE=.018, 95%CI=.271-.443) than the RA children (mean=.335, SE=.019, 95%CI=.297-.373 $p < .05$), while D (mean=.344, SE=.023, 95%CI=300-385) and DAR children (mean=.335, SE=.031, 95%CI=.273-.397) did not significantly differ from any of the other groups.

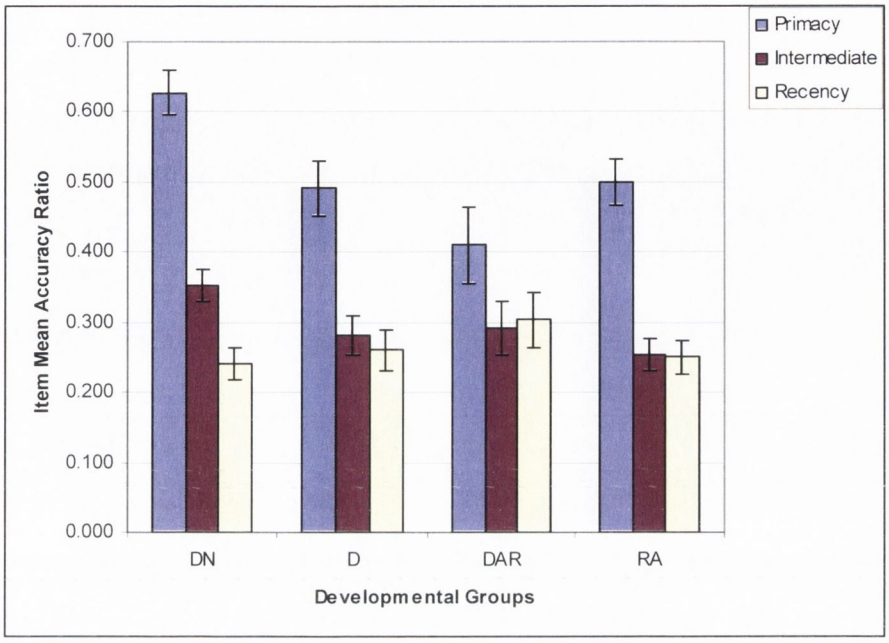

Figure 3.2 Bar chart displaying the interaction between developmental groups and serial position accuracy when stimuli are displayed using the serial presentation type.

Table 3.3 Mean accuracy ratios, standard error and 95%CI between developmental groups across serial position items, when stimuli are displayed using the serial presentation type.

Development	Serial Order	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	0.627	0.032	0.564	0.690
	Intermediate	0.353	0.022	0.309	0.397
	Recency	0.241	0.023	0.196	0.287
D	Primacy	0.491	0.039	0.413	0.569
	Intermediate	0.282	0.028	0.228	0.337
	Recency	0.260	0.028	0.204	0.316
DAR	Primacy	0.410	0.054	0.302	0.518
	Intermediate	0.291	0.038	0.215	0.366
	Recency	0.303	0.039	0.226	0.381
RA	Primacy	0.500	0.033	0.434	0.566
	Intermediate	0.254	0.023	0.208	0.300
	Recency	0.251	0.024	0.203	0.298

A significant interaction between development and serial position was also indicated $F(6,214)=4.091$, $p < .001$. As Table 3.3 and Figure 3.2 highlight, the interaction was due to DN children demonstrating significantly ($p < .05$) better recall

accuracy on intermediate items over recency items, while the other groups did not significantly differ on these items.

Response Times

A repeated measures analysis was run with RTs for correctly recalled sequences as the dependent measure across the 3 visual representation conditions and between developmental groups (DN n=38, D n=25, DAR n=10, RA n=35). Significant differences were revealed between developmental groups $F(1, 104)=6.782$, $p < .001$, with pairwise comparisons indicating that both DN children (mean=4820ms, SE=169, 95%CI=4485-5156) and D (mean=4564ms, SE=208, 95%CI=4150-4977) were responding significantly more quickly than RA children (mean=5687ms, SE=169, 95%CI=5337-6036, $p < .001$ and $p < .005$ respectively), while DAR children (mean=5013ms, SE=.329, 95%CI=4359-5666) did not significantly differ from any of the other groups (see Figure 3.3). Significant differences were found between the visual representation stimulus types $F(2, 208)=74.838$, $p < .001$, with animal stimuli (mean=6758ms, SE=230, 95%CI=6302-7215) having significantly longer RTs than either symbol stimuli (mean=4604ms, SE=173, 95%CI=4259-4949, $p < .001$) or face stimuli (mean=3700ms, SE=150, 95%CI=3402-3997, $p < .001$) additionally children recalled symbol stimuli sequences significantly than face stimuli sequences ($p < .001$). There was no significant interaction found between developmental group and visual representation stimuli $F(6, 208)=1.530$, $p > .05$, see Table 3.4.

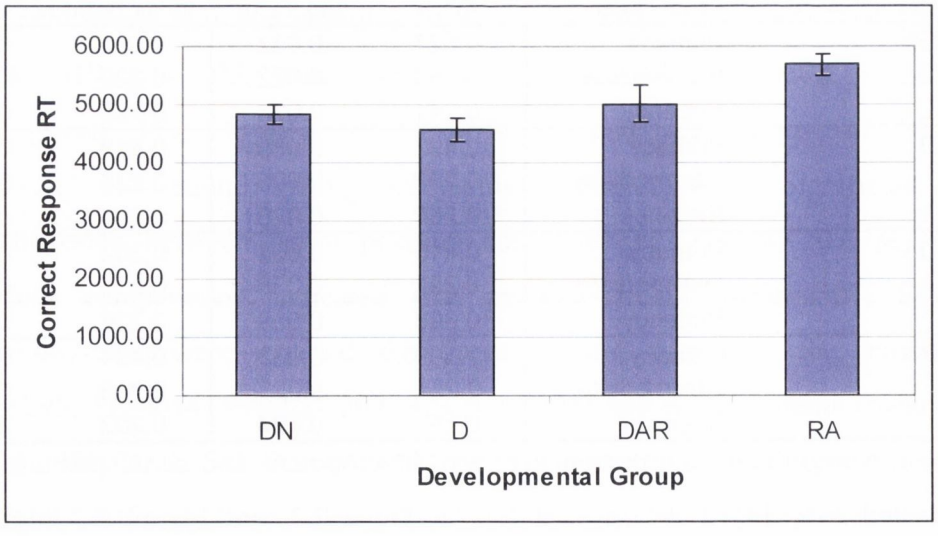

Figure 3.3 Bar chart displaying mean RT for correctly recalled sequences across developmental groups when stimuli are displayed using serial presentation.

Table 3.4 Summary table for correctly recalled RT mean scores, standard error and 95%CI across visual representation and between developmental groups

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	6354	338	5683	7024
	Symbol	4462	256	3955	4969
	Face	3646	220	3209	4084
D	Animal	5820	417	4993	6647
	Symbol	4573	315	3948	5198
	Face	3299	272	2760	3838
DAR	Animal	7039	659	5731	8346
	Symbol	4172	498	3184	5160
	Face	3829	430	2977	4682
RA	Animal	7823	352	7124	8522
	Symbol	5212	266	4684	5740
	Face	4026	230	3571	4482

Table 3.5 Summary table for incorrectly recalled RT mean scores, standard error and 95%CI across visual representation and between developmental groups

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	11965	735	10508	13421
	Symbol	11434	652	10142	12726
	Face	13204	812	11595	14813
D	Animal	12242	906	10446	14037
	Symbol	9269	803	7676	10861
	Face	11572	1001	9588	13556
DAR	Animal	11596	1256	9107	14086
	Symbol	11846	1114	9637	14054
	Face	10646	1388	7895	13397
RA	Animal	14134	765	12616	15651
	Symbol	12530	679	11184	13876
	Face	12988	846	11311	14664

A second repeated measures analysis was carried out on the RT data for incorrectly recalled sequences across the 3 visual representation conditions and between developmental groups (DN n=38, D n=25, DAR n=13, RA n=35). Unlike the previous analysis, no significant differences were found across developmental groups $F(3, 107)=2.098$, $p > .05$, with DN (mean=12200ms, SE=576, 95%CI=11057-13343), D (mean=11027ms, SE=710, 95%CI=9618-12436), DAR (mean=11362ms, SE=985, 95%CI=12026-14408), and RA (mean=13217ms, SE=600, 95%CI=12026-14408) children having very similar RTs to one another. The analysis found no significant differences in RT across visual representation conditions $F(2, 214)=3.021$, $p > .05$, although this was approaching significance P=.051, as while children responded similarly to animal (mean=12484ms, SE=469, 95%CI=11553-13414) and face (mean=12102ms, SE=518, 95%CI=11074-13130) stimuli, symbol

(mean=11269ms, SE=416, 95%CI=10444-12094) stimuli RTs were somewhat shorter than the other 2 representation types. Nor was there evidence for a significant interaction between development and representation type $F(6, 214)=1.804$, $p > .05$, see Table 3.5.

Discussion

Scoring Methods

In line with the findings of Experiment 2 the profile of results between the two scoring methods were consistent with one another. The analysis did indicate that the longest span length scoring method was less sensitive than the CRT scoring method, as the longest span measure did not uncover the significant differences in children's recall span between symbol and face stimuli in contrast to the CRT method, although both methods indicated a highly similar trend. It was for this reason we decided to base the subsequent analysis on the CRT method, given that while only correctly recalled trials are scored it nonetheless offers an additional indirect measure of error propensity across trials as well, which is lacking from the longest span measure.

Span Capacity

The repeated measures analysis found that animal stimuli were recalled by all children better than both face and symbol, and that face stimuli were more difficult to recall than symbol stimuli. Lowered recall span for face stimuli may be due to the increased processing demands required to carryout face discrimination given the need for configurational encoding and retrieval. Against the hypothesis concerning episodic buffer functioning in dyslexic children, we found no significant interaction between development and visual representation type. Interestingly, there did not seem to be any evidence that DN children were experiencing an additional benefit on the animal stimuli relative to the other developmental groups, perhaps suggesting that they were not scaffolding performance with verbal storage, as neither the RA or literacy impaired children would be expected to use spontaneous verbalisation during the task.

In contradiction to the findings of existing research (Jeffries & Everatt, 2004; Kibby et al., 2004; McDougall et al., 1994; Pickering & Gathercole, 2004) and the

findings of Experiment 1.2, D children were found to have significantly lower visual WM capacity than DN children. But in contrast to the findings of Experiment 2, these differences were significant even across the cruder longest span length scoring method, suggesting that the lack of findings in earlier research papers which indicated normal visual WM performance in D children were unlikely to be simply due to insensitivity of the scoring method, but were more likely due to either floor effects, heterogeneity between sequence length and task difficulty and/or a lack ecological validity in the selection of test stimuli in these studies. Even on the more abstract Chinese character stimuli, children, though naïve to the character representations, were likely drawing on similarities between the characters and existing letter discrimination representations in LTM in order to encode the visual representations. Supporting this view it was observed that in the symbol stimuli pre-test for stimuli item inclusion, that the most common signification of familiarity and therefore reason to reject stimulus items from the test measures was a statement in the form of "it looks like the letter..." or "looks kind of like the letters...", suggesting that children were drawing on LTM representations when faced with novel visual stimuli.

All groups essentially followed the same profile pattern across the visual representation types, although DN children demonstrated a significantly increased recall span relative to the D, DAR and RA children across representation types, with none of the other developmental group meaningfully differing. This would suggest that, across representation types, literacy impaired children are experiencing a similar development delay in visual WM capacity to their delay in literacy development, as they performed similarly to their reading age matched cohorts. Thus, there is little evidence at least from the present analysis that dyslexic children are showing a selective deficit specific to episodic buffer functioning (Baddeley, 2000).

Serial Order Effects

There was no evidence of the traditional serial order bow effect on the analysis of serial order. Once again primacy items were best recalled, with intermediate and recency items showing the worst recall accuracy. Like Experiment 2, the analysis indicated that RA children recalled fewer items correctly than DN children when span exceeded capacity, suggesting potential developmental increases in the manner in which items are stored, while the literacy impaired children were not found to significantly differ from either group. The suggestion of developmental

changes in the manner in which items are stored was further supported by the interaction between development and serial order. DN children, in contrast to the other children, demonstrated significantly better recall on the intermediate items than on the recency items, perhaps suggesting that sequence representations are more resilient to decay in these children, even when storage capacity has been exceeded.

Response Times

When RTs for correctly recalled sequence trials were assessed, a similar profile to Experiment 2 was found. This time both D and DN children responded significantly more quickly than RA children, with DAR children not differing from either group. Given the findings from the serial order analysis, it is possible that RA children are less aware that representations are more vulnerable to decay or overwriting as the delay between sequence and response increases. Part of DN children's increased span capacity relative to RA children may relate to a decreasing turnaround speed between sequence presentation and response completion. This is further supported by the finding of no significant differences between groups in respect to RT for incorrect recalls. This is in line with Pickering's (2001) observation that the quicker the response, the higher the likelihood of a correct recall, and possibly indicates that if RA children had responded as quickly as D or DN children they may have attained a slightly higher recall span. If the above argument holds and D children have an equivalent VSWM capacity to RA children, we would expect them to demonstrate a slightly enhanced span capacity, due to their speeded up RTs. Indeed, consistently across scoring measures and stimuli types, D children do demonstrate a slightly increased though non-significantly higher span capacity than RA children. Similarly, as DAR children's RTs do not significantly differ from those of RA children, we would expect a more similar performance between these groups, which is exactly the case, as highlighted in Tables 3.1-3.2.

Summary

Experiment 3.1 used serial presentation due to the findings in Experiment 1.2 and the existing research which has posited that dyslexic individuals have a deficit in their ability to direct the size of spatial focus (Facoetti, Paganoni, Turatto et al., 2000; Rayner et al., 1989). As Experiment 3.1 test stimuli were presented one at time in the same central position, there can be no case for the position that dyslexic children's

reduced visual WM capacity related to visual interference from flanking stimuli items due to weakened spatial focus. The findings indicated that dyslexic children performed significantly worse than their age matched cohorts on these clean measures of visual WM capacity, but reacted no differently to the separate visual representation stimuli than the literacy unimpaired children. In line with the spatial focus research and Experiment 1.2, it is possible that the dyslexic children will experience additional deficits above and beyond those found in the current experiment if stimuli are presented in a non-serial fashion. This will form the basis of Experiments 3.2 and 3.3.

Experiment 3.2 Introduction

Building on the manipulation involving visual representations, the current round of experiments wished to further clarify the implications of presentation format on visual WM tasks. Logie's (1995) research offers strong empirical support that separate functional systems are involved in processing of visual versus spatial information. In his study, participants experienced a selective impairment on spatial tasks when faced with a secondary requirement to carry out arm movements, but there was no impairment when participants were required to watch but ignore irrelevant picture presentations during the retention interval. In a colour discrimination memory task, participants recall ability was selectively impaired with the addition of irrelevant picture presentations, but not when required to carry out secondary arm movements. In contrast, recent research has suggested that the split in functionality may not be quite as clear-cut. Jiang, Olson and Chun's (2000) research found that on colour change detection tasks the ability to detect colour shifts was impaired if the colour stimuli were rearranged from the initial presentation into a new spatial configuration, but not if the absolute locations were modified by proportionally increasing the distances between all items uniformly. They argued that, in visual (object) encoding, the spatial representations between these objects are also incidentally encoded. Olson and Marshuetz's (2005) research further clarified this position suggesting that in the visual encoding of objects, spatial references to other objects within the local visual arena are also implicitly encoded. This explains why absolute shifts that maintain the interrelations between objects, but uniformly vary the spatial distance between items, do not affect retrieval and processing ability, but shifts that change the configurations between objects, which nonetheless stay within the same locality, do.

Existing research has suggested that dyslexic children have difficulties establishing strong automatic connective links between visual and verbal codes (Fawcett & Nicolson, 2004; Høien, 2002), it is therefore possible that dyslexic children likewise do not experience the same interconnectedness between visual and spatial codes. In fact there is supportive evidence for this position. Research by Levin (1990) found that dyslexic children matched more details to the wrong areas on the Rey Osterrieth complex figures tests than developmentally normal children, suggesting a deficit in visual organisation. If the interrelations between visual and spatial codes are automatically established in non-literacy impaired children, they should experience an additional resource demand when processing the visual codes which have had the spatial representations from the presentations stage rendered redundant in the retrieval stage of the task. Effective spatial redundancy is established by using a separate response screen to the screen which is used to present stimuli sequences. In contrast, if dyslexic children do not automatically establish dual visual and spatial representations when asked to recall visual objects, there should be no change in performance between serial presentations and presentation displays where the spatial components have been rendered redundant at the recall stage in these children.

Given that one of the primary functions of the CE is argued to be the selection and enhancement of certain incoming streams of information while rejecting/inhibiting others (Baddeley, 1996), we would suspect that such functionality will be tapped by the separate modes of presentation. If spatial codes are automatically incorporated into visual representations in developmentally normal children but not dyslexic children, the tasks may necessitate an additional CE load in literacy unimpaired children. This may be due to the requirement to inhibit spatial representations which may lead to similar performance between the developmental groups, given the CE is suggested to play a role in all VSWM tasks (Vandierendonck et al., 2004). However, if dyslexic children automatically incorporate spatial representations in visually encoded stimuli, we would expect these children to demonstrate an additional impairment beyond their literacy unimpaired cohorts, due to the established inhibitory difficulties experienced by these children (Reiter et al., 2005; van der Schoot, Licht, Horsley, & Sergeant, 2000).

Method

Procedure

The testing procedure between Experiments 3.1 and 3.2 was identical except that in the sequence presentation stage of the task, sequences were presented using parallel spatially redundant display types (see Figure 3.4). Thus, stimuli would flash up one at a time for 500ms with a between item interval of 1000ms. That is before the start of a sequence all 9 stimulus items are presented at the dormant level of illumination, with sequence trials being built up by individual stimulus items one at a time changing to the 'flashing' level of abrupt luminance change, which is maintained for 500ms before returning to the dormant level of illumination, after 1000ms the next stimuli item would change to the flash level of luminance for 500ms and so on and so forth until the required sequence length.

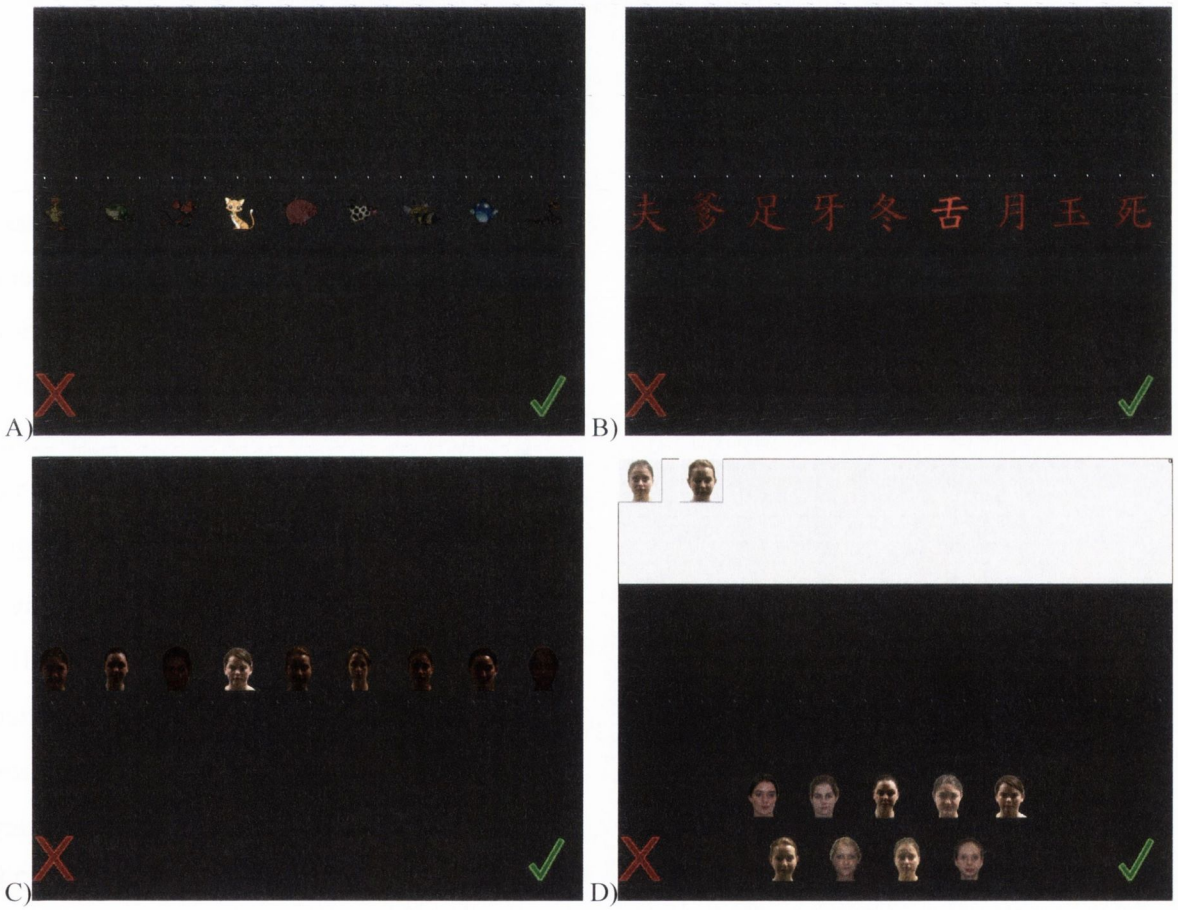

Figure 3.4 Screen shots of the parallel presentation types across the three visual representation types and response screen. A) Animal stimuli B) Symbol stimuli C) Face stimuli, and D) the face stimuli response screen, indicating that a 2 item sequence has been copied.

The presentations were rendered spatially redundant by using a different response screen than the one that was used to present the sequence trial. Importantly the response screen on which children copied out the order items flashed up on the screen had no spatial correlates with the sequence presentation screen. In this way children needed to ignore the spatial codes between stimuli items which were present at the encoding phase and focus on the visual representations of the stimuli items, as it was only visual representations which could be used at the retrieval stage.

Again repeated measures analyses were carried out across the 3 visual representation stimuli (animal, symbol and face) between the 4 developmental groups (DN, D, DAR, and RA children) individually on the CRT and longest span dependent measures. Additional, analyses involved item serial order accuracies, RTs for correct and incorrectly recalled sequence trials as the dependent measures, using Bonferroni conversions to adjust the relevant P-values.

Results

Span Capacity

A repeated measures analysis was carried out on the spatially redundant parallel presentations across the visual representation conditions and between developmental groups with CRT as the dependent variable. Visual representation stimuli were found to significantly differ $F(2,212)=74.247$, $p < .001$, with pairwise comparisons indicating the animal stimuli (mean=5.47, SE=.229, 95%CI=5.01-5.92) were recalled significantly better than both symbol (mean=3.80, SE=.223, 95%CI=3.36-4.25, $p < .001$) and face stimuli (mean=2.55, SE=.177, 95%CI=2.20-2.90, $p < .001$). In line with the analysis from the serial presentation displays, children recalled symbol stimuli significantly better than the face stimuli ($p < .001$). In keeping with the 3.1 analysis, significant differences were indicated between development conditions, with Bonferroni comparisons indicating that DN children (mean=5.71, SE=.252, 95%CI=5.21-6.21) had significantly higher recall accuracy than D (mean=3.71, SE=.306, 95%CI=2.10-4.31, $p < .001$), DAR (mean=3.23, SE=.425, 95%CI=2.39-4.07, $p < .001$) and RA children (mean=3.11, SE=.259, 95%CI=2.59-3.62, $p < .001$) with none of the other groups significantly differing form one another.

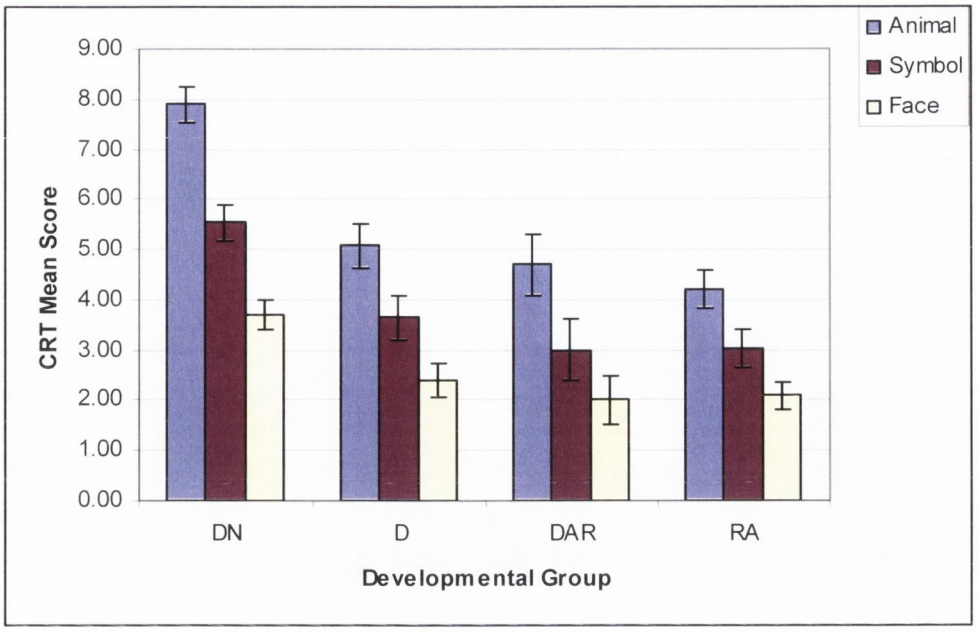

Figure 3.5 Bar chart of the interaction between developmental groups and visual representation stimuli when stimuli displayed using the spatially redundant parallel presentation type with CRT is the dependent variable.

Table 3.6 Mean CRT scores and 95% CI across developmental groups and visual representation stimuli for spatially redundant parallel placement presentations.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	7.89	0.363	7.17	8.61
	Symbol	5.54	0.353	4.84	6.24
	Face	3.70	0.280	3.15	4.26
D	Animal	5.08	0.441	4.21	5.95
	Symbol	3.64	0.430	2.79	4.49
	Face	2.40	0.341	1.72	3.08
DAR	Animal	4.69	0.612	3.48	5.91
	Symbol	3.00	0.596	1.82	4.18
	Face	2.00	0.473	1.06	2.94
RA	Animal	4.20	0.373	3.46	4.94
	Symbol	3.03	0.363	2.31	3.75
	Face	2.09	0.288	1.51	2.66

There was also a significant interaction between the development and visual representation conditions $F(6, 212)=2.637$, $p < .05$ (see Figure 3.5). The interaction was due to DAR children demonstrating no significant differences in recall span between symbol and face stimuli in contrast to the other developmental groups, see Table 3.6.

The repeated measures analysis with longest span as the dependent measure indicated an almost identical profile of results to the findings described above.

Significant differences in recall span were again indicated between developmental groups ($p < .001$) $F(3, 106)=19.826$, $p < .001$, with Bonferroni pairwise comparisons indicating that the DN (mean=3.84, SE=.097, 95%CI=3.65-4.03) children had significantly higher recall performance than D (mean=3.01, SE=.118, 95%CI=2.78-3.25, $p < .001$), DAR (mean=2.97, SE=113, 95%CI=2.65-3.30, $p < .001$) and RA (mean=2.86, SE=.099, 95%CI=2.66-3.05, $p < .001$) Children, with none of the other groups significantly differing from one another. Again, significant differences were indicated between visual representation stimuli $F(2,212)=43.113$, $p < .001$, with pairwise comparisons indicating that children recalled animal stimuli (mean=3.70, SE=.088, 95%CI=3.53-3.87) significantly better than symbol (mean=3.16, SE=.096, 95%CI=2.97-3.56, $p < .001$) and face stimuli (mean=2.65, SE.084, 95%CI=2.48-2.82, $p < .001$), with once again children recalling sequences presented with symbol stimuli significantly better than face stimuli ($p < .001$). No significant interaction between development and visual representation was indicated $F(6, 212)=1.401$, $p > .05$, see Table 3.7, as the developmental groups reacted similarly one another across the 3 visual representation conditions.

Table 3.7 Longest span mean scores and 95% CI across developmental groups and visual representation stimuli for spatially redundant parallel placement presentations.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	4.62	0.139	4.35	4.90
	Symbol	3.70	0.152	3.40	4.00
	Face	3.19	0.133	2.93	3.45
D	Animal	3.48	0.169	3.15	3.81
	Symbol	3.00	0.185	2.63	3.37
	Face	2.56	0.162	2.24	2.88
DAR	Animal	3.38	0.234	2.92	3.85
	Symbol	3.15	0.257	2.64	3.66
	Face	2.38	0.225	1.94	2.83
RA	Animal	3.31	0.143	3.03	3.60
	Symbol	2.80	0.157	2.49	3.11
	Face	2.46	0.137	2.19	2.73

Serial Order Effects

Serial position accuracy was assessed across visual representation stimuli. No significant differences were found between the 3 visual representation conditions in respect to serial position accuracy $F(2, 214)=.824$, $p > .05$, with animal (mean=.379, SE=.017, 95%CI.346-.413), symbol (mean=.353, SE=.016, 95%CI=.320-386) and

face (mean=.376, SE=.016, 95%CI=.345-408) stimuli having very similar item accuracy ratios. The analysis indicated significant differences between developmental groups $F(3,107)=5.913$, P=.001. Once again DN children (mean=.423, SE=.016, 95%CI=.392-.454) had a significantly higher accuracy ratio than the RA children (mean=.331, SE=.016, 95%CI=.299-363, $p < .001$), while D (mean=.359, SE=.019, 95%CI=.321-.397) and DAR children (mean=.365, SE=.027, 95%CI=.321-417) did not significantly differ from any of the other groups. Significant differences were found in the recall accuracy of the individual serial position items $F(2,214)=162.068$ $p < .001$, with children recalling primacy items (mean=.575, SE=.018, 95%CI=.540-.610) significantly better than both the intermediate (mean=.323, SE=.015, 95%CI=.294-.352 $p < .001$) and the recency items (mean=.211, SE=.014, 95%CI=.184-.239, $p < .001$). The children also recalled intermediate items significantly better than recency items ($p < .001$). A significant interaction was indicated between serial position and developmental group $F(6, 214)=4.626$, $p < .001$. As Figure 3.6 highlights, the interaction was due to the DAR children demonstrating no significant difference in recall accuracy ratio on the primacy items relative to the intermediate items, similarly the RA children did not perform significantly better on the intermediate items relative to the recency, see Table 3.8.

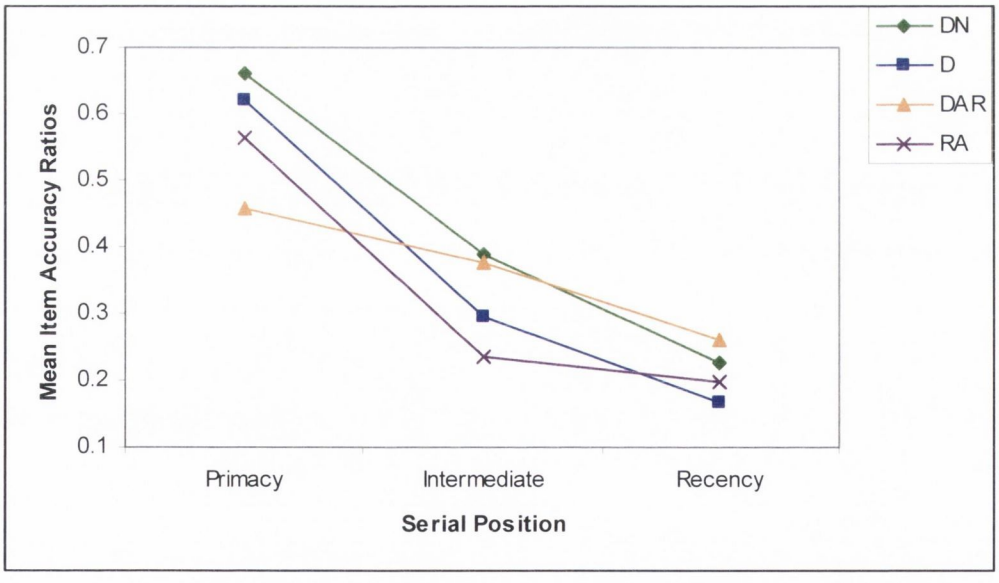

Figure 3.6 Line graph representing the interaction between developmental group and serial position accuracy for stimuli presented on the spatially redundant parallel presentation.

Table 3.8 Summary table with mean accuracy item ratios, standard error and 95%CI across serial position items and developmental group.

Development	Serial Order	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	0.658	0.028	0.603	0.713
	Intermediate	0.388	0.023	0.342	0.434
	Recency	0.224	0.022	0.180	0.267
D	Primacy	0.620	0.034	0.552	0.688
	Intermediate	0.293	0.028	0.237	0.350
	Recency	0.164	0.027	0.111	0.218
DAR	Primacy	0.457	0.047	0.363	0.551
	Intermediate	0.376	0.039	0.298	0.454
	Recency	0.261	0.037	0.187	0.335
RA	Primacy	0.563	0.029	0.506	0.621
	Intermediate	0.233	0.024	0.186	0.281
	Recency	0.197	0.023	0.152	0.242

Response Times

A repeated measures analysis was carried out on the RT data for correctly recalled responses across the 3 visual representation conditions and developmental groups (DN n=38, D n=22, DAR n=10, and RA n=35). No significant differences were found between visual representation stimuli $F(2,202)=.575$, $p > .05$, as RTs were very similar between animal (mean=5662ms, SE=212, 95%CI=5241-6083), symbol (mean=5801ms, SE=254, 95%CI=5297-6305) and face (mean=5425ms, SE=279, 95%CI=4870-5980) stimuli. There was no significant interaction between representation type and development group $F(6,202)=.528$, $p > .05$ see Table 3.9. Once again significant differences were found between developmental groups $F(3,101)=2.958$, $p < .05$, with pairwise comparisons indicating that D children (mean=5153ms, SE=273, 95%CI=4610-5697) were again responding significantly more quickly than RA children (mean=6167ms, SE=217, 95%CI=5736-6597, $p < .05$), but neither DN (mean=5725ms, SE=208, 95%CI=5311-6139) nor DAR (mean=5473ms, SE=406, 95%CI=4667-6279) children significantly differed from any other group.

Table 3.9 Mean RT, standard error and 95% CI for correctly recalled sequences across visual representation and developmental groups for stimuli displayed on the spatially redundant parallel presentation type.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	5431	308	4821	6042
	Symbol	5989	368	5258	6720
	Face	5755	406	4951	6560
D	Animal	4862	405	4059	5664
	Symbol	5422	484	4461	6383
	Face	5177	533	4120	6234
DAR	Animal	5886	600	4695	7076
	Symbol	5533	718	4108	6958
	Face	5002	791	3434	6570
RA	Animal	6471	321	5835	7107
	Symbol	6263	384	5501	7025
	Face	5767	423	4929	6605

A repeated measures analysis was carried out on the RT data for incorrectly recalled responses across the 3 visual representation conditions and developmental groups (DN n=38, D n=25, DAR n=13, and RA n=35). When the analysis was rerun on the RT data for incorrectly recalled responses, no significant differences were found between developmental groups $F(3, 107)=2.431$, $p > .05$, with DN (mean=11247ms, SE=771, 95%CI=1078-13697), D (mean=11666ms, SE=901, 95%CI=9879-13452), DAR (mean=11103ms, SE=1249, 95%CI=8625-13581), and RA (mean=14225ms, SE=761, 95%CI=12715-15735). Nor were significant differences indicated between the visual representation conditions $F(2,214)=2.534$, $p > .05$, with animal (mean=12516ms, SE=522, 95%CI=11480), symbol (mean11656ms, SE=601, 95%CI=10463-12847) and face (mean=12760ms, SE=534, 95%CI=11701-13820) stimuli or interactions involving visual representation and development $F(6, 214)=.943$, $p > .05$. The overall mean RT for incorrectly recalled sequences (mean=12310ms, 95%CI=11385-13236) was once again significantly slower than the RT for correctly recalled sequences (mean=5629ms, 95%CI=5344-5915, $p < .001$).

Discussion

Span Capacity

The profile of how visual representation stimuli types affected recall on the spatially redundant parallel presentation displays was similar to the recall profile found on the serial presentation condition. That is, animal stimuli were better recalled

than both face and symbol stimuli. In addition, children experienced better recall on the symbol stimuli than the face stimuli. DN children were again demonstrating a significantly higher recall span than any of the other developmental groups, which did not meaningfully differ from one another. Once again suggesting that while D and DAR children are experiencing a delay in the development of visual WM capacity it is a delay which is similar in magnitude to their developing literacy ability given the similarity in recall span between the literacy impaired children and their reading age matched cohorts. In contrast to the serial presentation display findings, a significant interaction between development and representation type was indicated in the current analysis. DAR children did not demonstrate significantly higher recall span on the symbol stimuli versus the face stimuli, although there was a strong trend in that direction, possible suggesting that the lack of significant effects may have been due to the smaller sample size in this group.

Serial Order Effects

Once more, there was no evidence of the traditional bow effect between serial positions, but in keeping with early findings, significantly better recall occurred on primacy items relative to intermediate and recency items, with children experiencing better recall accuracy on the intermediate items than the recency items. The analysis of serial position accuracy found that DN children showed higher accuracy ratios than the RA children, while D and DAR children did not differ from either group. An interaction between development and serial position was also indicated that DAR children, in contrast to the other developmental groups, demonstrated no meaningful differences in accuracy ratios between primacy and intermediate items. The DAR children's lack of markedly better recall accuracy on the primacy items and the slightly elevated accuracy ratios on the recency items relative to than D or DN children, may suggest that, unlike the other children test termination in these children may have related to inattention rather than capacity overload. The interaction was also due to the RA children, in contrast to the other developmental groups, not showing a marked impairment in performance between intermediate and recency items. This offers further support for the position that RA children's storage capacity, once exceeded, shows a less gradual rate of decay across the serial positions, as the intermediate accuracy ratios were as low as recency items accuracy ratios.

Response Times

RTs for correctly recalled sequences were once again quicker than RTs for incorrectly recalled trials. The only other significant effect on RT occurred between developmental groups, with RA children once more showing markedly slower RT than D children, with none of the other groups differing. In keeping with observations from Experiment 3.1, it is of note that D children responded on sequence trials more quickly than RA children, and at the same time continued to show a slight though non-significantly enhanced span capacity consistently across all the visual representation conditions.

Summary

The analysis suggested that while the literacy impaired and DN children were relatively matched in terms of RT and serial position accuracy, the D and DAR children nonetheless consistently demonstrated significantly lower visual WM capacity than DN children. In line with existing research, RA children showed a reduced visual WM capacity in relation to DN children (Logie & Pearson, 1997; Pickering, 2001; Pickering et al., 2001). Given that across the scoring measures D and DAR children have shown similar visual WM span capacity to RA children, it is suggested that they may be experiencing a delay in visual WM development that is in line with their delay in the acquisition of literacy skills.

Experiment 3.3 Introduction

Following on from the experimental manipulation in Experiment 3.2, Experiment 3.3 assessed children's visual WM capacity on spatially redundant matrix presentations as further exploration of the possible interference effects due to task extraneous information. It was believed that as children in Experiment 2 were found to have greater spatial recall span on matrix as opposed to parallel presentations, they may elicit greater interferences effects due to the loss of spatial representations than those produced by the parallel presentations in 3.2.

Method

The testing procedure and analyses of Experiment 3.3 were identical to Experiments 3.1 and 3.2, except that visual representation stimuli were now presented using matrix spatially redundant display types (see Figure 3.7). The same participants as

Experiments 3.1 and 3.2, were used in the current experiment, except that the data from one DN child was lost due to computer error, (DN n=37, D n=25, DAR n=13, RA n=35).

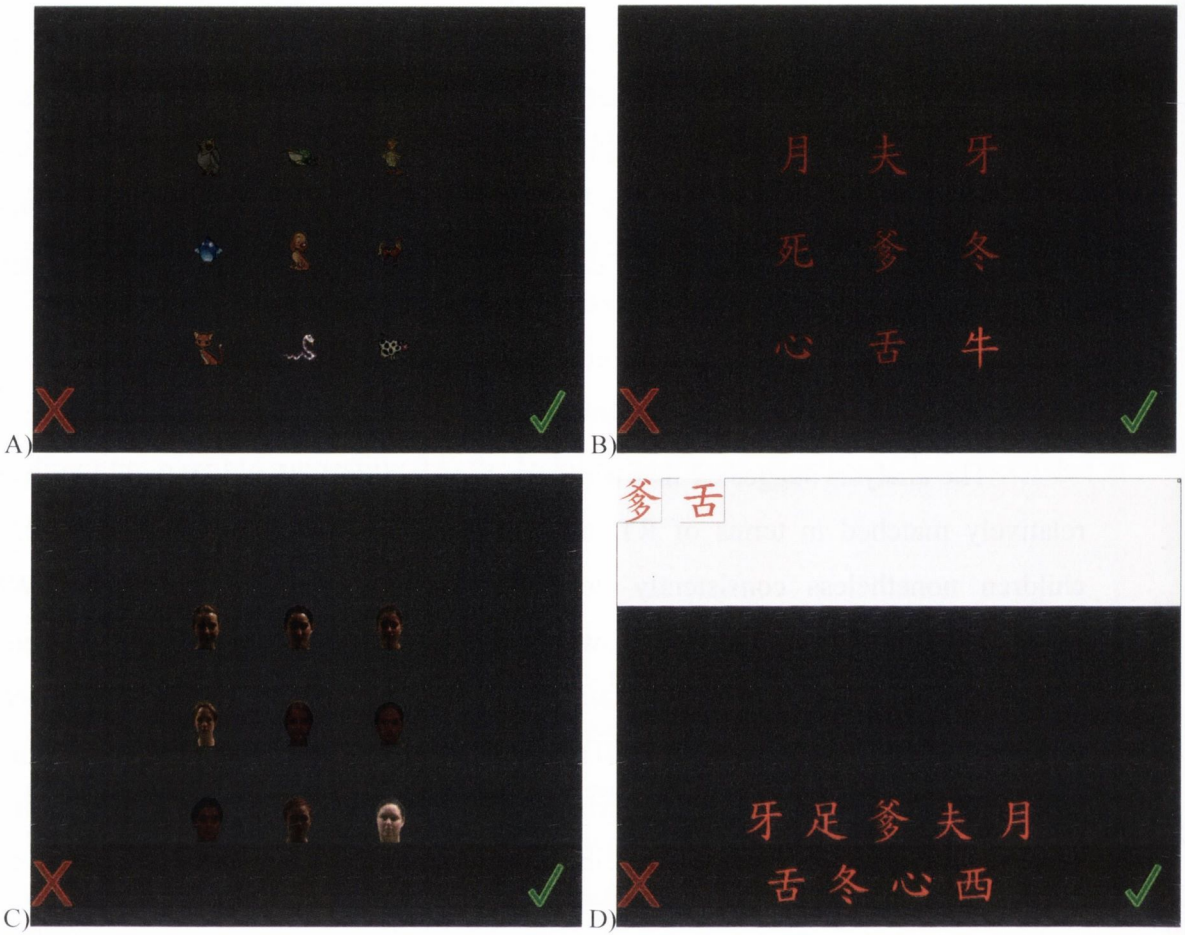

Figure 3.7 Screen shots of the matrix presentations across the three visual representation types and response screen. A) Animal stimuli B) Symbol stimuli C) Face stimuli, and D) the Symbol stimuli response screen, indicating that a 2 item sequence has been copied

While the 9 stimulus items were now presented in a 3 x 3 matrix display, sequence trials were built up in exactly the same manner as Experiment 3.2, with individual stimulus items changing one at a time to the 'flashing' level of abrupt luminance change, which was maintained for 500ms before returning to the dormant level of illumination, after 1000ms the next stimuli item would change to the flash level of luminance for 500ms and so on and so forth until the required sequence length was reached. The presentations once again being rendered spatially redundant by using a different response screen than the one that was used to present the sequence trial.

Results

Span Capacity

A repeated measures analysis was carried out across the visual representation conditions which were presented on a spatially redundant matrix display between developmental groups with CRT as the dependent measure. The analysis showed that children demonstrated significantly changes in recall span across the visual representation conditions $F(1.872, 198.459)=65.363$, $p < .001$, with pairwise comparisons indicating that once again children recalled animal stimuli (mean=5.54, SE=.235, 95%CI=5.07-601) better than either symbol (mean=3.81, SE=.205, 95%CI=3.40-4.21 $p < .001$) or face stimuli (mean=2.66 SE=.183, 95%CI=2.30-3.02 $p < .001$). Additionally children also showed better recall on the symbol stimuli than the face stimuli ($p < .001$) (see Figure 3.8). The analysis also revealed significant differences in recall span between the development groups $F(3,106)=19.362$, $p < .001$. Bonferroni comparisons revealed that DN children (mean=5.68, SE=.235, 95%CI=5.21-6.14) had significantly higher recall accuracy than D (mean=3.53, SE=.286, 95%CI2.97-4.10, $p < .001$), DAR (mean=3.28, SE=.297, 95%CI=2.50-4.07, $p < .001$) and RA children (mean=3.51, SE=.242, 95%CI=3.04-3.99, $p < .001$), with none of the other groups significantly differed from one another. There was no interaction between visual representations and development type $F(5.617, 198.459)=1.220$ $p > .05$, see Table 3.10.

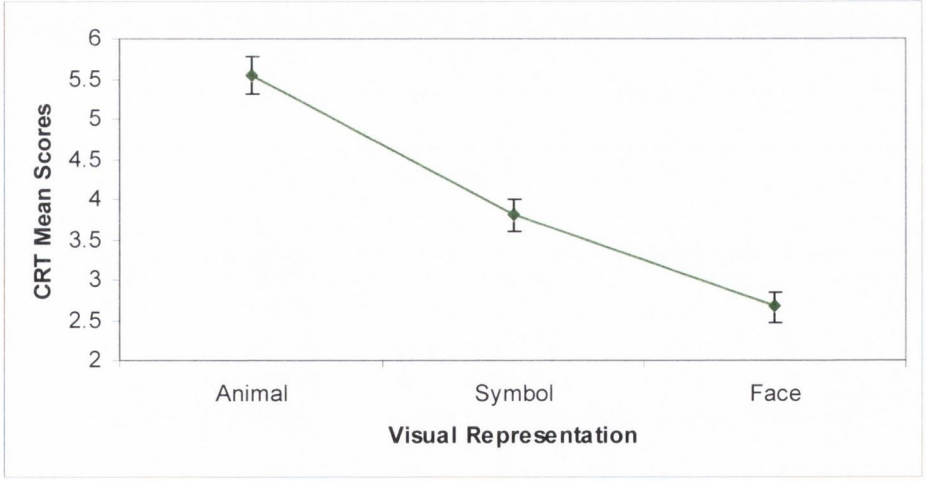

Figure 3.8 Line graph demonstrating CRT mean scores across visual representation conditions when stimuli are presented on a spatially redundant matrix display.

Table 3.10 CRT mean scores, standard error and 95% CI across visual representation stimuli and developmental groups for spatially redundant matrix displays.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	7.32	0.372	6.59	8.06
	Symbol	5.86	0.324	5.22	6.51
	Face	3.84	0.290	3.26	4.41
D	Animal	5.04	0.453	4.14	5.94
	Symbol	3.28	0.394	2.50	4.06
	Face	2.28	0.353	1.58	2.98
DAR	Animal	4.54	0.628	3.29	5.78
	Symbol	3.08	0.547	1.99	4.16
	Face	2.23	0.489	1.26	3.20
RA	Animal	5.26	0.383	4.50	6.02
	Symbol	3.00	0.333	2.34	3.66
	Face	2.29	0.298	1.69	2.88

The repeated measures analysis across the visual representation stimuli and between developmental groups with longest span as the dependent measure revealed a completely identical profile of results. Visual representation conditions significantly differed $F(2, 212)=54.165$, $p < .001$, with recall on the animal stimuli sequences (mean=3.79, SE=.101, 95%CI=3.59-3.99) being significantly higher than either symbol (mean=3.07, SE=.098, SE=2.87-3.26, $p < .001$) or face (mean=2.62, SE=.085, 95%CI=2.45-2.79, $p < .001$)stimuli, and symbol enabling better recall than face stimuli ($p < .001$).

Table 3.11 Longest span mean scores, standard error and 95% CI across visual representation stimuli and developmental groups for spatially redundant matrix displays

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	4.43	0.160	4.12	4.75
	Symbol	3.92	0.155	3.61	4.23
	Face	3.38	0.135	3.11	3.65
D	Animal	3.44	0.194	3.05	3.83
	Symbol	2.88	0.189	2.51	3.25
	Face	2.44	0.165	2.11	2.77
DAR	Animal	3.62	0.270	3.08	4.15
	Symbol	2.69	0.262	2.17	3.21
	Face	2.23	0.228	1.78	2.68
RA	Animal	3.66	0.164	3.33	3.98
	Symbol	2.77	0.159	2.46	3.09
	Face	2.43	0.139	2.15	2.70

Significant differences again were found between developmental groups $F(3,106)=18.152$, $p < .001$, resulting from DN children (mean=3.91, SE=.109, 95%CI=3.69-4.13) having higher recall accuracy than D (mean=2.92, SE=.133, 95%CI=2.66-3.18, $p < .001$), DAR (mean=2.85, SE=.184, 95%CI=2.48-3.21, $p <$

.001) and RA (mean=2.95, SE=.112, 95%CI=2.73-3.18, $p < .001$), with no other significant differences found between groups. Once again there was no significant interaction between development and visual representation conditions $F(6, 212)=.575$, $p > .05$, see Table 3.11, as the developmental groups reacted similarly to changes in the stimuli representations used to present sequences.

Serial Order Effects

Serial position accuracy was assessed across visual representations and developmental conditions. No significant differences were found between visual representation types in serial position accuracy $F(2,214)=1.279$, $p > .05$, with once again animal (mean=.401, SE=.020, 95%CI=.362-.440), symbol (mean=.373, SE=.019, 95%CI=.336-.410) and face (mean=.363, SE=.019, 95%CI=.325-.400) stimuli having very similar item recall ratios. Serial order positions again significantly differed from each other (2,214)=194,699, $p < .001$, with pairwise tests indicating that children had a significantly higher recall accuracy ratio on the primacy items (mean=6.07, SE=.020, 95%CI=.568-.646) than either the intermediate (mean=.313, SE=.016, 95%CI=.281-.346 $p < .001$) or recency items (mean=.217, SE=.016, 95%CI=.185-.248 $p < .001$). Intermediate items were recalled with a higher accuracy ratio than recency items ($p < .001$). Developmental groups were found to significantly differ also $F(3,107)=6.803$, $p < .001$. As with the earlier findings, DN children (mean=.447, SE=.020, 95%CI=.408-.486) had significantly higher overall accuracy ratios than RA children (mean=.324, SE=.021, 95%CI=284-365, $p < .001$), with neither D (mean=.401, SE=.014, 95%CI=.352-.449) or DAR (mean=.344, SE=.034, 95%CI=.277-.411) children significantly differing from any other group. A significant interaction between serial position and development was found $F(6,214)=5.005$, $p < .001$. As Figure 3.9 demonstrates DN and RA children, unlike the literacy impaired children, had significantly better recall accuracy on the intermediate items relative to the recency items (see Table 3.12).

Figure 3.9 Bar chart displaying item recall accuracies across serial order position and between development conditions, for spatially redundant matrix presentation tests

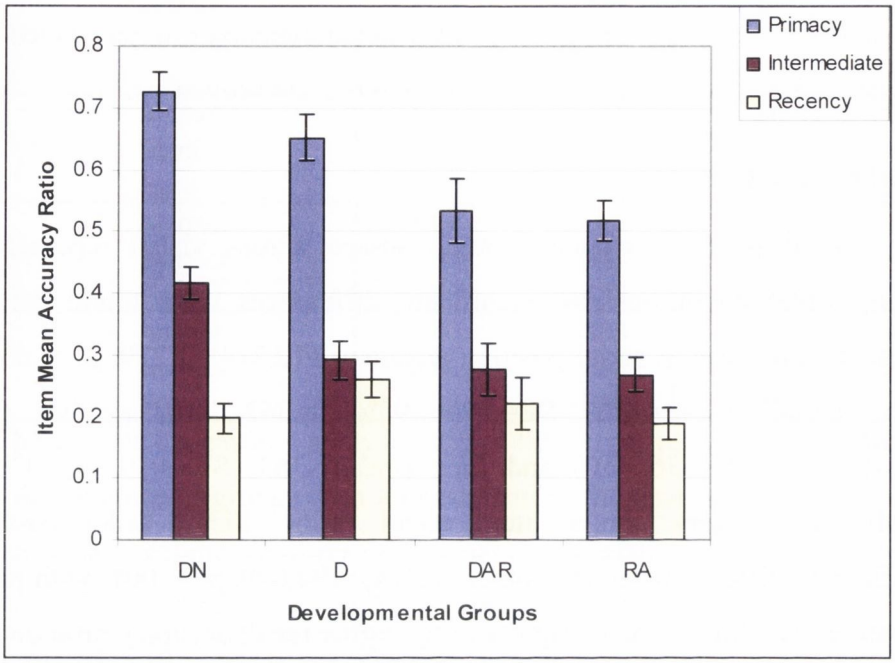

Table 3.12 Mean accuracy recall ratios for the individual serial positions between developmental groups, for spatially redundant matrix presentation tests.

Development	Serial Order	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	0.727	0.031	0.666	0.788
	Intermediate	0.417	0.026	0.366	0.468
	Recency	0.197	0.025	0.148	0.246
D	Primacy	0.651	0.038	0.576	0.726
	Intermediate	0.291	0.032	0.229	0.354
	Recency	0.260	0.031	0.200	0.320
DAR	Primacy	0.534	0.053	0.430	0.639
	Intermediate	0.276	0.044	0.190	0.363
	Recency	0.222	0.042	0.138	0.306
RA	Primacy	0.517	0.032	0.454	0.581
	Intermediate	0.268	0.027	0.215	0.321
	Recency	0.187	0.026	0.136	0.238

Response Times

A repeated measures analysis was carried out on the RT data for correctly recalled responses across the 3 visual representation conditions and developmental groups (DN n=38, D n=22, DAR n=10, and RA n=34). Once again there were significant differences indicated between developmental groups $F(3,100)=6.581$, $p < .001$. Pairwise comparisons indicating that both DN children (mean=4097ms, SE=146, 95%CI=3806-4389, $p < .005$), and D (mean=3951ms, SE=193,

95%CI=3568-4334, P=.001) responded significantly more quickly than RA children (mean=4894ms, SE=155, 95%CI=4586-5202), while DAR children (mean=4504, SE=286, 95%CI=3936-5072) did not significantly differ form any other group. Significant differences in RT were also indicated between visual representation conditions $F(2,200)=10.405$, $p < .001$. RTs for animal stimuli (mean=5027ms, SE=205, 95%CI=4620-5434) were significantly slower than RTs for symbol stimuli (mean=3930ms, SE=155, 95%CI=3620-4239, $p < .001$) and face stimuli (mean=4128ms, SE=173, 95%CI=3783-4473, $p < .01$), with symbol and face stimuli not meaningfully differing in terms of RT. The analysis indicated that development and representation conditions did not significantly interact $F(6,200)=.892, p > .05$, see Table 3.13.

Table 3.13 Mean RT, standard error and 95% CI for correctly recalled sequences across visual representation and developmental groups for stimuli displayed on the spatially redundant matrix presentation type.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	4809	297	4220	5398
	Symbol	3666	226	3218	4113
	Face	3820	251	3321	4319
D	Animal	4506	390	3732	5281
	Symbol	3755	297	3166	4343
	Face	3594	331	2938	4249
DAR	Animal	4992	579	3844	6140
	Symbol	3925	440	3053	4798
	Face	4596	490	3624	5569
RA	Animal	5803	314	5181	6426
	Symbol	4374	239	3901	4848
	Face	4505	266	3977	5032

A repeated measures analysis was carried out on the RT data for incorrectly recalled responses across the 3 visual representation conditions and developmental groups (DN n=38, D n=25, DAR n=13, and RA n=35). The analysis indicated there were no significant differences between visual representation types $F(2,214)=1.768$, $p > .05$, as RTs on animal (mean=-12258ms, SE=413, 95%CI=11438-13078), symbol (mean=11244ms, SE=1066, 95%CI=9231-13458) and face (mean=12979ms, SE=559, 95%CI=11971-14088) were very similar. The analysis also indicated no interaction between representation type and developmental group $F(6,214)=.887$, $p > .05$, see Table 3.14. A significant main effect was indicated between development conditions $F(3,107)=2.849$, $p < .05$. However, Bonferroni comparisons indicated that DN (mean=12136ms, SE=838, 95%CI=10473-13798), D (mean=11534, SE=1033,

95%CI=9484-13584), DAR (mean=10533ms, SE=1433, 95%CI=7690-13375) and RA (mean=14573ms, SE=873, 95%CI=12841-16306) children were not significantly differing from each other in respect to incorrectly recalled sequence RTs. In keeping with previous findings, RTs for incorrect responses (mean=12194ms, 95%CI=11132-13256) were found to be significantly slower than RTs for correct responses (mean=4362ms, 95%CI=4160-4563 $p < .05$).

Table 3.14 Mean RT, standard error and 95% CI for correctly recalled sequences across visual representation and developmental groups for stimuli displayed on the spatially redundant matrix presentation type.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	11767	648	10483	13051
	Symbol	11174	1669	7865	14483
	Face	13467	875	11733	15202
D	Animal	11718	799	10135	13301
	Symbol	10375	2058	6296	14455
	Face	12510	1079	10371	14649
DAR	Animal	12344	1108	10149	14540
	Symbol	8844	2854	3187	14501
	Face	10411	1496	7445	13378
RA	Animal	13204	675	11866	14542
	Symbol	14987	1739	11539	18435
	Face	15531	912	13723	17339

Discussion

Span Capacity

Independent of developmental group, all children demonstrated markedly better recall span on the animal stimuli than either the symbol or face stimuli, while symbol stimuli were better recalled than the face stimuli. Given the RA children's age range it is highly unlikely that they spontaneously recoded visual stimuli into verbal labels, even when such labels are highly accessible (Hitch et al., 1988), as is the case for the animal stimuli items. The lack of a significant interaction between development and representation type would suggest that the increased recall span on the animal stimuli may be due to existing representations for these stimuli rather than verbalisation. Additionally, the higher recall capacity for symbol rather than sequences presented with face stimuli, may relate to the possibility of drawing on similarities with existing representations from LTM (letter/number discrimination representations). Due to the configurational nature of face discrimination (Baenninger, 1994), it is not possible to draw simple parallels with existing

representations, but instead requires novel connections between multiple representations to be established before new faces to be temporally encoded/ retrieved. While the developmental groups reacted similarly to the representation types, DN children were still demonstrating a significantly enhanced recall span relative to D, DAR and RA children, who performed equivalently to one another across test measures. The CRT and longest span scoring methods suggested an identical profile of results.

Serial Order Effects

The analysis of the serial position data found no significant differences in serial position recall accuracy between stimulus representation types, and none of these representations demonstrated the traditional bow effect. Even on the animal stimuli children may not have used verbal recall at the retrieval stage (Brown & Brown, 1982), as all representation types demonstrated the same gradual drop off in recall accuracy, with primacy items being recalled best, then intermediate items with recency items having the worst recall rates. Once again DN children were found to have higher accuracy ratios across serial positions than the RA children, adding further support to the suggestion that their visual representations may be less vulnerable to decay. A second possibility is that this advantage relates to quicker RTs on the part of DN children, and that the rate of decay is similar between DN and RA children, but that DN children's faster response style means that decay has less of an effect (Cowan, 1997).

A significant interaction between serial position and development groups in recall accuracy showed that only DN and RA children had a significantly higher recall on the intermediate relative to the recency items. This perhaps suggests that as D children are responding quicker than RA children, but are not showing the same enhanced intermediate recall accuracy, they may be experiencing quicker representation decay (Visser et al., 2004).

Response Times

The analysis of RT suggested that, in contrast to the parallel presentation findings, there were meaningful differences in the speed at which children responded to the individual representation types. As with the serial presentation type, children were found to respond significantly more slowly to the animal stimuli than either the

face or symbol stimuli, which did not differ from one another. Taking the error data into account, it is possible that the differences in RT between visual representation stimuli may relate to the strength of representations in LTM. For example, given the animal stimuli have existing LTM representations, they may be more resistant to temporal decay. If this were the case, children could take longer to recall sequences which used animal stimuli, albeit unintentionally, than the other stimuli types without negatively affecting recall ability. Supporting this suggestion are the findings that while there are no significant difference in RTs for incorrectly recalled sequence trials between stimulus representation types, RTs for the correctly recalled trials are slower on the animal stimuli but do not differ on either face or symbol stimuli. The findings that RA children responded more slowly than either DN or D children across stimulus types may simply relate to a lack of awareness that item decay increases with time. On sequences which have not exceeded their storage capacity, this slower rate of response is not likely to be a problem given that all the items have the capacity to be rehearsed. However, the response style is likely to truncate their recall capacity as, on sequences which are just outside the rehearsal capacity range, recency items are likely to have decayed before they have had a chance to recall these position items.[15]

Integrated Analysis of Experiments 3.1 - 3.3

The 3 visual representation stimuli conditions (animal, symbol and face) were compared across the 3 presentation display conditions (serial, spatially redundant parallel and spatially redundant matrix presentations) as a means of further exploring the relationship between representation type and interference effects between developmental groups.

Span Capacity

Repeated measures analysis was carried out across visual representation, presentation and development conditions (DN n=37, D n=25, DAR n=13, RA n=35), with CRT as the dependent measure. The analysis found significant differences

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[15] For experiments 4.1-4.2 and experiment 5 the analysis of RTs for incorrectly recalled sequence trials are included in Appendix IV rather then the main body of text as the findings remained similar across experiments.

across presentation type $F(2, 212)=11.305$, $p < .001$, pairwise comparisons indicated that on the serial display (mean=4.47, SE=.137, 95%CI=4.20-4.75) children experienced significantly higher recall accuracy than on either the parallel (mean=3.94, SE=.159, 95%CI=3.6-4.25, $p < .001$) or matrix display types (mean=4.00, SE=.149, 95%CI=3.71-4.27, P=.001), which didn't significantly differ from one another. Children's recall span again significantly differed between the visual representation stimuli conditions $F(2, 212)=133.941$, $p < .001$, post hoc comparisons indicated that, in line with previous findings, the children experienced significantly better recall span on the animal stimuli (mean=5.66, SE=.180, 95%CI=5.30-6.02) than either the symbol (mean=3.90, SE=.171, 95%CI=3.56-4.24, $p < .001$) or face stimuli (mean=2.85, SE=.140, 95%CI=2.58-3.13, $p < .001$). Children also showed significantly better recall on symbol stimuli presentations over face stimuli presentations ($p < .001$). Significant differences in recall span were again indicated between the developmental groups $F(3, 106)=27.559$, $p < .001$, Bonferroni comparisons indicated that DN children (mean=5.86, SE=.207, 95%CI=5.45-6.27) had significantly more correctly recalled trials than D (mean=3.83, SE=.252, 95%CI=3.33-4.33, $p < .001$), DAR (mean=2.40, SE=.349, 95%CI=2.71-4.09, $p < .001$) and RA children (mean=3.46, SE=.213, 95%CI=3.04-3.88, $p < .001$), with none of the other developmental groups significantly differing from one another.

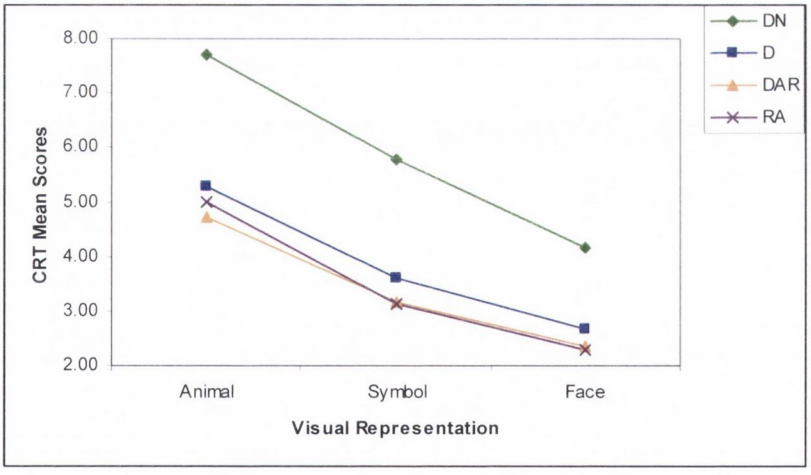

Figure 3.10 line graph of CRT mean scores, between the individual developmental groupings across visual representation types.

No significant interaction was indicated between the visual representation conditions and developmental groups $F(6, 214)=1.596$, $p > .05$, as Figure 3.10 demonstrates, the effect of visual representation was highly consistent across development groups see Table 3.15. Nor was there a significant interaction indicated

between presentation type and developmental group $F(6, 214)=.781$, $p > .05$, as supported by the data summary in Table 3.16 the developmental groups were reacting similarly to changes in sequence presentation type, see figure 3.11. Lastly there was no significant interaction indicated between visual representation and the presentation conditions $F(4, 424)=.841$, $p > .05$, see Table 3.17.

Table 3.15 CRT mean scores, standard error and 95% CI across visual representation stimuli and developmental groups

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	7.69	0.285	7.13	8.26
	Symbol	5.76	0.270	5.22	6.29
	Face	4.14	0.221	3.70	4.57
D	Animal	5.25	0.347	4.56	5.94
	Symbol	3.57	0.329	2.92	4.23
	Face	2.65	0.269	2.12	3.19
DAR	Animal	4.72	0.482	3.76	5.67
	Symbol	3.15	0.456	2.25	4.06
	Face	2.33	0.373	1.59	3.07
RA	Animal	4.97	0.293	4.39	5.55
	Symbol	3.11	0.278	2.56	3.67
	Face	2.30	0.228	1.84	2.75

Table 3.16 CRT mean scores, standard error and 95% CI across presentation types and developmental groups

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Serial	6.20	0.218	5.77	6.63
	Parallel	5.71	0.252	5.21	6.21
	Matrix	5.68	0.235	5.21	6.14
D	Serial	4.24	0.265	3.72	4.76
	Parallel	3.71	0.306	3.10	4.31
	Matrix	3.53	0.286	2.97	4.10
DAR	Serial	3.69	0.367	2.96	4.42
	Parallel	3.23	0.425	2.39	4.07
	Matrix	3.28	0.397	2.49	4.07
RA	Serial	3.76	0.224	3.32	4.21
	Parallel	3.10	0.259	2.59	3.62
	Matrix	3.51	0.242	3.03	3.99

Table 3.17 CRT mean scores, standard error and 95% CI across presentation and representation conditions

Representation	Presentation	Mean	Std. Error	95% Confidence Interval	
Animal	Serial	5.97	0.19	5.59	6.35
	Parallel	5.47	0.23	5.01	5.92
	Matrix	5.54	0.24	5.07	6.01
Symbol	Serial	4.09	0.21	3.68	4.50
	Parallel	3.80	0.22	3.36	4.24
	Matrix	3.81	0.20	3.40	4.21
Face	Serial	3.36	0.19	2.98	3.74
	Parallel	2.55	0.18	2.20	2.90
	Matrix	2.66	0.18	2.30	3.02

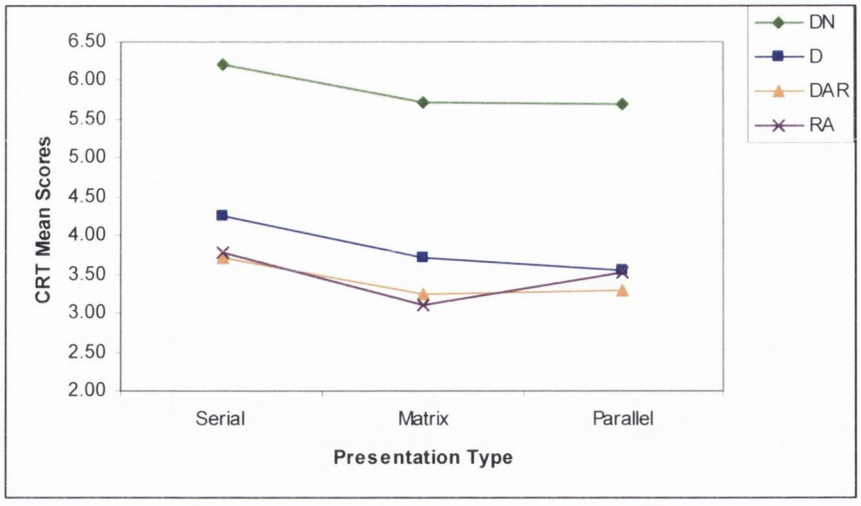

Figure 3.11 line graph of CRT mean scores, between the individual developmental groupings across presentation types.

A second Repeated measures analysis was carried out across visual representation, presentation types and developmental (DN n=37, D n=25, DAR n=13, RA n=35) groups with longest span as the dependent measure. While the analysis indicated a significant main effect across presentation conditions $F(2, 212)=3.087$, $p < .05$, pairwise comparisons did not indicate significant differences in recall span between the serial (mean=3.29, SE=.062, 95%CI=3.16-3.41) parallel (mean=3.17, SE=.061, 95%CI=3.05-3.29) or matrix display types (mean=3.16, SE=.069, 95%CI=3.02-3.29). Children's recall span again significantly differed between the visual representation stimuli conditions $F(2, 212)=96.266$, $p < .001$, in line with the CRT analysis post hoc comparisons indicated that children experienced significantly better recall span on the animal stimuli (mean=3.76, SE=.071, 95%CI=3.62-3.90) than either the symbol (mean=3.13, SE=.076, 95%CI=2.98-3.28, $p < .001$) or face stimuli (mean=2.73 SE=.062, 95%CI=2.60-2.85, $p < .001$). Children also showed significantly better recall on symbol stimuli presentations over face stimuli presentations ($p < .001$). Significant differences in recall span were again indicated between the developmental groups $F(3, 106)=27.559$, $p < .001$, Bonferroni comparisons indicated that DN children (mean=3.91, SE=.087, 95%CI=3.74-4.08) had a significantly longer recall span than D (mean=3.01, SE=.106, 95%CI=2.80-3.22, $p < .001$), DAR (mean=2.95, SE=.146, 95%CI=2.66-3.24, $p < .001$) and RA children (mean=2.95, SE=.089, 95%CI=2.78-3.13, $p < .001$), with none of the other developmental groups significantly differing from one another.

Table 3.18 Longest span mean scores, standard error and 95% CI across visual representation types and developmental groups

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	4.51	0.112	4.29	4.74
	Symbol	3.84	0.120	3.60	4.08
	Face	3.37	0.098	3.17	3.56
D	Animal	3.48	0.137	3.21	3.75
	Symbol	2.95	0.146	2.66	3.24
	Face	2.61	0.120	2.38	2.85
DAR	Animal	3.51	0.189	3.14	3.89
	Symbol	2.90	0.203	2.50	3.30
	Face	2.44	0.166	2.11	2.77
RA	Animal	3.53	0.115	3.30	3.76
	Symbol	2.84	0.124	2.59	3.08
	Face	2.49	0.101	2.28	2.69

In keeping with the CRT data the longest span analysis found no significant interaction between the visual representations conditions and developmental groups $F(6, 214)=1.596$, $p > .05$, as Figure 3.12 demonstrates, the effect of visual representation was highly consistent across development groups (see Table 3.18). Yet again no significant interaction was indicated between presentation type and developmental group $F(6, 214)=.513$, $p > .05$. As supported by the data summary in Table 3.19, the developmental groups were reacting similarly to changes in sequence presentation type. Lastly no significant interaction was indicated between visual representation and the presentation conditions $F(4, 424)=1.389$, $p > .05$, see Table 3.20.

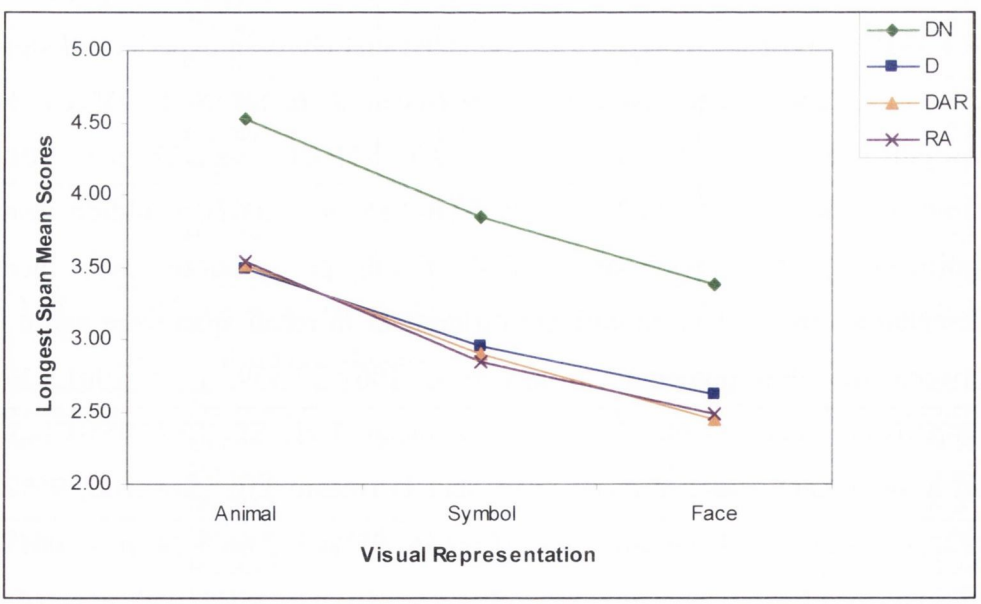

Figure 3.12 line graph of longest span mean scores, between the individual developmental groupings across visual representation types.

Table 3.19 Longest span mean scores, standard error and 95% CI across presentation types and developmental groups

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Serial	3.97	0.099	3.78	4.17
	Parallel	3.84	0.097	3.65	4.03
	Matrix	3.91	0.109	3.69	4.13
D	Serial	3.11	0.120	2.87	3.35
	Parallel	3.01	0.118	2.78	3.25
	Matrix	2.92	0.133	2.66	3.18
DAR	Serial	3.03	0.167	2.69	3.36
	Parallel	2.97	0.163	2.65	3.30
	Matrix	2.85	0.184	2.48	3.21
RA	Serial	3.05	0.102	2.85	3.25
	Parallel	2.86	0.099	2.66	3.05
	Matrix	2.95	0.112	2.73	3.18

Table 3.20 Longest span mean scores, standard error and 95% CI across presentation and representation conditions

Representation	Presentation	Mean	Std. Error	95% Confidence Interval	
Animal	Serial	3.79	0.08	3.63	3.96
	Parallel	3.70	0.09	3.53	3.87
	Matrix	3.79	0.10	3.59	3.99
Symbol	Serial	3.16	0.10	2.97	3.35
	Parallel	3.16	0.10	2.97	3.35
	Matrix	3.07	0.10	2.87	3.26
Face	Serial	2.91	0.10	2.72	3.10
	Parallel	2.65	0.08	2.48	2.81
	Matrix	2.62	0.09	2.45	2.79

Response Times

A repeated measures analysis was run with RTs for correct recalled sequence trials as the dependent measure across presentation, representation and development conditions (DN n=38, D n=21, DAR n=9, RA n=34). A significant main effect was found on the presentation condition $F(2,196)=31.960$, $p < .001$, RTs on parallel display types (mean=5623ms, SE=150, 95%CI=5324-5923) were found to be significantly longer than both serial (mean=5010ms, SE=118, 95%CI=4775-5246, $p < .001$) and matrix displays (mean=4372ms, SE=105, 95%CI=4162-4582, $p < .001$), with RTs on matrix displays being significantly quicker than serial presentations ($p < .001$). Significant differences were found between developmental groups $F(3.98)=9.180$, $p < .001$, which pairwise comparisons between developmental groups indicated that RA (mean=5599ms, SE=131, 95%CI=5338-5859) children had significantly longer RTs than DN (mean=4881ms, SE=124, 95%CI=4635-5127, P=.001) and D (mean=4576ms, SE=166, 95%CI=4245-4907, $p < .001$) children,

while DAR (mean=4952ms, SE=254, 95%CI=4446-5457) children did not significantly differ from any of the other groups. Significant differences were found between visual representation stimuli in respect to RT $F(1.817,178.056)=23.242$ $p < .001$, pairwise comparisons finding that RTs on animal stimuli (mean=5797ms, SE=175, 95%CI=5449-6146) were significantly slower than either symbol (mean=4787ms, SE=126, 95%CI=4534-5038, $p < .001$) or face stimuli (mean=4422ms, SE=141, 95%CI=4141-4704, $p < .001$) with neither symbol nor face stimuli significantly differing from one another.

Table 3.21 Correctly recalled sequences RT mean scores, standard error and 95% CI across visual representation types and developmental groups

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	5531	246	5043	6020
	Symbol	4706	178	4353	5058
	Face	4407	199	4013	4801
D	Animal	5091	331	4434	5748
	Symbol	4631	239	4157	5105
	Face	4008	267	3478	4538
DAR	Animal	5810	506	4807	6814
	Symbol	4563	365	3838	5287
	Face	4483	408	3674	5293
RA	Animal	6758	260	6242	7275
	Symbol	5247	188	4874	5619
	Face	4792	210	4376	5209

Table 3.22 Correctly recalled sequences RT mean scores, standard error and 95% CI across presentation types and developmental groups

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Serial	4820	166	4490	5150
	Parallel	5725	211	5306	6144
	Matrix	4097	148	3803	4392
D	Serial	4592	223	4148	5036
	Parallel	5175	284	4611	5739
	Matrix	3961	199	3566	4357
DAR	Serial	4875	341	4197	5553
	Parallel	5444	433	4583	6306
	Matrix	4536	304	3931	5140
RA	Serial	5753	175	5404	6102
	Parallel	6149	223	5706	6592
	Matrix	4894	156	4583	5205

The analysis did not find a significant interaction between visual representation and developmental group $F(6, 196)=1.201$, $p > .05$, see Table 3.21. Nor was there a significant interaction indicated between presentation type and developmental group $F(6, 196)=.747$, $p > .05$, see Table 3.22. A significant interaction was indicated between the presentation and visual representation

conditions $F(3.230, 312.533)=17.087$, $p < .001$. As Figure 3.13 suggests, the interaction was due to the slower RT profile for animal stimuli on serial relative to parallel presentations (see Table 3.23).

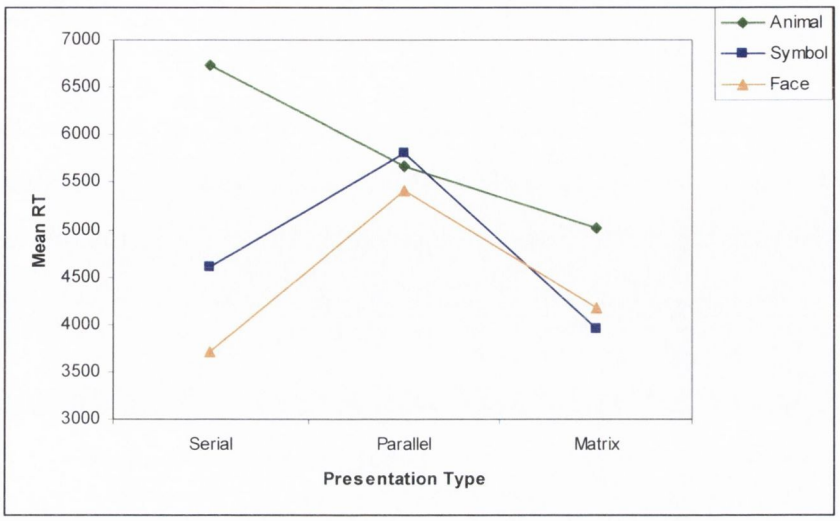

Figure 3.13 Line graph depicting the interaction between presentation and representation type, with correctly recalled RT as the dependent variable.

Table 3.23 Mean RT and 95%CI for correctly recalled sequences across spatially redundant presentation types and visual representation stimuli.

Representation	Presentation	Mean	Std. Error	95% Confidence Interval	
Animal	Serial	6732	244	6249	7217
	Parallel	5658	220	5220	6095
	Matrix	5003	213	4580	5426
Symbol	Serial	4603	183	4239	4966
	Parallel	5804	260	5289	6320
	Matrix	3952	162	3631	4274
Face	Serial	3696	155	3389	4003
	Parallel	5410	291	4832	5987
	Matrix	4162	179	3807	4518

Integrated Analysis of Experiments 3.1-3.3 Discussion

Span Capacity

When the representation and presentation conditions were assessed across developmental groups, the analysis supported the findings of the previous analyses. With respect to the developmental groups, DN children continued to demonstrate higher recall span than any of the other developmental groups, which didn't meaningfully differ from one another. With respect to the visual representation stimuli children again were found to have significantly higher recall span on the animal stimuli than the symbol or face stimuli, and higher recall on the symbol than

the face stimuli presentations. The analysis across the presentation display types indicated that children's recall span capacity was altered by the type of presentation display, with children recalling sequences presented on the serial presentation displays better than either the parallel or matrix presentations. However, in opposition to the hypothesis of increased interference effects on the matrix presentation displays, children's recall capacity did not significantly differ between parallel and matrix displays. The lack of any significant interactions between the experimental conditions would suggest that while the developmental groups differing in respect to span capacity, they do not meaningfully differ in the way in which they respond to representation or presentation types.

The similarity in recall span demonstrated by children on parallel and matrix displays is somewhat intriguing, given that Experiment 2 supported Kemp's (1999, 2000) thesis that sequences displayed on the matrix task were spatially enriched. If the reduced recall span on parallel and matrix displays relative to serial displays does relate to the lose of spatial codes, the matrix presentations should have produced greater interference effects. While existing research had suggested that recall capacity is not affected by the relative distances between items (Smyth & Scholey, 1994), that research was based on spatial recall tasks in which the spatial representations remained accessible throughout testing. In the current experiments there was a slightly shorter inter-item distance used on the parallel display (3/4cm) relative to the matrix display (2.5cm). This procedural deviation may have inadvertently created a shift in the type of interference effects which were produced between matrix and parallel presentations. As the ability to focus the window of spatial attention develops with age (Gottlob & Madden, 1999), the parallel displays may cause visual interferences effects due to the close proximity of flanking stimuli, given the short inter-item distances. In contrast, given the greater inter-item distances used on the matrix displays, it is less likely to elicit visual interference effects from flanking stimuli, but instead is likely to elicit spatial interference effects due to the enriched representations for these presentation types (Experiment 2).

Response Times

Similar to the previous analyses, RA children were found to respond significantly more slowly than both DN and D children, with DAR children not meaningfully differing from any of the other groups. The analysis of RTs across the

three visual presentation types indicated children were responding slower when recalling sequences displayed on parallel displays, responding quicker on serial displays but responding quickest on matrix displays. Overall animal stimuli trials were again found to be recalled significantly more slowly than both symbol or face sequences which did not differ from one another. However, the RT analysis indicated a significant interaction between representation and presentation types, indicating that children's response speeds to the animal stimulus sequences in particular were much slower in the serial presentation condition. This result suggests that children respond differently depending on the degree of LTM representation on the serial task, with items which have well established LTM representations having slower RTs. On items with less established representations, which are serially presented, children are seen to respond quickest, perhaps as a means of counteracting temporal decay. Across visual representations, children seem to respond similarly on the parallel presentations, yet significantly more slowly than on the matrix presentations. This would suggest children experience visual interference effects on the parallel presentations, as Olson and Marshuetz's (2005) research found that RTs are slower when visual interference effects are occurring.

General Discussion

The results from the serial presentations suggest that the literacy impaired children were demonstrating impairment in the development of visual WM capacity relative to their literacy matched age controls, which was not attributable to either visual or spatial interference effects, given the visually and spatially "clean" presentation method. Interestingly, the degree of impairment in recall span remained relatively consistent across the three visual representation stimulus types. This suggests that the literacy impaired children were not experiencing additional difficulties beyond those experienced by the literacy unimpaired children with the encoding and retrieval of new representations. The lack of significant differences between developmental groups in the ease of encoding and recalling new and existing representations from LTM would suggest that the literacy impaired children were not displaying a deficit in WM which is specific to episodic buffer functioning.

There was less of a deviation in performance due to changes in the type of presentation display than had been hypothesised in the introduction. For example, it was believed that there would be a gradually drop in recall span with serial

presentations having the best recall, lower recall on the parallel displays, with the worst recall on the matrix displays. While there was some support for a slight trend in this direction when animal and symbol representation stimuli were used, recall was highly similar between presentation displays when face stimuli were used. However, the repeated measures analysis found that children's recall span was only significantly lower on matrix and parallel presentations relative to serial presentations, with no significant differences in the degree of impairment to recall span incurred between parallel and matrix displays. When the analysis was run across the three presentation and representation conditions, no significant interaction was suggested between developmental group and the other experimental conditions, indicating that while the literacy impaired children were experiencing significant deficits in recall span relative to age matched controls, there were no differences in the manner in which they interacted with the individual representation stimuli or in the degree of impairment experienced due to the interference effects on the parallel and matrix presentations.

Smyth and Scholey (1996a) suggested that differences in VSWM may not be solely mediated by differences in capacity between individuals but additionally relate to differences in general processing speed. Pickering (2001) further developed this point by suggesting that as many as four separate mechanisms operate in relation to capacity limitations in VSWM (knowledge, processing strategy, processing speed, and attentional capacity), which may all play a role in VSWM development. The consistent profile of findings in the current experiments, in keeping with existing research, would suggest that literacy impaired and RA children may be using similar processing strategies to one another (R. S. Anderson & Johnston, 1998; Gathercole, 1998). Given the consistent finding that RA children take longer to correctly recall trials than D children, it is suggested that D children may have a processing advantage over RA children on visual WM tasks at least. If one considers RT as a measure of processing speed (Pickering, 2001), DN and D children's profiles are highly similar. Thus, the impairment in visual WM found in D children may relate to differences in knowledge base or the accessibility of representations. DAR children fall somewhere in between RA and DN children in terms of processing speed. If one then considers that RA children's ability to process information will speed up with development, but that D children are already experiencing the benefits of speeded processing, one would expect D children to show an enhanced capacity level (if all

other mechanisms are operating equivalently to RA children). In keeping with this position of developmental delay, rather than deficit, the findings across the measures did suggest that D children consistently show a slightly elevated though non-significantly higher span relative to RA children. We would suggest this relates to their having processing speeds in the normal range on tasks of this nature.

It is unclear from the present research whether the drop in span capacity between serial and the spatially redundant parallel and matrix presentations was actually due to spatial interference in the visual representations, as the experimental manipulation had intended, or if it was were due to visual interference from flanking stimuli. As children demonstrated a similar span impairment on both parallel and matrix presentations relative to serial tasks, the impairment could possibly be attributed to the simple loss of spatial representations. However, as Experiment 2 suggested that there may be differences in the degree of spatial representations between the parallel and matrix presentations, it seems unlikely that children would not demonstrate an equal impairment to span capacity due to the loss of parallel and spatial representations. If the impairment solely related to either the processing of irrelevant spatial representations at the encoding stage or interference effects due to visual interference from the flanking stimuli, children should have experienced increased impairment on the matrix relative to the parallel presentations. It is thus provisionally suggested that the impairments in recall span experienced on the matrix and parallel tests may indeed relate to separate interference effects. That is, due to the differences in the inter-item distances between stimuli, it seems possible that while parallel items were close enough to cause visual interference effects the matrix items were not. Likewise, as supported by the enhanced recall span on matrix presentations relative to parallel displays indicated in Experiment 2, sequences which are displayed on a matrix display (Kemps, 1999) may automatically be encoded as a sequence path rather than a collection of individual items due to enriched representations. Parallel displays, being more akin to a line of text, may be more prone to being encoded individually rather than sequence paths.

However, further research is required before these potential explanations can be accepted. By varying the inter-item distances on both matrix and parallel presentations displays, we should be able to adequately assess interference effects that can be legitimately attributed to visual versus those that can be attributed to spatial interference. Regardless of the specific nature of the interference effects, the

current set of experiments indicates that dyslexic children were no more vulnerable to these intrusions than their developmentally normal cohorts.

Chapter 5- Experiments 4.1 and 4.2

Visual-spatial working memory ability in dyslexic children, Implications of visual representation stimuli and spatial presentation display

Experiment 4.1 and 4.2 Introduction

The current chapter details 2 experiments which sought to assess literacy impaired and unimpaired children's recall capacity on measures that allow for combined visuo-spatial WM encoding and retrieval. Experiment 4.1 investigates possible differences between developmental groups in recall span on 9 item parallel presentation displays which use the same 3 visual representation stimuli types from Experiments 3.1-3.3 to mark spatial location, while Experiment 4.2 presented sequences using 3 x 3 matrix display types again using the 3 visual representation stimuli types to mark spatial location.

In Experiment 1.2, it was indicated that dyslexic children have a similar VSWM ability to age matched control children when required to forward recall. Due to the methodology used in the experiment, there were a number of reservations about accepting these findings at face value. The most overt issue was the fact that the shape stimuli used were easily nameable and as such the assessment may have more accurately been considered a verbal VSWM task. However, if both groups had used verbal encoding or retrieval strategies, we would have expected DN children to demonstrate an enhanced ability relative to the D children in line with existing research (de Jong, 1998; Kibby et al., 2004; Smith-Spark et al., 2003). This would suggest that the results may have related to a difference in strategy use rather than ability per se. In line with the above suggestion, but in opposition to the findings of Experiment 1.2, previous research which used visual presentation without spatial representations found that dyslexic children did show an impaired visual WM capacity when easily nameable picture stimuli are used as test stimuli compared with age-matched controls. However, dyslexic children were unimpaired when the stimuli consisted of novel doodle Figures (Katz, Shankweiler, & Liberman, 1981). This suggests that the findings of Experiment 1.2 may have related to the availability of

spatial representations in addition to the visual and verbal representations which could have been used at the retrieval stage in Katz' research.

A related methodological issue with Experiment 1.2 pertained to the degree of spatial complexity of the task, which may not have been sufficiently demanding to tax the spatial processing abilities of either of the developmental groups, given the task only required children to register six spatial locations in memory. While research has demonstrated that children experience an increased spatial WM capacity with age related development (Gathercole, Pickering, Ambridge, & Wearing, 2004; Logie & Pearson, 1997), it is possible that the spatial aspects of Experiment 1.2 were not sufficiently demanding to uncover developmental differences. This suggestion, coupled with the insensitivity of the scoring method, may have combined to show a lack of effects between the developmental groups.

The current round of experiments was developed to explore the nature of the apparent contradiction between Katz et al.'s research and the findings of Experiment 1.2. Namely, it was an attempt to discover if dyslexic children are simply unimpaired on VSWM tasks that use easily nameable stimuli, and if so, to find out whether this relates to differences in the use encoding and or retrieval strategy between groups or to the interplay of visual and spatial components in the task. While dyslexic children have been shown to be selectively impaired on both spatially dominant (Experiment 2) and visually dominant (Experiments 3.1-3.3) WM tasks, it is nonetheless possible (though unlikely) that they have normal ability in combined VSWM tasks. By including RA children in the task this time, one can assess if the task is sufficiently demanding to register the developmental differences that should exist between RA and DN children, thus allowing one to place the literacy impaired children's ability in the context of normal age appropriate VSWM development.

The majority of research that has sought to assess visual and spatial aspects simultaneously has used particularly novel visual representation stimuli, such as pattern matrices. These are unlikely to have much ecological validity in terms of the type of visual representations one is required to process and remember on a daily basis. Thus, they are unlikely to have much in the way of supportive non-verbalisable LTM representations. On account of this, it is hardly surprising that differences in ability between literacy impaired and unimpaired groups have not been revealed, as

both groups effectively perform at the floor of visual binding[16] ability, that is three to four items (Wheeler & Treisman, 2002). By using stimuli which have some form of LTM representations for the assessment of VSWM ability, task results may actually relate to how VSWM is used in the context of the real world. Like Experiments 3.1-3.3, the current round of assessments used the same three visual representation stimulus types, animal, symbol and face stimuli.

In line with Baddeley's (2000) WM model, it is suggested that the three representation stimulus types should differ in respect to the level of episodic buffer processing required. As the animal stimuli have pre-existing LTM representations, there should be very little buffer processing required, beyond simply accessing the existing animal representations from LTM. In contrast, the symbol stimuli will require the buffer to create and access new figural LTM codes, which is likely to draw on existing knowledge of letter figural information as a foundation for discriminating symbol stimuli. The face stimuli should require even more episodic buffer processing resources, given that simple figural codes will not be sufficient to discriminate between individual faces. Instead, face discrimination will require multi-configurational codes to be created and accessed for accurate recall to take place (Baenninger, 1994).

As dyslexic children are less likely to use verbal codes at the retrieval stage in visually presented WM tasks (R. S. Anderson & Johnston, 1998), the results suggested in Experiment 1.2 may actually relate to D children processing the combined visuospatial components while DN children converted the VS information into verbal representations. This may in turn have led to the similar performance outcome between groups. In opposition to this suggestion are the alignment findings from Experiment 1.2, which indicated that both D and DN children demonstrated an equal impairment on vertical alignments relative to the horizontal alignments when required to copy sequence trials. This indicated that it is highly likely that DN children were not processing the spatial representations to some extent on these tasks.

By using three separate types of visual representation stimulus, we should be able to assess the impact that aspects such as verbalisability or visual discriminability have on tasks that allow for spatial encoding. It is believed that on tasks that contain a high degree of spatial location redundancy (Kemps, 1999, 2000), like the matrix

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[16] Visual binding refers to the process of creating a unified percept from multiple stimulus aspects.

presentations, children may be less likely to use the visual representation stimuli as relevant placeholders for sequence items. That is, due to the higher interrelatedness between spatial items on the matrix task, children are less likely to use the stimulus items themselves as markers of spatial location but instead will only process the spatial representations, even though the visual codes are available. However, if children do process the visual representation stimuli rather than simply encoding the spatial location, we would expect better performance on the animal, followed by the symbol stimuli, with the face stimuli experiencing the worst performance due to the additional CE (episodic buffer) processing required to visually discriminate amongst these stimuli. It remains a possibility that the findings from Experiment 1.2 actually related to DN children suffering impaired performance from using a verbally dominant retrieval strategy (Palmer, 2000b). Thus it remains a possibility that in the current round of experiments, dyslexic children may actually outperform their age matched cohorts when sequences are presented on a matrix display, given the high degree of spatial location redundancy in these arrays.

Given that the nine item parallel presentation displays which form the basis of Experiment 4.1 will have lower spatial redundancy between item locations than the matrix presentations (Experiment 4.2), this may encourage children to use visual representations as a key to fixing item location. In line with the argument above, it is suggested that DN children are likely to automatically switch to a verbal rather than a VS retrieval strategy on the animal stimuli and as a consequence D children in this way may reveal a similar span capacity to DN children, in line with Experiment 1.2. Given that RA children are also unlikely to spontaneously name stimuli, we would expect them to have a similar span capacity to DN children on the animal parallel tasks. In contrast, for the symbol and face stimuli representations, it is expected that RA children will show an age-appropriate but lower span capacity compared with DN children, in line with existing research (Gathercole et al., 2004).

The lowered performance in both DN and D children on the vertical alignment condition in Experiment 1.2 offered some suggestion that DN children may not use verbally dominant retrieval strategies on VSWM in which the spatial location information remains present throughout testing. By assessing performance profiles across the representation stimulus conditions, we should gain further insight into this potential exception to dominant verbal recoding in developmentally normal 9-11 year old children.

Experiment 4.1 and 4.2 Method

Participants

The same participants who took part in Experiments 2 and 3.1-3.3 were used in the current round of experiments, DN n=37, D n=26, DAR n=13 and RA n=35.

Procedure

An identical procedural layout to the one discussed in Experiment 2 was used in the current round of experiments, except that instead of using the same stimulus placeholder at all spatial locations e.g. a blue square in Experiment 2, spatial locations were now marked with visually distinct placeholders; namely, the three visual representation stimulus types from experiment 3.1-3.3: animal, symbol and face stimuli. As Figure 4.1 demonstrates in the combined VSWM tasks the stimulus item locations remain in an identical position between presentation and response screens on both parallel and matrix tasks. In Experiment 4.1, VSWM performance was assessed using the parallel spatial layout, while Experiment 4.2 used the matrix spatial displays. The findings were then integrated in a third combined analysis. As in Experiment 2, children responded on an identical display screen to the one used to present sequence stimuli, except that the screen contained an answer box in which the copied sequence would be displayed.

In Experiment 4.1 repeated measures analysis was carried across the 3 visual representation stimuli presented on parallel displays between the 4 developmental groups, using with CRT as the dependent measure. Further repeated measures analysis were carried out using longest span and RTs for correctly recalled sequences as the dependent measures for comparative purposes, as well as item serial order accuracy. In Experiment 4.2 there was an identical analysis carried out except that sequence trials were now presented using matrix displays

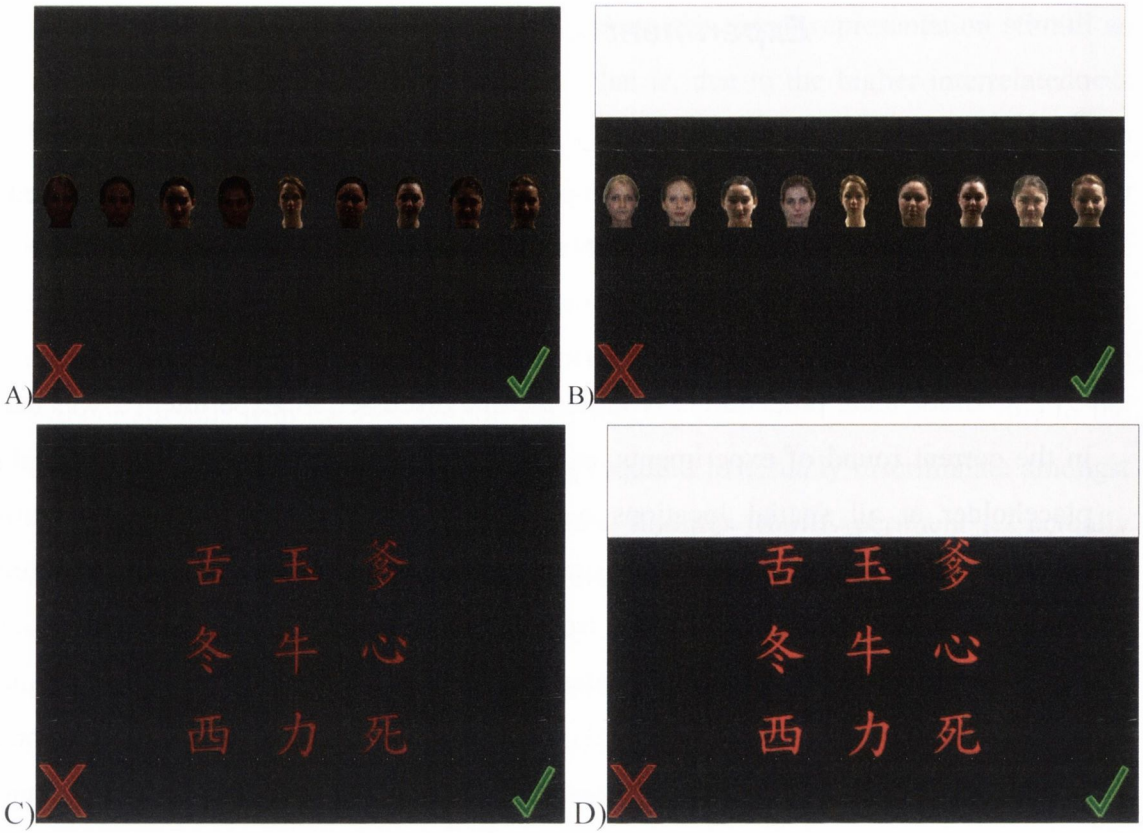

Figure 4.1 Screen-shots of combined VSWM presentation displays. A) Displays a parallel presentation with visually distinct face placeholders for spatial location. B) A parallel display response screen with answer box. C) Displays a matrix presentation display with symbol stimuli to mark spatial location. D) A matrix display response screen with answer box.

Experiment 4.1

Results

Span capacity

The effect of visual representation stimulus was assessed across the development groups on parallel presentation displays, with CRT as the dependent measure. A main effect across representation stimulus was indicated, $F(2,214)=9.302$, $p < .001$, with Bonferroni comparisons finding that children recalled sequences which used face stimuli at the spatial locations significantly worse (mean=6.10, SE=.180, 95%CI=5.74-6.46) than animal (mean=7.07, SE=.234, 95%CI=6.60-7.53, $p < .001$) or symbol stimuli (mean=6.72, SE=.214, 95%CI=6.30-7.15, $p < .01$) displays, but recalled the animal and symbol stimuli displays similarly. Significant differences

were also found between developmental groups $F(2,107)=22.702$, $p < .001$. Planned comparisons indicated that the recall span of DN children (mean=8.51, SE=.261, 95%CI=7.99-9.02) was significantly enhanced compared with the D (mean=6.86, SE=.312, 95%CI=6.24-7.48, P=.001), DAR (mean=5.46, SE=.441, 95%CI=4.59-6.34, $p < .001$) and RA children (mean=5.71, SE=.269, 95%CI=5.17-6.24, $p < .001$). In addition, D children revealed a significantly higher span capacity than RA children ($p < .05$), and were just short of reaching a statistically higher span capacity (P=.06) than the DAR children (see Figure 4.2). No significant interaction was indicated between the development and representation conditions $F(6,214)=1.122$, $p > .05$, see Table 4.1.

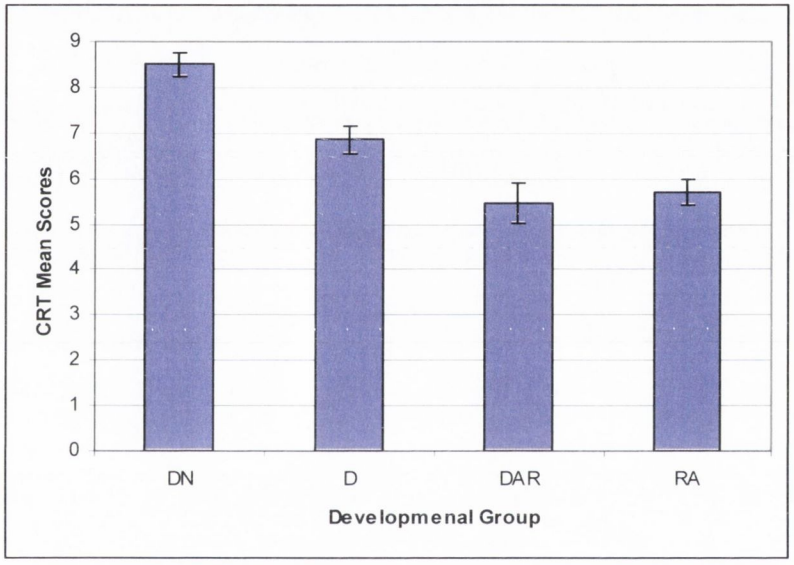

Figure 4.2 Bar chart displaying CRT mean scores across the developmental groups when stimuli are presented on a parallel display.

Table 4.1 CRT mean scores, standard error and 95%CI across visual representation stimuli and developmental groups, when stimuli are presented in a parallel display.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	8.57	0.373	7.83	9.31
	Symbol	8.73	0.340	8.06	9.40
	Face	8.22	0.286	7.65	8.78
D	Animal	7.54	0.445	6.66	8.42
	Symbol	6.85	0.405	6.04	7.65
	Face	6.19	0.341	5.52	6.87
DAR	Animal	6.23	0.629	4.98	7.48
	Symbol	5.62	0.573	4.48	6.75
	Face	4.54	0.483	3.58	5.50
RA	Animal	5.94	0.383	5.18	6.70
	Symbol	5.71	0.349	5.02	6.41
	Face	5.46	0.294	4.87	6.04

The repeated measures analysis was rerun across visual representation stimuli and between the development groups on parallel presentation displays, but this time with longest span as the dependent measure. A significant main effect was found between visual representation stimuli $F(1.855,198.437)=4.764$, $p < .05$, indicating that children recalled sequence trials with animal (mean=4,24, SE=.095, 95%CI=4.05-4.43) stimuli placeholders better than those that contained face (mean=3.90, SE=.086, 95%CI=3.73-4.07, $p < .05$) stimuli, while recall span on the symbol stimuli (mean=4.12, SE=.088, 95%CI=3.94-4.29) displays did not significantly differ from recall on the other stimuli displays. The analysis indicated a significant main effect between developmental groups $F(3,107)=16.426$, $p < .001$, with DN (mean=4.70, SE=.099, 95%CI=4.51-4.90) children showing a higher span capacity than D (mean=4.05, SE=.118, 95%CI=3.82-4.28, $p < .001$), DAR (mean=3.90, SE=.166, 95%CI=3.47-4.13, $p < .001$) and RA (mean=3.79, SE=.101, 95%CI=3.59-3.99, $p < .001$) children, with none of the other groups significantly differing. The analysis indicated that visual representation and development did not significantly interact $F(6, 214)=.504$, $p > .05$, see Table 4.2

Table 4.2 Longest span mean scores, standard error and 95%CI across visual representation stimuli and developmental groups, when stimuli are presented in a parallel display.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	4.76	0.152	4.46	5.06
	Symbol	4.78	0.139	4.51	5.06
	Face	4.57	0.137	4.30	4.84
D	Animal	4.27	0.181	3.91	4.63
	Symbol	4.12	0.166	3.79	4.44
	Face	3.77	0.163	3.45	4.09
DAR	Animal	4.08	0.256	3.57	4.58
	Symbol	3.77	0.235	3.30	4.24
	Face	3.54	0.231	3.08	4.00
RA	Animal	3.86	0.156	3.55	4.17
	Symbol	3.80	0.143	3.52	4.08
	Face	3.71	0.141	3.44	3.99

A one-way ANOVA was carried out on each of the 3 visual representation stimuli types between DN and D children with CRT as the dependent measure for comparative purposes with Experiment 1.2. Differences in recall span between the developmental groups fell short of statistical significance, $F(1,62)=3.021$, $p > .05$ when animal stimuli were used, with DN (mean=8.55, SD=2.60, 95%CI=7.7-9.41) children's recall span non-significantly higher than D (mean=7.54, SD=1.97, 95%CI=6.83-8.24) children. Significant differences were found on symbol stimuli

$F(1,62)=11.553$, P=.001, with DN (mean=8.66, SD=2.17, 95%CI=7.94-9.37) children having significantly higher recall than D (mean=6.85, SD=1.97, 95%CI=6.05-7.64) children. Additionally, significant differences in recall span were also indicated between developmental groups on the face stimuli $F(1,61)=20.479$, $p < .001$, with once again DN (mean=8.22, SD=1.65, 95%CI=7.67-8.77) children having significantly higher recall than D (mean=6.19, SD=1.88, 95%CI=5.43-6.95) children.

Serial Order Effects

A repeated measures analysis was run across the 3 visual representation, 3 serial order positions conditions and between the developmental groups (DN n=38, D n=26, DAR n=13, and RA n=35), with item recall accuracy as the dependant measure. A significant main effect was found between serial position levels $F(1.857, 200.503)=87.640$, $p < .001$), Bonferroni pairwise comparisons indicated that primacy items (mean=.560, SE=.020, 95%CI=.521-598) were better recalled than either intermediate (mean=.344, SE=.017, 95%CI=.311-.377, $p < .001$) or recency items (mean=.293, SE=.014, 95%CI=.264-.322, $p < .001$), while intermediate items were recalled significantly more accurately than recency items ($p < .05$). Significant effects were found between developmental groups $F(3,108)=3.961$, P=.01, with DN children (mean=.445, SE=.018, 95%CI=.408-.482) attaining significantly higher recall accuracy ratios than RA children (mean=.362, SE=.019, 95%CI=.328-.400, $p < .05$), while neither D (mean=.422, SE=.022, 95%CI=.378-.466) nor DAR children (mean=.366, SE=.032, 95%CI=.303-.429) significantly differed from any of the other groups. Significant differences were not indicated between visual representation stimuli $F(2, 216)=.885$, $p > .05$, with children recalling sequence trials which used animal (mean.395, SE=.018, 95%CI=.360-.430), symbol (mean=.385, SE=.017, 95%CI=.350-.420) and face (mean=.416, SE=.018, 95%CI=.381-.451) stimuli as accurately as each other. A significant interaction between serial position and developmental group was found, $F(5.570,200.503)=3.414$, $p < .005$. As Table 4.3 details, the interaction between development and serial position was due to DN children showing significantly better recall accuracy ratios on the intermediate items than the recency items, while these item positions did not differ significantly for any of the other groups (see Figure 4.3).

Table 4.3 Mean accuracy ratio scores, standard error and 95%CI across the development and serial position conditions, for sequences presented on a parallel display.

Development	Serial Position	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	0.643	0.031	0.582	0.704
	Intermediate	0.421	0.026	0.370	0.473
	Recency	0.270	0.023	0.225	0.316
D	Primacy	0.607	0.037	0.533	0.681
	Intermediate	0.358	0.032	0.296	0.421
	Recency	0.301	0.028	0.247	0.356
DAR	Primacy	0.466	0.053	0.361	0.570
	Intermediate	0.325	0.045	0.236	0.413
	Recency	0.308	0.039	0.231	0.385
RA	Primacy	0.522	0.032	0.458	0.586
	Intermediate	0.270	0.027	0.216	0.324
	Recency	0.292	0.024	0.245	0.339

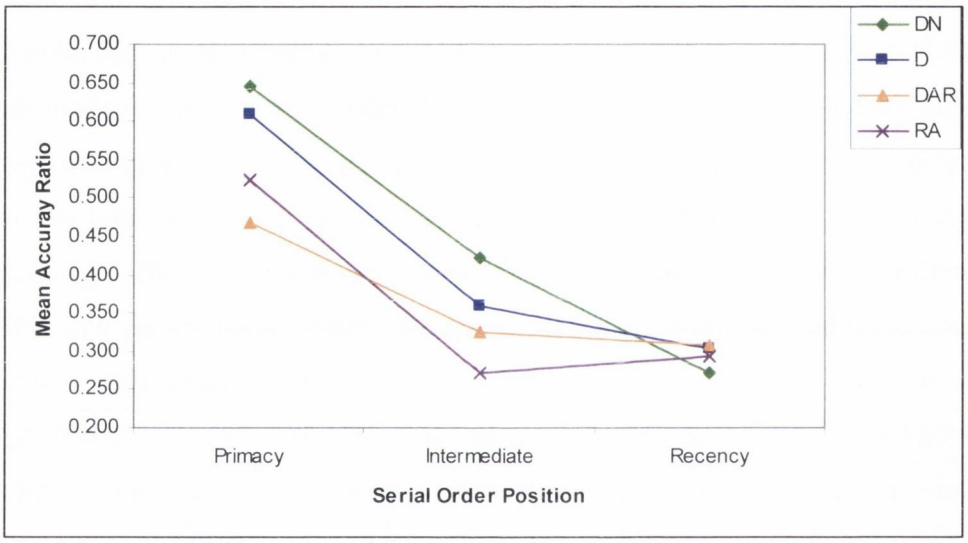

Figure 4.3 Line graph depicting the interaction between development and serial position, for when sequences are presented on a parallel display.

Response Times

A repeated measures analysis was carried out on the RT data for correctly recalled responses across the 3 visual representation conditions and developmental groups (DN n=38, D n=23, DAR n=10, and RA n=35). The analysis indicated no significant differences between the visual representation stimuli, $F(2,204)=1.181$ $p > .05$, with RTs for animal (mean=5780ms, SE=331, 95%CI=5123-6437), symbol (mean=5555ms, SE=243, 95%CI=5072-6038) and face (mean=5156ms, SE=262, 95%CI=4635-5676) stimuli being very similar to each other. Nor was there a significant interaction indicated between representation type and development

$F(6,204)=.870$, $p > .05$, see Table 4.4. Significant differences between developmental groups were indicated, $F(1,102)=11.898$, $p < .005$, with the Bonferroni comparisons showing that D children (mean=5024ms, SE=285, 95%CI=4462-5586) were responding significantly more quickly than RA children (mean=6281ms, SE=229, 95%CI=5825-6736, $p < .005$) with neither DN (mean=5682ms, SE=220, 95%CI=5245-6119) or DAR children (mean=5001ms, SE=429, 95%CI=4149-5854) significantly differing from any of the other groups.

Table 4.4 Mean RT, standard error and 95% CI for correctly recalled sequences across visual representation and developmental groups for stimuli displayed on parallel presentation displays

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	5815	482	4858	6772
	Symbol	5451	355	4747	6154
	Face	5783	382	5024	6541
D	Animal	5184	620	3954	6414
	Symbol	5197	456	4292	6101
	Face	4693	491	3718	5667
DAR	Animal	5041	940	3176	6907
	Symbol	5814	692	4442	7186
	Face	4150	745	2671	5628
RA	Animal	7081	503	6084	8078
	Symbol	5762	370	5029	6496
	Face	6000	398	5210	6791

Discussion

Span Capacity

The repeated measures analysis found that when performance across the three visual representation stimulus conditions was considered, DN children had significantly higher recall span than any of the other developmental groups. Interestingly, the D children also demonstrated a significantly enhanced recall span relative to RA children. This suggests that D children perform better on tasks which combine visual and spatial representations compared to predominantly visual (Experiments 3.1-3.3) or spatial tasks (Experiment 2). It is worth noting that DAR children's mean scores on the parallel tasks were actually lower than RA children's mean scores, and these were almost statistically significantly lower than scores for D children ($p < .06$). This would tentatively suggest that DAR children do not benefit from multi-representational codes, and that this may represent a potential developmental difference between these two dyslexic subgroups.

When parallel presentation displays are used the analysis of performance across the 3 visual representation conditions indicated that DN children may have been using the same encoding and/or retrieval strategies as the other developmental groups. As Table 4.1 highlighted, DN children's performance when animal and symbol stimuli were used as placeholders was highly similar. Given that Chinese characters are unlikely to be verbalised (Vandierendonck et al., 2004), this is a possible indication that DN children may have used VS representations rather than verbal at the retrieval stage.

Interestingly, in keeping with the findings of Experiment 1.2, but in contradiction to Katz et al's (1981) research, no significant differences were found between D and DN children when easily-nameable animal stimuli were used. Again in contrast to Katz findings, when the un-verbalisable face and symbol stimuli were used, significant differences were found between D and DN children. This suggests that the relatively impaired recall span may relate in some way to either the use, creation or accessing of new visual representations in D children compared with DN children, as the spatial components between tasks was identical. Such a suggestion is in line with Nicolson and Fawcett's (1990, 2000) impaired automaticity hypothesis.

Serial Order Effects

The analysis of the serial order data once again found no evidence of a bow effect in accuracy ratios across serial positions, with accuracy of serially positioned items degrading with the shift from initial to terminal items. While no significant differences in serial accuracy were found between visual representation items, DN children demonstrated an increased accuracy ratio overall compared with RA children. With D and DAR children's overall item accuracy ratios falling between the two literacy unimpaired groups. This is further support for the notion that part of capacity differences may relate to the way information is stored, even when capacity limits are exceeded.

Response Times

The lack of significant differences in RT between visual representation items, or an interaction between development and representation type is further supportive evidence that similar retrieval strategies were used independent of stimulus items and developmental group. The only significant difference for RT related to D children

responding significantly more quickly than RA children. In line with the earlier suggestion, this may relate to D children's relatively elevated performance on the parallel measures, that is as D children respond quicker, recall is less likely to experience temporal decay (Pickering, 2001). Another possibility is that D children may be simply more aware of the overwriting interference effects than RA children, and hence speed up RT as a means of overcoming these difficulties (in line with the suggestions of Experiment 1.2).

Summary

The analysis of the parallel presentation displays offers further evidence that on measures that assess VSWM performance, dyslexic children demonstrate an impaired performance relative to their age-matched literacy unimpaired cohorts. Additionally the results would suggest that DAR children may demonstrate an additional delay relative to D children in combined VSWM tasks. Experiment 4.2 is a further investigation as to whether such impairments are apparent with matrix spatial presentations.

Experiment 4.2

Results

Span Capacity

The effect of visual representation stimulus was assessed between the development groups (DN n=37, D n=26, DAR n=13, RA n=35) on matrix presentation displays, with CRT as the dependent measure. The analysis indicated significant differences in recall span between developmental groups, $F(3,107)=20.265$, $p < .001$, with Bonferroni comparisons showing that DN children (mean=11.93, SE=.331, 95%CI=11.27-12.59) had significantly higher recall span than D (mean=9.55, SE=.395, 95%CI=8.77-10.34 $p < .001$), DAR (mean=8.41, SE=.559, 95%CI=7.30-9.52), and RA children (mean=8.56, SE=.341, 95%CI=7.70-9.42). None of the other groups differed significantly from one another. Significant main effect were found across the visual representation conditions, $F(1.878, 200.999)=7.883$, P=.001. Post hoc comparisons indicated that children recalled sequences with face stimuli (mean=10.23, SE=.251, 95%CI=9.73-10.73) significantly better than either animal (mean=9.12, SE=.262, 95%CI=8.60-9.94, P=.001) or

symbol stimuli (mean=9.49, SE=.251, 95%CI=8.93-10.05, P=.01), with recall span on animal and face stimuli not significantly differing from one another. No significant interaction was found between visual representation and development conditions (see Table 4.5).

Table 4.5 CRT mean scores, standard errors and 95%CI across the development and visual representation conditions, for sequences presented on a matrix display.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	11.46	0.417	10.63	12.29
	Symbol	11.73	0.449	10.84	12.62
	Face	12.59	0.399	11.80	13.39
D	Animal	9.04	0.498	8.05	10.02
	Symbol	9.58	0.535	8.52	10.64
	Face	10.04	0.476	9.10	10.98
DAR	Animal	7.92	0.704	6.53	9.32
	Symbol	8.08	0.757	6.58	9.58
	Face	9.23	0.673	7.90	10.56
RA	Animal	8.06	0.429	7.21	8.91
	Symbol	8.57	0.461	7.66	9.49
	Face	9.06	0.410	8.24	9.87

A second repeated measures analysis was run across the visual representation conditions and between the development groups on matrix presentation displays, with longest span as the dependent measure. Again a significant main effect between developmental groups was indicated $F(3, 107)=14.235$, $p < .001$, which found that DN (mean=5.87, SE=.128, 95%CI=5.62-6.13) children again were demonstrating significantly higher recall span than D (mean=5.12, SE=.153, 95%CI=4.81-5.42, $p < .001$), DAR (mean=4.82, SE=.216, 95%CI=4.39-5.25, $p < .001$) and RA (mean=4.75, SE=.131, 95CI=4.49-5.01, $p < .001$) with none of the other groups significantly differing from one another. The analysis in opposition to the CRT findings indicated that there was no significant main effect across the visual representation conditions $F(2, 214)=2.182$, $p > .05$, with children recalling animal (mean=5.10, SE=.106, 95%CI=4.89-5.31), symbol (mean=5.03, SE=.111, 95%CI=4.81-5.25) and face (mean=5.29, SE=.110, 95%CI=5.07-5.51) stimuli similarly to one another. In line with the CRT analysis no significant interaction between visual representations and development $F(6, 214)=.232$, $p >.05$, see Table 4.6.

A one-way ANOVA was carried out on each of the 3 visual representation stimuli types between DN and D children with CRT as the dependent measure. Significant differences in recall span were indicated when animal stimuli were used as spatial markers $F(1,62)=14.013$, $p < .001$, the analysis indicated that DN (mean=11.45, SD=2.24, 95%CI=10.71-12.18) children had significantly higher recall

span than D children. Significant differences in span were also indicated when symbol stimuli were used as spatial markers $F(1,62)=11.522$, P=.001, with DN (mean=11.71, SD=2.24, 95%CI=10.97-12.45) children again demonstrating higher recall span than D (mean=9.58, SD=2.77, 95%CI=8.46-10.70) children. The analysis of face stimuli indicated in line with the findings above that DN (mean=12.59, SD=2.03, 95%CI=11.82-13.27) children had a significantly higher span $F(1,61)=19.390$, $p < .001$), than D (mean=10.04, SD=2.57, 95%CI=9.00-11.08) children.

Table 4.6 Longest span mean scores, standard errors and 95%CI across the development and visual representation conditions, for sequences presented on a matrix display.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	5.89	0.169	5.56	6.23
	Symbol	5.76	0.177	5.41	6.11
	Face	5.97	0.175	5.63	6.32
D	Animal	5.12	0.201	4.72	5.51
	Symbol	5.04	0.211	4.62	5.46
	Face	5.19	0.208	4.78	5.61
DAR	Animal	4.77	0.285	4.20	5.33
	Symbol	4.62	0.299	4.02	5.21
	Face	5.08	0.295	4.49	5.66
RA	Animal	4.63	0.173	4.28	4.97
	Symbol	4.71	0.182	4.35	5.07
	Face	4.91	0.180	4.56	5.27

Serial Order Effects

A repeated measures analysis was run across the 3 visual representation, 3 serial order positions conditions and between the developmental groups (DN n=38, D n=26, DAR n=13, and RA n=35). No significant main effect was found between developmental groups, $F(3,108)=2.491$, $p > .05$, as recall accuracy was similar between DN (mean=.439, =.019, 95%CI=.402-476), D (mean=.383, SE=.023, 95%CI=.338-428), DAR (mean=.349, SE=.032, 95%CI=.285-412) and RA (mean=.398, SE=.020, 95%CI=.359-437) children. No significant differences were indicated in recall accuracy across visual representation stimuli, $F(2,216)=.327$, $p > .05$, with children recalling animal (mean=.398, SE=.017, 95%CI=.365-432), symbol (mean=.382, SE=.017, 95%CI=.348-417) and face (mean=.397, SE=.016, 95%CI=.364-.429) stimuli items as accurately as one another. Once again significant effects were found for serial position, $F(1.573, 169.845)=131.236$, $p < .001$, with pairwise comparisons indicating that children were recalling significantly more

primacy items (mean=.578, SE=.021, 95%CI=.537-.620) than intermediate (mean=.351, SE=.014, 95%CI=.323-.379, $p < .001$) or recency items (mean=.248, SE=.015, 95%CI=.218-.277, $p < .001$), and with children recalling intermediate items significantly better than recency items ($p < .001$). A significant interaction between development group and serial position was found, $F(4.718,169.845)=2.600$. $p < .05$. As Table 4.7 indicates the interaction related to DAR children not demonstrating significantly higher recall accuracy on primacy items relative to intermediate items, in contrast with the other developmental groups, with DAR children demonstrating significantly lower primacy item accuracy than DN, D and RA, but not significantly differing from the other developmental groups in intermediate and recency item recall accuracy, (see Figure 4.4),.

Table 4.7 Mean accuracy ratios, standard error and 95%CI for the serial position items between developmental groups, when sequences trials are presented on matrix displays.

Development	Serial Order	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	0.665	0.033	0.600	0.731
	Intermediate	0.403	0.022	0.358	0.447
	Recency	0.250	0.023	0.204	0.296
D	Primacy	0.592	0.040	0.513	0.671
	Intermediate	0.335	0.027	0.282	0.388
	Recency	0.222	0.028	0.166	0.278
DAR	Primacy	0.444	0.056	0.333	0.556
	Intermediate	0.328	0.038	0.252	0.403
	Recency	0.274	0.040	0.194	0.353
RA	Primacy	0.611	0.034	0.543	0.679
	Intermediate	0.338	0.023	0.292	0.384
	Recency	0.244	0.024	0.196	0.293

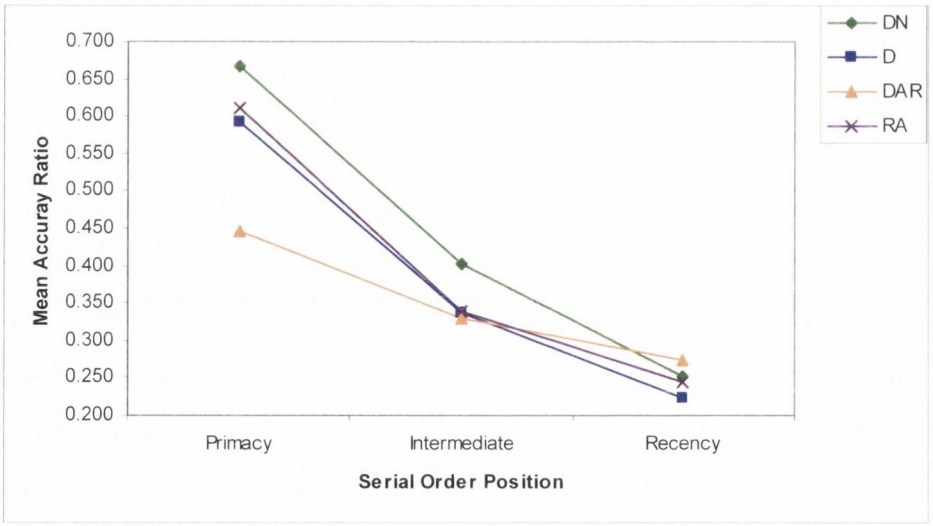

Figure 4.4 Line graph of the interaction between developmental groups and serial position items when sequences are presented on matrix displays.

Response Times

A repeated measures analysis was carried out on the RT data for correctly recalled responses across the 3 visual representation conditions and developmental groups (DN n=38, D n=22, DAR n=10, and RA n=35) for sequences presented on a matrix display. The analysis indicated that there were no significant differences on the visual representation condition $F(1.863, 186.259)=1.349$, $p > .05$, as children's RTs on animal (mean=5770ms, SE=239, 95%CI=5296-6244), symbol (mean=5206ms, SE=228, 95%CI=4753-5660) and face (mean=5562ms, SE=278, 95%CI=5010-6115) stimuli were largely similar. There was no significant interaction between representation and development $F(5.588, 186.259)=1.198$, $p > .05$, see Table 4.8. Significant differences were however found between developmental groups $F(3, 100)=5.627$, P=.001, with pairwise tests indicating that D children (mean=5145ms, SE=283, 95%CI=4584-5707) responded significantly more quickly than DN children, (mean=6238ms, SE=218, 95%CI=5805-6671, $p < .05$), while DAR children (4693ms, SE=419, 95%CI=3660-5526) responded significantly more quickly than both RA (mean=5976ms, SE=224, 95%CI=5531-6421, $p < .05$) and DN children ($p < .01$), with RTs between D and DAR children not significantly differing.

Table 4.8 Mean RT, standard error and 95% CI for correctly recalled sequences across visual representation and developmental groups for stimuli displayed on matrix presentation displays

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	5890	351	5195	6586
	Symbol	6185	335	5520	6850
	Face	6640	408	5829	7450
D	Animal	5512	455	4610	6415
	Symbol	4778	435	3916	5640
	Face	5146	530	4096	6197
DAR	Animal	5092	674	3754	6430
	Symbol	4671	645	3392	5950
	Face	4319	786	2760	5877
RA	Animal	6588	360	5873	7303
	Symbol	5194	345	4510	5878
	Face	6147	420	5314	6980

Discussion

Span Capacity

The analysis of VSWM tasks presented on matrix displays indicated that DN children had an increased recall span relative to D, DAR and RA children. The

planned comparisons between DN and D children across the individual representation conditions indicated that DN children were outperforming D children across all representation stimuli. While there was no suggestion of an interaction between development and representation type, an interesting significant effect was found for representation type, as children had a higher recall span on the face stimuli displays compared with either symbol or animal stimuli displays. This finding completely contradicts the hypothesis relating to episodic buffer functioning and the interaction between representation type and spatial location. Namely, that the face stimuli would elicit the worst performance due to the additional CE (episodic buffer) processing required to visually discriminate amongst these stimuli. However, there is a possible explanation. What is suggested is that due to the already highly redundant spatial representations implicit in the matrix presentation displays, children were less likely to use visual representation as a spatial marker which would require additional CE resources (Vandierendonck et al., 2004). However on the animal and symbol stimuli, a proportion of resources are likely to be automatically diverted into processing the visual representations in terms of LTM representations. In the case of animal stimuli, resources are likely to be automatically diverted towards making available semantic and verbal representations. In contrast, it is likely that due to the demands of establishing face discrimination, children are unlikely to encode the stimuli beyond a cursory visual representation. Possibly this lack of processing relates to frequent day-to-day experiences of interacting with unrecognised people, e.g. in a crowded room or walking down the street, we often process the location of a person without any strict analysis of their appearance or visual representation. In such a way it is believed that more processing resources may be freed up to maintain spatio-temporal representations.

Serial Order Effects

The analysis of serial position accuracy suggested that children experience the most accurate recall on primacy items, followed by the intermediate, with most inaccurate recall occurring on the recency items, when span capacity is exceeded. The analysis indicated that DAR children both showed a significantly lowered primacy recall accuracy and did not demonstrate a significantly more accurate recall ratio on the intermediate serial items relative to the recency items. This was in contrast to D,

DN and RA children, possibly suggesting that DAR children may have encoded and/or retrieved sequence codes differently from the other developmental groups

Response Times

The analysis of the RTs for when children correctly recalled sequence trials indicated a developmental shift between literacy group pairings, as both D and DAR children responded significantly more quickly than DN children, with DAR children additionally being found to respond significantly more quickly than RA children. In keeping with the previous suggestion, this perhaps relates to dyslexic children attempting to respond before sequence representation decays (Visser et al., 2004).

Summary

The analysis of the matrix presentations suggested once again that the dyslexic children, regardless of their attentional capacity, were showing a lowered span relative to their age-matched controls, across all the visual representation types. In contrast to the parallel presented sequences, D children were not found to have significantly higher recall span than the RA children. In an attempt to gain a better understanding of the possible difference in performance between parallel and matrix presentations, the data from Experiments 4.1 and 4.2 were integrated so that performance between presentation modes could be compared.

Integrated Analysis of Experiments 4.1 and 4.2- Results

Span Capacity

A repeated measures analysis was run on the 3 visual representation stimuli conditions (animal, symbol and face) across the 2 spatial presentation conditions (parallel and matrix) and between developmental groups (DN n=37, D n=26, DAR n=13, RA n=35) with CRT as the dependent measure. The analysis indicated significant main effect for spatial presentation condition $F(1,107)=340.999$, $p < .001$, with Bonferroni comparisons indicating that children recalled the parallel presentations (mean=6.63, SE=.164, 95%CI=6.31-6.96, $p < .001$) significantly worse than the matrix presentations (mean=9.61, SE=.208 95%CI=9.20-10.03). Significant effects were also found between developmental groups, $F(1, 107)=25.708$, $p < .001$, with pairwise tests once again indicating that DN children (mean=10.22, SE=.269,

95%CI=9.68-10.75) had significantly higher span accuracy than D (mean=8.21, SE=321, 95%CI=7.57-8.84, $p < .001$), DAR (mean=6.94, SE=.454, 95%CI=6.04-7.84, $p < .001$) and RA children (mean=7.13, SE=.277, 95%CI-6.58-7.68, $p < .001$), with none of the other groups significantly differing. While no significant differences were indicated between visual representation stimuli, $F(1.812,193.852)=.076$, $p > .05$, with the analysis suggested that recall span on animal (mean=8.10, SE=.212, 95%CI=7.67-8.52), symbol (mean=8.12, SE=.215, 95%CI=7.68-8.53) and face (mean=8.17, SE=.180, 95%CI=7.81-8.52) stimuli was highly similar, a significant interaction between visual representation and spatial presentation conditions indicated there was more going on between experimental conditions $F(1.970, 210.752)=19.350$, $p < .001$. As Figure 4.5 highlights, this was due to a divergence in profile between visual representation conditions across the two presentation types, that is while recall span on sequences that used face stimuli was significantly higher than sequences that used animal stimuli for matrix presentations, the exact opposite profile was found on for sequences presented on parallel displays (see Table 4.9).

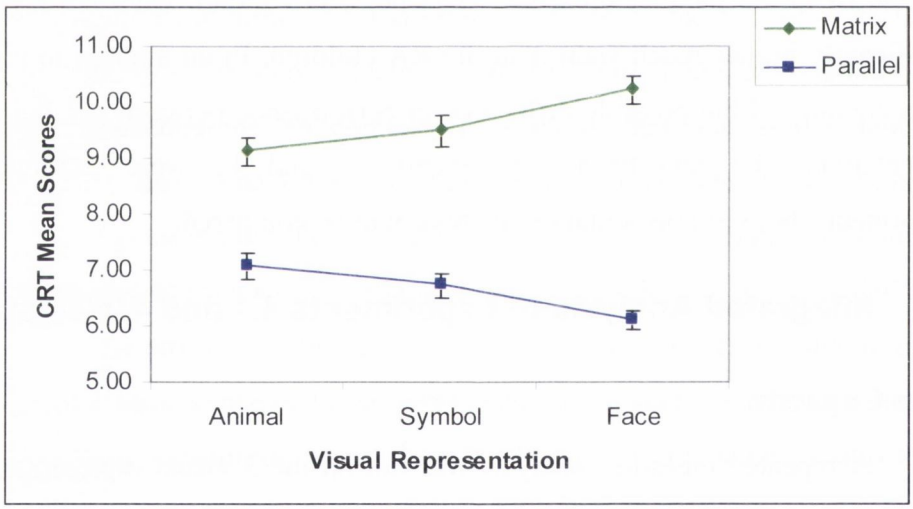

Figure 4.5 Line graph highlighting the interaction between the visual representation and spatial presentation conditions, with CRT as the dependant measure.

Table 4.9 CRT mean scores, standard error and 95%CI across the spatial presentation and visual representation conditions.

Presentation	Representation	Mean	Std. Error	95% Confidence Interval	
Parallel	Animal	7.07	0.234	6.61	7.53
	Symbol	6.73	0.214	6.30	7.15
	Face	6.10	0.180	5.74	6.46
Matrix	Animal	9.12	0.262	8.60	9.64
	Symbol	9.49	0.282	8.93	10.05
	Face	10.23	0.251	9.73	10.73

The analysis did not indicate a significant interaction between visual representation and development $F(6, 214)=.318$, $p > .05$, (see Table 4.10), as developmental groups reacted similarly to changes in visual representations. Neither was a significant interaction between spatial presentation and development $F(3, 107)=1.341$, $p > .05$, (see Table 4.11), again as developmental groups reacted similarly to changes in presentation display..

Table 4.10 CRT mean scores, standard error and 95%CI across visual representation and between development conditions.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	10.01	0.338	9.34	10.68
	Symbol	10.23	0.342	9.55	10.91
	Face	10.41	0.286	9.84	10.97
D	Animal	8.29	0.403	7.49	9.09
	Symbol	8.21	0.409	7.40	9.02
	Face	8.12	0.341	7.44	8.79
DAR	Animal	7.08	0.570	5.95	8.21
	Symbol	6.85	0.578	5.70	7.99
	Face	6.88	0.482	5.93	7.84
RA	Animal	7.00	0.347	6.31	7.69
	Symbol	7.14	0.352	6.44	7.84
	Face	7.26	0.294	6.68	7.84

Table 4.11 CRT mean scores, standard error and 95%CI across the spatial presentation and between development conditions.

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Parallel	8.50	0.261	7.99	9.02
	Matrix	11.93	0.331	11.27	12.58
D	Parallel	6.86	0.312	6.24	7.48
	Matrix	9.55	0.395	8.77	10.33
DAR	Parallel	5.46	0.441	4.59	6.34
	Matrix	8.41	0.559	7.30	9.52
RA	Parallel	5.70	0.269	5.17	6.24
	Matrix	8.56	0.341	7.89	9.24

A second repeated measures analysis was run on the 3 visual representation stimuli conditions (animal, symbol and face) across the 2 spatial presentation conditions (parallel and matrix) and between developmental groups (DN n=37, D n=26, DAR n=13, RA n=35) this time using longest span as the dependent measure. The analysis found children performed significantly worse on the parallel (mean=4.09, SE=.062, 95%CI=3.96-4.31) than the matrix (mean=5.14, SE=.080, 95%CI=4.98-5.30) presentations $F(1,107)=213.347$, $p < 001$. Significant differences between the developmental groups $F(3,107)19.960$, $p < .001$, were once again attributed to DN (mean=5.29, SE=.099, 95%CI=5.09-5.48) children out-performing

the D (mean=4.58, SE=.118, 95%CI=4.35-4.82, $p < .001$), DAR (mean=4.31, SE=.166, 95%CI=3.98-4.64, $p < .001$) and RA (mean=4.27, SE=.101, 95%CI=4.07-4.47, $p < .001$) children, with none of the other groups significantly differing. Consistent with the CRT analysis no significant differences were suggested across visual representation stimuli $F(1.845, 197.440)=.701$, $p > .05$, as recall span between animal (mean=4.67, SE=.081, 95%CI=4.51-4.83), symbol (mean=4.57, SE=.082, 95%CI=4.41-4.74) and face (mean=4.59, SE=.075, 95%CI=4.45-4.74) was indicated to be highly similar, but once again a significant interaction between representation type and spatial presentation $F(1.989, 212.871)=6.076$, $p < .005$ was indicated, (see Table 4.12). As Figure 4.6 highlights the interaction once again was due to children demonstrating significantly lower recall span on face relative to animal sequences presented on parallel displays, but showing the exact opposite profile on the matrix displays.

Table 4.12 Longest span mean scores, standard error and 95%CI across the spatial presentation and visual representation conditions.

Presentation	Representation	Mean	Std. Error	95% Confidence Interval	
Parallel	Animal	4.24	0.095	4.05	4.43
	Symbol	4.12	0.088	3.94	4.29
	Face	3.90	0.086	3.73	4.07
Matrix	Animal	5.10	0.106	4.89	5.31
	Symbol	5.03	0.111	4.81	5.25
	Face	5.29	0.110	5.07	5.51

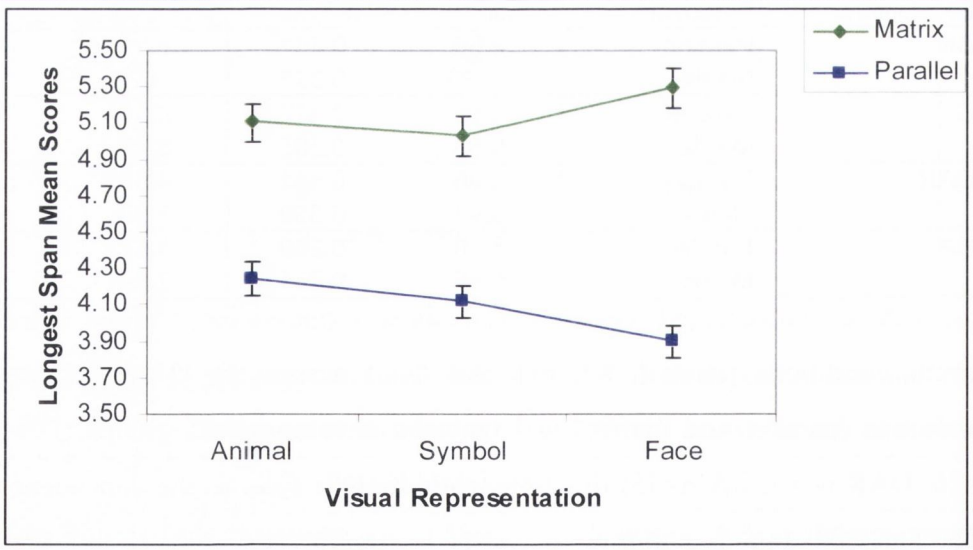

Figure 4.6 Line graph highlighting the interaction between the visual representation and spatial presentation conditions, with longest span as the dependant measure.

Table 4.13 Longest span mean scores, standard error and 95%CI across the spatial presentation and between development conditions.

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Parallel	4.70	0.099	4.51	4.90
	Matrix	5.87	0.128	5.62	6.13
D	Parallel	4.05	0.118	3.82	4.28
	Matrix	5.12	0.153	4.81	5.42
DAR	Parallel	3.79	0.166	3.47	4.12
	Matrix	4.82	0.216	4.39	5.25
RA	Parallel	3.79	0.101	3.59	3.99
	Matrix	4.75	0.131	4.49	5.01

Table 4.14 Longest span mean scores, standard error and 95%CI across visual representation and between development conditions.

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	5.32	0.130	5.07	5.58
	Symbol	5.27	0.130	5.01	5.53
	Face	5.27	0.119	5.03	5.51
D	Animal	4.69	0.155	4.38	5.00
	Symbol	4.58	0.155	4.27	4.88
	Face	4.48	0.142	4.20	4.76
DAR	Animal	4.42	0.220	3.99	4.86
	Symbol	4.19	0.219	3.76	4.63
	Face	4.31	0.201	3.91	4.71
RA	Animal	4.24	0.134	3.98	4.51
	Symbol	4.26	0.133	3.99	4.52
	Face	4.31	0.123	4.07	4.56

Serial Order Effects

A repeated measures analysis was run across the 3 visual representation, the 2 spatial presentation, 3 serial order positions conditions and between the developmental groups (DN n=38, D n=26, DAR n=13, and RA n=35). Item recall accuracy was similar between animal (mean=.396, SE=.014, 95%CI=.369-423), symbol (mean=.384, SE=.014, 95%CI=.357-.411) and face (mean=.406, SE=.012, 95%CI=.382-431) stimuli indicating no significant differences between visual representation conditions $F(2, 216)=.978$, $p > .05$. Similarly there were no significant differences in recall accuracy indicated spatial presentation conditions $F(1, 108)=.201$, $p > .05$, with children recalling parallel (mean=.399, SE=.012, 95%CI=.375-.422) presentation items as accurately as matrix (mean=.392, SE=.012, 95%CI=.369-.416) presentation items. Significant differences were indicated between serial position items $F(1.579, 170.515)=161.120$, $p < .001$, with higher recall accuracy on the primacy items (mean=.569, SE=.017, 95%CI=.535-.603) than on

both the intermediate (mean=.347, SE=.011, 95%CI=.325-.369, $p < .001$) and recency items (mean=.270, SE=.012, 95%CI=.247-.294, $p < .001$), additionally children recalled intermediate items significantly more accurately than recency items ($p < .001$).

Table 4.15 Mean accuracy ratios, standard error and 95%CI across presentation and representations conditions

Presentation	Representation	Mean	Std. Error	95% Confidence Interval	
Parallel	Animal	0.395	0.018	0.360	0.430
	Symbol	0.385	0.017	0.350	0.420
	Face	0.416	0.018	0.381	0.451
Matrix	Animal	0.398	0.017	0.363	0.432
	Symbol	0.382	0.017	0.348	0.417
	Face	0.397	0.016	0.364	0.429

There was no significant interaction indicated between representation and presentation conditions $F(2, 216)=.318$, $p > .05$, (see Table 4.15), or representation by serial position $F(4, 432)=.686$, $p > .05$. The analysis indicated significant differences in item recall accuracy ratios between developmental groups, $F(3,108)=4.272$, $p < .01$, with Bonferroni comparisons indicating that the effects were due to DN children (mean=.442, SE=.015, 95%CI=413-471) having significantly higher accuracy ratios across the serial positions than both DAR (mean=.357, SE=.025, 95%CI=.308-407, $p < .05$) and RA children (mean=.380, SE=.015, 95%CI=.349-.410, $p < .05$), with D children (mean=.403, SE=.018, 95%CI=.367-.438) not differing from any of the other groups.



Figure 4.7 Line graph of the interaction between serial position items and developmental groups

A significant interaction between development and serial position was also indicated, $F(4.737,170.515)=4.011$, $p < .005$. As Figure 4.7 highlights, the interaction

was due to DAR children not demonstrating quite the same advantage on primacy items relative to the other groups, coupled with the finding that both D and DN children had significantly better intermediate item recall accuracy than recency item recall accuracy, with both DAR and RA children's accuracy ratios not differing across these positions (see Table 4.16).

Table 4.16 Mean accuracy ratios, standard error and 95%CI across the individual serial position items and between developmental groups

Development	Serial Position	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	0.654	0.027	0.601	0.708
	Intermediate	0.412	0.017	0.377	0.447
	Recency	0.260	0.018	0.224	0.297
D	Primacy	0.599	0.033	0.534	0.664
	Intermediate	0.347	0.021	0.305	0.389
	Recency	0.262	0.022	0.217	0.306
DAR	Primacy	0.455	0.046	0.363	0.547
	Intermediate	0.326	0.030	0.267	0.386
	Recency	0.291	0.032	0.228	0.353
RA	Primacy	0.567	0.028	0.511	0.623
	Intermediate	0.304	0.018	0.268	0.340
	Recency	0.268	0.019	0.230	0.306

A second significant interaction was indicated between presentation and serial position conditions $F(2, 216)=3.915$, $p < .05$, see Figure 4.8. The interaction related to children having highly similar accuracy ratios on parallel and matrix presentations for primacy and intermediate serial positions, but demonstrating significantly enhanced accuracies on the parallel recency items relative to matrix presentations on the recency items, see Table 4.17.

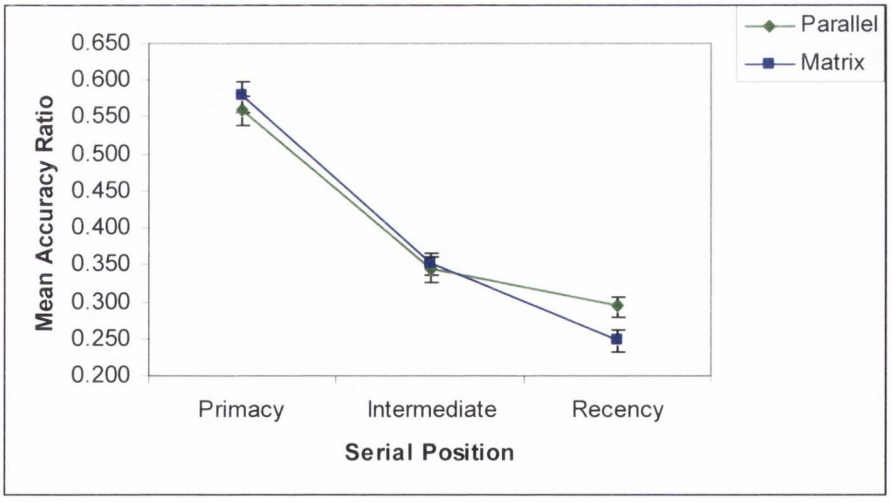

Figure 4.8 Line graph of the interaction between spatial presentation and serial position conditions

Table 4.17 Mean accuracy ratios, standard error and 95%CI across spatial presentation and serial position conditions

Presentation	Serial Position	Mean	Std. Error	95% Confidence Interval	
Parallel	Primacy	0.560	0.020	0.521	0.598
	Intermediate	0.344	0.017	0.311	0.377
	Recency	0.293	0.014	0.264	0.322
Matrix	Primacy	0.578	0.021	0.537	0.620
	Intermediate	0.351	0.014	0.323	0.379
	Recency	0.248	0.015	0.218	0.277

Response Times

A repeated measures analysis was carried out on the RT data for correctly recalled responses across the 3 visual representation conditions, 2 spatial presentation and between developmental groups (DN n=37, D n=22, DAR n=10, and RA n=35). The analysis indicated no main effect for visual representation, $F(2,200)=.987$, $p >$ 05, as children's RTs on animal (mean=5724ms, SE=214, 95%CI=5298-6150), symbol (mean=5389ms, SE=194, 95%CI=5003-5776) and face (mean=5351ms, SE=196, 95%CI=4961-5742) were very similar. Likewise RTs did not significantly differ between presentation conditions $F(1,100)=.062$, $p > .05$, as RTs on parallel (mean=5464ms, SE=151, 95%CI=5164-5763) presentations were comparable to matrix (mean=5513ms, SE=148, 95%CI=5208-5808) presentations.

Table 4.18 RT mean scores, standard error and 95%CI across visual representation and between developmental groups

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	5853	315	5228	6477
	Symbol	5811	286	5244	6378
	Face	6149	289	5576	6722
D	Animal	5144	408	4335	5954
	Symbol	5028	371	4292	5763
	Face	4950	375	4207	5694
DAR	Animal	5067	605	3866	6267
	Symbol	5242	550	4151	6334
	Face	4234	556	3132	5337
RA	Animal	6834	324	6192	7476
	Symbol	5478	294	4895	6061
	Face	6074	297	5484	6663

Significant differences were indicated between developmental groups $F(3,100)=8.453$, $p < .001$, with pairwise comparisons indicating that D children (mean=5040ms, SE=213, 95%CI=4618-5463) responded significantly more quickly than both DN (mean=5937ms, SE=164, 95%CI=5611-6263, $p < .01$) and RA children (mean=6128ms, SE=168, 95%CI=5793-6464, P=.001), and that DAR children (mean=4847ms, SE=316, 95%CI=4220-5474) responded significantly more

quickly than both DN ($p < .05$) and RA ($p < .005$), with neither D or DAR children differing from one another. The interaction between representation by developmental group was non significant $F(6, 200)=1.430$, $p > .05$, see Table 4.18, as was the interaction between spatial presentation and developmental group $F(3, 100)=1.782$, $p > .05$, see Table 4.19.

Table 4.19 RT mean scores, standard error and 95%CI across spatial presentation and between developmental groups

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Parallel	5637	221	5198	6076
	Matrix	6238	218	5805	6671
D	Parallel	4936	287	4366	5506
	Matrix	5146	283	4584	5707
DAR	Parallel	5002	426	4156	5847
	Matrix	4694	420	3861	5527
RA	Parallel	6281	228	5829	6733
	Matrix	5976	224	5531	6422

Integrating Experiments 4.1 and 4.2 - Discussion

Span Capacity

In line with the earlier findings, the analysis indicated that DN children had higher recall span than D, DAR and RA children. While no significant differences were found for representation stimuli, a significant interaction between representation and presentation type was found. The interaction indicated that visual representation stimuli affected recall span differently depending on whether sequences were presented using parallel or matrix displays. That is while face stimuli elicited improved recall span relative to animal sequences on the matrix presentations, children demonstrated reduced recall span on face relative to animal sequences when parallel presentations were used. The profile of results found on the parallel presentation is more in keeping with the original hypothesis as set out in the introduction. That is, if face stimuli were going to be used to fix spatial location it could lead to a reduction in recall span relative to animal or face stimuli as face discrimination requires multi-configurational codes to establish a representation (Baenninger, 1994), reducing the available CE resources which can be directed towards aiding sequence recall. While both animal and stimuli can be discriminated with simply figural codes, freeing up CE resources which can be directed towards item rehearsal (Vandierendonck et al., 2004). However, the reversed profile relating

to visual representation stimuli for the matrix presentation condition may relate to the degree of spatial localisation redundancy. In the matrix condition, due to the highly interrelated item locations (Kemps, 2000), high levels of visual processing may actually hinder performance by unnecessarily diverting encoding and retrieval resources away from the spatial aspects. Thus, on matrix-like tasks, children do not process the visual stimuli beyond that which is automatically activated through visual inspection. Children recall animal stimuli sequences worst, as semantic and verbal signifiers are likely to be automatically activated diverting CE resources away from rehearsal. Likewise symbol stimuli are likely to promote an automatic attempt at letter or numerical matching due to their figural nature. Given the demanding nature of face discrimination, it is possible that there is a requirement for top-down encouragement before resources will be diverted towards the processing face stimuli. This explains why children demonstrated better recall on face stimuli sequences that used matrix presentations

Recall span on the parallel tasks, however is much more in line with the results of the Olson and Marshuetz (2005) study: remembering "what" fixes the "where" in memory. That is, as parallel spatial locations are more difficult to fix without a visual marker, children are more likely to attempt to divert resources towards item discrimination. Hence the more automatic the distinguishing process the better the recall span. On parallel tasks if either symbol or face stimuli are used as to fix spatial location this could require additional resource demand in order to establish visual item discrimination, diverting a proportion of CE resources away from simple maintenance and retrieval tasks, thus lowering overall VSWM capacity (Vandierendonck et al., 2004).

Serial Order Effects

When both presentation type and representation stimulus were analysed in terms of serial position accuracy, once span capacity has been exceeded, DN children demonstrated an increased accuracy ratio relative to both DAR and RA children. That is, in DN children, the remembered sequence items form a closer approximation, though incomplete, of the sequence trial as it was presented. The findings support the notion that there may be a shift in the manner in which information is processed or stored with age-appropriate development. There is further supportive evidence for this suggestion in the interaction between serial position and developmental group,

which indicated that D and DN children, unlike DAR and RA children, recalled the intermediate items more accurately than the recency items. It is possible that the relatively impaired primacy item recall accuracy in DAR children may suggest that test termination related to drifting attention or inattention rather than capacity overload. Overall though, the analysis indicated that children had significantly higher item accuracy ratios on the primacy items, with once again no evidence suggesting the traditional bow effect in serial accuracy.

Response Times

Interestingly, RTs for correctly recalled sequences did not differ between representation type or spatial presentation condition. This may suggest that for VSWM tasks which have been accurately encoded, recall needs to be immediate to avoid decay or temporal sequence recall related interference effects. The only significant difference was indicated between developmental groups, finding that both DN and D children responded more quickly than RA children. Suggesting that DN and D children are either more away of the effects of temporal decay or that there is a developmental increase in the visuospatial retrieval mechanism leading to speedier retrieval in these children. Hence the speeded up turnaround time between sequence presentation and sequence response.

General Discussion

The findings from the current round of experiments constitute further evidence that dyslexic children have an impairment in VSWM ability. Evidence from Experiment 4.1 would suggest that D children have a relative delay in VSWM development, but the delay is not as severe as their delay in literacy development. Given that while D children's span capacity was below DN children they showed a significantly larger capacity than the RA children (with DAR children performing similarly to RA children). While in Experiment 4.2, DN children had a greater span capacity than all the other developmental groups, with D children no longer performing better than RA children. These differences in span capacity profiles between presentation types are unlikely to be related to differences in RTs. Consistently across both presentation types, D children responded significantly more quickly than RA children. One suggestion is that the shift in performance relates to the nature of the pre-existing representations between presentation types. That is, on

tasks where item locations are less distinct e.g. the parallel presentations, D children may have a more developed ability to combine the 'what' and 'where' representations, but that this ability is not as helpful on tasks with a high degree of interconnectivity between item locations. Alternatively, the lack of enhanced recall ability demonstrated on the matrix tasks may possibly relate to an inability to integrate new sensory information with pre-existing representations in LTM, in line with Nicolson and Fawcett's (1990, 2000) theory of impaired automaticity. The last possibility, in line with the findings from chapter 3, it is suggested that matrix-style presentations simply have a larger degree of individual variability as the task allows scaffolding of recall span from both CE and LTM representations. This suggests that matrix presentations are simply not as sensitive measures of VSWM as parallel displays, given that children may be able to draw on CE and existing spatial LTM representations to a varying degree depending to their life experiences (Baddeley & Andrade, 2000), thus demonstrated recall span may reflect changes in these secondary modalities rather than actual increases in the core visuospatial ability between these children.

The evidence from the above analysis suggests that on tasks that have removed easily chunked sequences, and used more ecologically valid spatial location placeholders, both dyslexic groups have demonstrated an impaired span capacity on combined visual-spatial WM tasks relative to age-matched control children. Of particular relevance to future research are the findings which indicate that D children had a significantly higher recall span than RA children on parallel but not matrix tasks. This shift in span capacity in the D children may relate to a lack of facilitation when tasks allow for high interconnectivity between spatial items (Kemps, 1999). Interestingly, in line with the suggestion first put forth in Experiment 1.2, there was further evidence that DN children may be using VS representations rather than verbal representations at the retrieval stage, given that their recall span was significantly lower on the animal stimuli sequences presented on the parallel compared with the matrix displays. If predominately verbal encoding and retrieval were being used, changes in the spatial presentation should have had no effect on recall. Second, of interest to future research was the significant interaction between representation and presentation conditions on recall span. For example, relative to animal stimuli, face stimuli were associated with enhanced recall on the matrix displays and impaired recall on parallel displays. Indicating that recall span in combined visuospatial tasks

is modified differently depending on the interplay between ease by which item discrimination can be achieved and the nature of the spatial layout used in the presentation.

Chapter 6- Experiment 5

Visuospatial implicit learning in dyslexic children

Experiment 5 Introduction

Nicolson and Fawcett's (1990) dyslexic automatisation deficit (DAD) theory suggests that the deficits in ability experienced by dyslexic individuals actually relate to an impairment in the process of skill acquisition; specifically, the ability to reach a level of automatised performance which no longer requires conscious monitoring. The authors note, however, that on most tasks dyslexic individuals can achieve a level of performance equivalent to developmentally normal individuals but that they achieve this through conscious compensatory strategies. In line with this view is the finding that most adult dyslexics learn to read to a normative level but that it remains a labour-intensive and slower process than the automatic decoding of the phonemic structure experienced by literacy-unimpaired individuals (Snowling, 2000).

Implicit learning can be roughly defined as an adaptation towards more efficient behaviour which is derived from a sensitivity to regularities within the environment and not from an intentional, explicit knowledge of these features (Gombert, 2003; Mayr, 1996). Gombert has argued that a possible root cause of dyslexic children's inability to carry out efficient automatic grapheme-phoneme correspondences (GPC) is related to their capacity for implicit learning. She suggests that while children may be taught GPC explicitly, unless a foundation of implicit phonological representations is acquired/established, even in verbal communication, phonological organisations will remain unspecified. Consequently, there will not occur an automatic amalgamation with orthographic or semantic representations. With implicitly established specificity for sound and letter correspondences, each exposure to the written or spoken word leads to greater efficiency in one's decoding ability and hence a means of establishing greater, more efficient implicit GPC, which in turn leads to more efficient automatic decoding capacity. Indeed, recent research has demonstrated that dyslexic children's performance was impaired relative to chronological and reading age matched controls, on tasks that required the use and/or perception of implicit phonological representations, including lexical gating, priming and syllable similarity tasks (Boada & Pennington, 2006).

On a conceptual level, there is considerable overlap between Gombert's implicit learning deficit theory of dyslexia and Nicolson and Fawcett's (1990) DAD theory. According to the DAD account, the deficit in ability is not specific to a deficit in implicit learning, but rather relates to a general deficit in the ability to automatise any tasks, encapsulating all potential learning behaviour, including motor development, language acquisition, and speed of processing, as well as phonemic structure. However, it seems likely that only through the unconscious acquisition of complex skills that is implicit learning, can automatisation be achieved. If the DAD theory is correct, we would expect dyslexic children to demonstrate an impaired ability when learning both tasks that are reliant on a degree of implicit understanding and those where learning relates to explicitly derived representations which become automatised.

Mayr's (1996) research demonstrated that spatial learning occurs even when tasks primarily call for object/visual-based identification and discrimination. This learning effect, which was demonstrated in the form of quicker RTs, still existed when the response to spatial sequences was completely decoupled from the motor response output, ensuring that this speed increase did not relate to a primed motor response. Mayr suggested instead that implicit learning of this nature related to the occurrence of eye movements, as learning effects did not occur when participants were required to shift attention without co-occurring eye movements when encoding the visual information. Given that multiple representations can be implicitly encoded at once, Mayr suggested that implicit learning is not a unitary process but instead can involve parallel acquisition from multiple modalities simultaneously, encoding separate individual regularities from a single perceptual experience.

Interestingly, a recent study using Mayr's serial reaction time task (Kelly et al., 2002) with adult dyslexic university students, matched with literacy-unimpaired university students, found no differences in the rate of implicit learning of pseudo-random sequences between groups. The findings of the study suggested that while dyslexic individuals responded more slowly overall, the rate of decrease in RTs due to implicit encoding of presentation regularities was similar between both developmental groups. However, as the sample was made up of individuals currently enrolled in third-level education, the dyslexic participants may not have constituted the most reliable indicator of general dyslexic functioning, given their high educational attainment.

Supporting this view, and in opposition to Kelly et al's findings, research using a similar procedure to Mayr's serial reaction time task, but this time involving dyslexic children, suggested that they do suffer from an implicit learning deficit (Vicari et al., 2003). Interestingly, contrary to predictions from DAD theory, the authors found that the dyslexic children had similar accuracy and RTs to literacy-unimpaired control children when the sequence information was made explicitly available to them. This suggests that on a speeded response task, which requires a high degree of automaticity in response, dyslexic children were no more impaired than their developmentally normal cohorts.

Research has also demonstrated that poorer readers have a deficit in implicitly derived categorical learning, relative to literacy-unimpaired individuals (Sperling et al., 2004). Further research, which addressed the capacity for classically conditioned eye-blink responses in teenagers, found that 25% of dyslexic participants showed no conditioning at all, with a further 50% demonstrating abnormally poor tuning to and a lack of accuracy in the timing of the conditioned eye-blink response (Nicolson et al., 2002). The authors suggested that the conditioning deficit related to impaired cerebellar functioning, in line with the cerebellar deficit hypothesis of dyslexia. However, their findings were not conclusive, given that 25% of the developmentally normal control children also demonstrated very weak and infrequent conditioned responses.

Kemps (2001) has shown that as little as one exposure to a complex sequence path in a 5x5 matrix presentation was enough to produce specific and long-term learning effects, as demonstrated by enhanced recall accuracy, when assessed on the same sequence trial 24 hours later. The suggestion was that, as sequence paths become even implicitly more familiar, they no longer elicit the same demands they once placed on visuo-spatial short-term storage. Indeed, Kemps' research indicated that eight intermittent exposures to a complex sequence path sufficiently enhanced the accuracy of recall to a level equivalent to that demonstrated on highly structured paths. This indicates that as LTM representations become established, even complex sequence paths can be reconstructed from partial information, even when the representation of the sequence path is likely to be largely unconsciously derived.

Following their initial encoding/acquisition, memory representations often demonstrate subsequent development which occurs after the encoding event. The most recognised of these processes involves memory consolidation, which is

suggested to strengthen the representation against interference or decay with time (Walker, Brakefield, Hobson, & Stickgold, 2003). The process of consolidation, however, not only stabilises memories but can enhance them as well, with the stabilisation stage occurring largely during our waking hours, and the enhancement stage occurring primarily, if not exclusively, during sleep (Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002). Research has indicated that this sleep-dependant enhancement in memory representations is due to more than just a simple reactivation during sleep of neural circuits which were associated with wakeful activity (Walker et al., 2002; Walker & Stickgold, 2004).

Indeed, post-encoding enhancement experienced during sleep has been related to a reorganisation of the consolidated memory representations, its integration with other existing representations, reconsolidation following recall, the anatomical reorganisation of codes, as well as active erasure of memory representations; all of which occur outside of conscious awareness, and without additional training on the original stimuli (Walker et al., 2003). Indeed, Walker et al. (2002) found that as much as a 20% increase in motor response speed occurred after a night's sleep, while no increase in response speed occurred after an equivalent interval of wakefulness between training and retest. Walker and Stickgold (2004) further argued that for implicit memory offline enhancement to take place, sleep is a necessity.

Kemps suggested that the sense of figural goodness in a spatial display related to the degree of redundancy between item locations or sequence paths (Kemps, 1999, 2000, 2001). This sense of goodness or redundancy may be more accurately understood as an aspect of familiarity, which may underlie the Gestalt principles such as continuity, closure, etc. That is, the sense of figural goodness may be an effect of exposure, where experience shapes the specificity of representation and thereby our sense of goodness in the design. In the current research, individual item locations and the paths between items are likely to develop implicit LTM representations due to the repeated exposure to stimulus items during the test procedure. To test this hypothesis, we assessed initial capacity on the matrix presentation display when visually indistinct spatial location placeholders were used. Children were then reassessed at a later stage on an identical matrix display as a measure of implicitly derived capacity increase. Secondly it was of interest to investigate if an implicit increase in recall span were occurring, whether the increase in ability was consistent between the developmental groups.

Method

Participants

The same participants who took part in Experiments 2-4 took part in the current experiment, DN n=38, D n=26, DAR n=13 and RA n=35.

Apparatus

The test environment, setup and apparatus was identical to the matrix presentation condition used in Experiment 2, that is a 3X3 matrix array with all spatial locations marked with the same visual placeholder e.g. a blue square, see Figure 5.1.

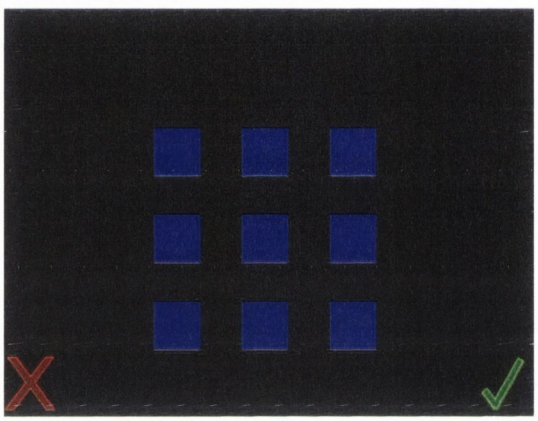

Figure 5.1 Screen shot of matrix presentation spatial layout which was used to present sequence trials for the initial and final assessments.

Procedure

In carrying out Experiments 2-5, children were tested on the individual subtests on 3 separate days. This allowed for the possibility of two separate sleep-dependent memory consolidation enhancements to implicit matrix path representations. Whilst the order in which individual children carried out the individual tests was randomised, the randomisation was constrained in such a way that between the initial and final assessments all children would have experienced 4 assessments which displayed sequence trials with matrix presentations between the initial and final assessment. While for two of these interim assessments the spatial representations were removed at the retrieval stage, e.g. the spatially redundant matrix presentations which formed the basis of Experiment 3.3, Mayr's (1996) research had demonstrated that these spatially redundant presentations should still

elicit the same implicit spatial learning effects as the spatially relevant matrix displays. This meant that each child carried out 12 trials at each sequence length between the initial and final assessment, according to their ability range, which should offer sufficient exposure for implicitly derived learning to take place. Distinct sequence trials were used on the initial and final assessments, which ensured that explicit encoding of particular sequence trials was not possible, and hence could not be used as an explanation for any increases in recall span demonstrated between assessments.

Repeated measures ANOVAs were carried out across the implicit learning condition (initial and final assessment) between developmental groups, with individual analyses using either CRT, longest span and RTs for correctly recalled sequences as the dependent measures. Another repeated measures ANOVA was carried out across the implicit learning, serial order position (primacy, intermediate and recency) and between developmental groups with item recall accuracy ratios as the dependent measure.

Results

Span Capacity

A repeated measures analysis was carried across the implicit learning conditions between the developmental groups (DN n=38, D n=26, DAR n=13, RA n=35), with CRT as the dependent measure. The analysis indicated that overall significant differences existed between initial and final assessments $F(1,108)=4.238$, $p < .05$, with children showing significantly better recall on the final assessment (mean=9.60, SE=.272 95%CI=9.06-10.14) than the initial assessment (mean=9.09, SE=.252 95%CI=8.59-9.59). Significant differences were once again found between developmental groups $F(3,108)=15.055$, $p < .001$, with planned comparisons indicating that DN children (mean=11.32, SE=.362, 95%CI=10.59-12.03) had significantly higher span capacity than D (mean=9.64, SE=.438, 95%CI=8.77-10.50, $p < .05$), DAR (mean=8.50, SE=.619 95%CI=7.27-9.73, P=.001), and RA children (mean=7.93, SE=.237 95%CI=7.18-8.68, $p < .001$). In addition, D children were found to be performing significantly better than RA children ($p < .05$). No significant interaction was found for the implicit learning condition and developmental groups, $F(1,108)=.949$, $p > .05$ (see Table 5.1). While the interaction was non-significant,

between initial and final assessments the D children, unlike the other 3 developmental groups, did not demonstrate even a slight increase in spatial working memory capacity (see Figure 5.2).

Table 5.1 CRT mean scores and 95%CI across the implicit leaning condition and developmental groups.

Development	Implicit	Mean	Std. Error	95% Confidence Interval	
DN	Initial	10.84	0.396	10.06	11.63
	Final	11.79	0.428	10.94	12.64
D	Initial	9.65	0.479	8.70	10.60
	Final	9.62	0.517	8.59	10.64
DAR	Initial	8.31	0.677	6.96	9.65
	Final	8.69	0.731	7.24	10.14
RA	Initial	7.54	0.413	6.72	8.36
	Final	8.31	0.446	7.43	9.20

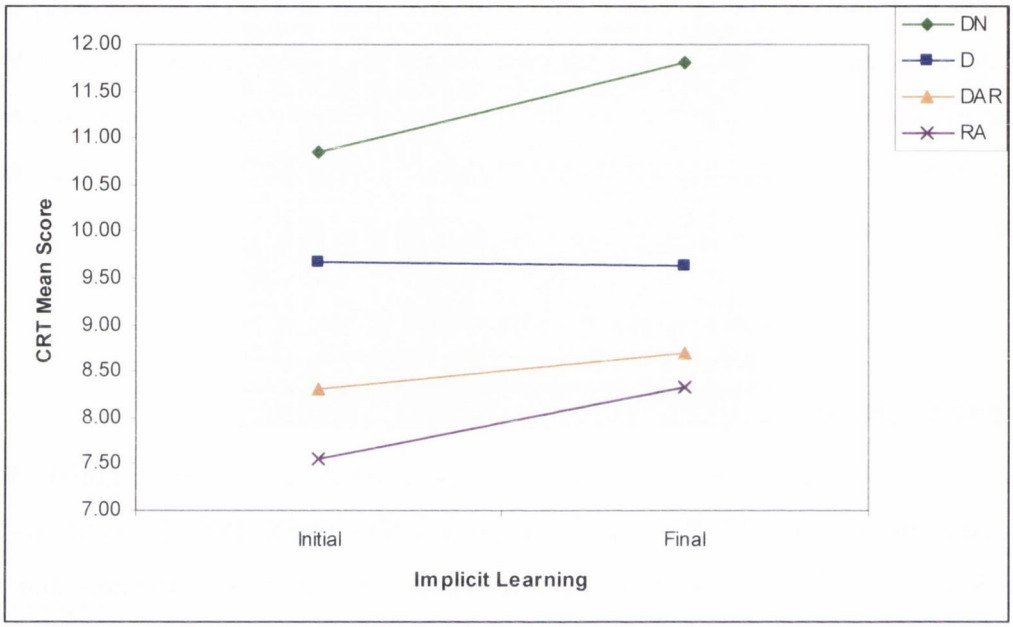

Figure 5.2 Line graph of CRT mean scores between developmental groups across the implicit learning condition.

A repeated measures analysis was carried across the implicit learning conditions (initial and final assessment) between the developmental groups (DN n=38, D n=26, DAR n=13, RA n=35), with longest span as the dependent measure. Significant differences in recall span were indicated between developmental groups $F(3, 108)=11.657$, $p < .001$, with DN (mean=5.62, SE=.129, 95%CI=5.36-5.87) children once again demonstrating significantly higher recall span than DAR (mean=4.69, SE=.221, 95%CI=4.26-5.13, $p < .005$) and RA (mean=4.57, SE=.135, 95%CI=4.31-4.84, $p < .001$) children but did not significantly differ in respect to the recall of D (mean=5.15, SE=.129, 95%CI=5.36-5.87, $p > .05$) children. In addition the analysis indicated that D children were demonstrating a significantly higher recall

span than RA children ($p < .05$). A significant main effect across the implicit learning condition was found $F(1,108)=4.255$, $p < .05$, in line with the CRT analysis, children demonstrated significantly higher recall span on the final (mean=5.12, SE=.104, 95%CI=4.92-5.33) than the initial (mean=4.90, SE=.094, 95%CI=4.71-5.08). No significant interaction was indicated between the implicit learning and developmental conditions $F(1, 108)=.505$, $p > .05$, as highlighted in table 5.2.

Table 5.2 CRT mean scores and 95%CI across the implicit leaning condition and developmental groups.

Developmental	Implicit	Mean	Std. Error	95% Confidence Interval	
DN	Initial	5.42	0.148	5.13	5.71
	Final	5.82	0.163	5.49	6.14
D	Initial	5.12	0.179	4.76	5.47
	Final	5.19	0.197	4.80	5.58
DAR	Initial	4.62	0.253	4.11	5.12
	Final	4.77	0.279	4.22	5.32
RA	Initial	4.43	0.154	4.12	4.73
	Final	4.71	0.170	4.38	5.05

As a means of further clarifying potential implicit learning differences between developmental groups, a second post hoc analysis was run between the initial and final assessment on each of the developmental groups individually. The individual assessments indicated that, in line with Figure 6.2, D children did not show any significant differences between initial (mean=9.65, SE=4.70, 95%CI=8.69-10.62) and final (mean=9.62, SE=.454, 95%CI=8.68-10.55) assessments $F(1,25)=.010$, $p > .05$, neither did DAR (initial mean=8.31, SE=.916, 95%CI=6.31-10.30 versus final mean=8.69, SE=.804, 95%CI=6.94-10.44) $F(1,12)=.490$, $p > .05$ or RA children (initial mean=7.54, SE=.292, 95%CI=6.75-8.34 versus final mean=8.31, SE=.526, 95%CI=7.25-9.38) $F(1,34)=2.119$, $p > .05$. In contrast to the other developmental groups DN children showed significant increases $F(1,37)=7.699$, $p < .01$, in capacity between initial (mean=10.84, SE=.365, 95%CI=10.10-11.58) and final (mean=11.79, SE=.364, 95%CI=11.05-12.53) assessments.

Serial Order Effects

A repeated measures analysis was carried out across the implicit learning, serial order conditions and between developmental groups (DN n=38, D n=26, DAR n=13, RA n=35) with item accuracy ratios as the dependent measure. The analysis indicated that the development groups did not differ in respect to item accuracy ratios $F(1,108)=1.627$, $p > 05$, with recall accuracy being similar between DN (mean=.437,

SE=.018, 95%CI=.400-.473), D (mean=.405, SE=.022, 95%CI=.359-.447), DAR (mean=.381, SE=.032, 95%CI=.318-.443) and RA (mean=.383, SE=.019, 95%CI=.344-.421) children. No significant differences were indicated on the implicit learning condition $F(1,108)=.194$, $p > .05$, with serial position accuracy similar between initial (mean=.394, SE=.016, 95%CI=.363-.428) and final (mean=.406, SE=.017, 95%CI=.373-.439) assessments. There was no significant interaction between the serial position and development conditions $F(5.388, 193.982)=.889$, $p > .05$, see Table 5.3. There was also no significant interaction suggested between implicit learning and development conditions $F(2, 216)=.461$, $p > .05$, see Table 5.4. In line with the findings of previous analyses, serial position accuracy once again contained significant differences between item positions $F(1.796, 193.982)=65.681$, $p < .001$, with pairwise comparisons indicating that children were significantly more accurate in recalling primacy items (mean=.556, SE=.021, 95%CI=.513-.598) than intermediate (mean=.379, SE=.018, 95%CI=344-414, $p < .001$) or recency items (mean=.268, SE=.017, 95%CI=234-301, $p < .001$), and were recalling intermediate items significantly more accurately than recency items ($p < .001$).

Table 5.3 Mean accuracy ratios, standard error and 95%CI for serial position and development conditions

Development	Serial Position	Mean	Std. Error	95% Confidence Interval	
DN	Primacy	0.632	0.034	0.565	0.699
	Intermediate	0.391	0.028	0.336	0.446
	Recency	0.287	0.027	0.235	0.340
D	Primacy	0.558	0.041	0.477	0.639
	Intermediate	0.402	0.034	0.335	0.468
	Recency	0.250	0.032	0.186	0.314
DAR	Primacy	0.513	0.058	0.398	0.627
	Intermediate	0.341	0.047	0.247	0.435
	Recency	0.288	0.045	0.198	0.378
RA	Primacy	0.521	0.035	0.452	0.591
	Intermediate	0.381	0.029	0.324	0.439
	Recency	0.245	0.028	0.190	0.300

Table 5.4 Mean accuracy ratios, standard error and 95%CI for the implicit learning and development conditions

Development	Implicit Learning	Mean	Std. Error	95% Confidence Interval	
DN	Initial	0.444	0.026	0.393	0.495
	Final	0.430	0.026	0.378	0.482
D	Initial	0.372	0.031	0.310	0.434
	Final	0.434	0.032	0.372	0.497
DAR	Initial	0.400	0.044	0.312	0.487
	Final	0.362	0.045	0.273	0.450
RA	Initial	0.368	0.027	0.314	0.421
	Final	0.398	0.027	0.344	0.452

Response Times

A repeated measures analysis was run across the implicit learning and between the development conditions (DN n=38, D n=26, DAR n=10, RA n=35) with correctly recalled sequence trials RTs as the dependent measure. The analysis indicated that there were no significant differences between developmental groups F91,105)=1.934, $p > .05$, with DN (mean=4078ms, SE=163, 95%CI=3755-4401), D (mean=3854ms, SE=197, 95%CI=3463-4224), DAR (mean=4128ms, SE=317, 95%CI=3498-4757) and RA (mean=4460ms, SE=170, 95%CI=4123-4799) children recalling sequence trials with the same rapidity. The interaction between the implicit learning and development conditions was non-significant $F(3,105)=1.742$, $p > .05$, see Table 5.5. Significant differences were found for the implicit learning condition, $F(1,105)=19.147$, $p < .001$, which indicated that RTs on the initial tests (mean=4607ms, SE=171, 95%CI=4268-4945) had significantly slower RTs than the final assessment (mean=3652ms, SE=138, 95%CI=3378-3925).

Table 5.5 RT mean scores, standard error and 95%CI between developmental groups across the implicit learning condition for correctly recalled sequence trials.

Development	Implicit Learning	Mean	Std. Error	95% Confidence Interval	
DN	Initial	4422	252	3922	4921
	Final	3734	204	3330	4137
D	Initial	4179	305	3575	4783
	Final	3528	246	3040	4016
DAR	Initial	4557	491	3584	5531
	Final	3698	397	2911	4484
RA	Initial	5271	262	4750	5791
	Final	3649	212	3228	4069

Table 5.6 RT mean scores, standard error and 95%CI for the one way ANOVA across the implicit learning condition for the individual developmental groups for correctly recalled sequence trials.

Development	Implicit learning	Mean	Std. Error	95% Confidence Interval	
DN	Initial	4422	183	4052	4792
	Final	3734	185	3360	4108
D	Initial	4179	220	3726	4632
	Final	3528	233	3049	4008
DAR	Initial	4557	491	3447	5668
	Final	3698	415	2758	4637
RA	Initial	5271	359	4541	6000
	Final	3649	237	3168	4130

When shifts in RT between implicit learning conditions were assessed individually for each developmental group, a developmental shift in performance was found. Both literacy unimpaired groups showed a significant decrease in RTs (DN:

$F(1,27)=7.979$, $p < .01$, and RA: $F(1,34)=14.932$, $p < .001$), while both the literacy-impaired groups did not demonstrate a significant decrease in RTs (D: $F(1,25)=3.648$, $p > .05$, and DAR: $F(1,9)=1.463$, $p > 05$), although D children's RTs were approaching significance P=.068) see Table 5.6.

Discussion

Span Capacity

Across levels of the implicit learning condition, and in line with the findings from earlier chapters, DN children were once again found to have a higher span capacity than any of the other developmental groups. Additionally, D children were found to have a significantly higher span capacity than the RA children, in line with the CRT findings of Experiment 2. This suggests that while D children are experiencing a developmental delay in spatial WM, it is not as impaired as their development of literacy skills. The analysis indicated that children were experiencing a significant increase in span capacity between the initial and final assessment, suggesting that learning was occurring. While the interaction between implicit learning and development was not significant, when performance between the initial and final assessments was assessed individually according to developmental group, the analysis indicated that only DN children had a significant increase in span capacity between initial and final assessments.

Kemps' (2001) research suggested that as little as one exposure to a complex sequence path presented on a 5x5 matrix display was enough to improve recall span on the sequence when the sequence path was presented again later in the experiment, or the following day. The current experiment suggests that repeated exposures to sequence trials, on a 3x3 matrix led to a general improvement in recall span, at least in developmentally normal children in the 9-11 age range. This improvement was not specific to particular sequence trials as participants were not tested on the same sequence trials on the initial and final assessment. The fact that learning generalised beyond previous exposure to sequence paths may be related to the reduced degree of complexity on the 9-item displays versus the 25 item spatial arrays in Kemps' study.

Serial Order Effects

No significant differences were found in respect to serial order effects between developmental groups or implicit learning conditions. The only significant effect related to higher accuracy on the primacy items over intermediate and recency items, with intermediate items having higher accuracy ratios than recency items. The lack of significant effects between the developmental groups and the lack of differences or significant effects between initial and final items across the implicit learning condition would suggest it is unlikely that the increase in span capacity shown by DN children relates to a shift in strategy use or retrieval procedure.

Response Times

Interestingly, across the RT analysis for correctly recalled sequences, the only significant difference related to a decrease in RTs on the final assessment relative to initial assessment. This indicated that there is some evidence for secondary improvement related to the turnaround time between the presentation of a sequence trial, sequence processing and response completion, between initial and final sequence presentations. However, when RTs were analysed separately by developmental group, only the literacy-unimpaired children demonstrated significant decreases in RT, although both the D and DAR children showed a trend in this direction. The results are in line with Mayr's (1996) research, which found that enriched, implicitly-derived sequence representations led to quicker RTs.

Summary

In the current experiment, dyslexic children did not demonstrate a significant enhancement in performance between initial and final assessments on either measures of span capacity or RT, in contrast to their developmentally normal age-matched cohorts. This lack of implicit learning is in line with a recently published article which found that dyslexic children did not demonstrate sleep-related enhancement in a mirror drawing task in contrast to age-matched control children (Vicari et al., 2005). However, if dyslexia does relate to a specific impairment in implicit learning, why then did the RA children's increases in span capacity not reach statistical significance, given it is unlikely that the capacity for implicit learning increases with age, as it is a capacity which is present from birth (Vicari et al., 2005)?

It is possible that the shift in implicit learning effects may relate to the degree of pre-established memory representations between developmental groups. It seems plausible that the DN children simply had a more enriched foundation of representations that could be referenced in relation to the matrix presentation displays. What is suggested is that, when memory consolidation was occurring in the form of memory association between pre-existing and new representations (Stickgold, 2005), this placed them in a stronger position to experience enhanced representations due to a greater scope for interconnectivity between memory representations. This argument mirrors Gombert's (2003) thesis that dyslexic children have a reduced implicit foundation with which new experiences can be easily associated. If such a theory is correct, it is likely that with increased exposure RA children would have experienced the same significant benefits to capacity levels as their DN counterparts, but that the representation foundation was simply less established in the first place. The reduced degree of adaptation to the test requirements indicated in the literacy-impaired children is very much in line with Nicolson and Fawcett's (2000) "square root rule" of dyslexic development. That is to say, dyslexic children will take longer by a factor of the square root of the time it normally takes to show the same degree of learning. Simply put, the dyslexic's reduced foundation, unlike the RA child's, does not relate to reduced exposure to specific stimuli or learning experiences but instead relates to a reduced ability to benefit from implicitly derived learning from such experiences. In line with the DAD theory proposal that dyslexic individuals eventually overcome impaired automatisation by conscious compensation (Nicolson & Fawcett, 1990), the square root rule of learning most likely relates to the level of exposure needed before declarative encoding can take over from their impaired, implicitly derived functioning.

Interestingly, in contrast to a completely generalised deficit in automatisation, there does seem to be some slight evidence for individual variation between D and DAR children's ability across the test measures. On span capacity and RT measures, while D children did not demonstrate any change in span capacity between initial and final assessments, there was a slight (though non-significant) trend in DAR children. Likewise, while D children's RTs approached significant effects in respect to quicker RTs on the final assessment, DAR children showed a much weaker trend. This

tentatively suggests that, depending on the particular dyslexic subgroup, the capacity for skill acquisition may differ, contingent upon which skill is under development.

It must be noted that the lack of implicit learning in the dyslexic children could relate to the degree of required eye movements in the different development groups, although this is unlikely. Mayr's (1996) research suggested that implicit learning did not occur when participants were required to covertly shift attention to the relevant locations, but that they did demonstrate enhanced performance when they were allowed to shift the fovea of vision to the spatial locations. Given that existing research has suggested that dyslexic children have trouble maintaining spatial focus (Facoetti, Paganoni, Turatto et al., 2000; Rayner et al., 1989), it is possible that there may have been a decrease in the extent to which overt eye movements occurred during the task and hence the lowered implicit learning effects. While this possibility is unlikely to be the root cause of the lowered enhancement in span capacity, it requires further research before it can be conclusively rejected.

Chapter 7- Experiments 6.1 and 6.2

Sustained attention and inhibitory control in dyslexic children

Introduction

The current chapter details 2 experiments which addressed sustained attention and inhibitory control in dyslexic children relative to age matched controls and reading age matched literacy unimpaired children. Experiments 6.1 and 6.2's findings are presented and discussed in turn, with a general discussion integrating the research findings between the two experiments.

Introduction to Experiments 6.1 and 6.2

There is a large body of research that has investigated the relationship between aspects of attentional functioning and dyslexia, with selective impairments being indicated in a number of attentional domains. These include: orienting attention (Brannan & Williams, 1987; Facoetti, Paganoni, Turatto et al., 2000; Facoetti et al., 2001), impaired attentional focusing (Facoetti, Paganoni, & Lorusso, 2000; Milberg, Whitman, & Galpin, 1981; Rayner et al., 1989; Richards, Samuels, Turnure, & Ysseldyke, 1990), visual attention (Fischer & Weber, 1990; Heiervang & Hugdahl, 2003; Iles, Walsh, & Richardson, 2000), magnocellular and temporal processing (Anderson, Brown, & Tallal, 1993; Stein & Walsh, 1997; Vidyasagar, 1999; Vidyasagar & Pammer, 1999), left mini neglect (Hari et al., 2001; Sireteanu, Goertz, Bachert, & Wandert, 2005), sustained attention (Smith-Spark et al., 2004; Tarnowski, Prinz, & Nay, 1986) and inhibition (Reiter et al., 2005; van der Schoot et al., 2000).

Research using the self-report Cognitive Failures Questionnaire (CFQ) and a similar modified measure administered to close companions of dyslexic individuals found that, not only were dyslexic adults self-reporting a higher frequency of attentional slips, but their companions also reported that the dyslexic individuals were experiencing an increased rate of lapses in attention as well, in comparison to individuals without a literacy impairment (Smith-Spark et al., 2004). Such casual slips in functioning can have far reaching consequences beyond the inconvenience of frequently having to reattach attention to task, including lower productivity due to

longer periods of inattention or off-task daydreaming (Augur, 1985) and greater difficulties in problem solving or goal-directed planning (Levin, 1990).

The Sustained Attention to Response Task (SART) (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) has been shown to predict the prevalence of such absent minded action slips, or errors in day-to-day functioning in both normal and brain damaged individuals (Manly, Davison, Heutink, Galloway, & Robertson, 2000; Manly et al., 2003). In fact, previous research has shown that the SART may provide a laboratory analogue of more naturalistic reports of everyday absentmindedness as indicated on the CFQ (Manly, Robertson, Galloway, & Hawkins, 1999). The usefulness of a viable measure of discriminating between children who are suffering from a secondary deficit in sustaining attention, and those who don't suffer such difficulties, would become particularly apparent in a remedial context. Thus, particular remedial interventions could be individually tailored to the relative capacity of individual children to follow or maintain task-directed functioning.

Two distinct versions of the SART have been developed, the Random and the Fixed. In the Random version, digits 1-9 are presented in a random order, with participants being asked to respond with a keypress response on every digit except for the digit 3, for which they are asked to withhold keypress. The Fixed version follows exactly the same rules of response and withholding as the random SART, except that digit presentation is now fixed in the same ascending sequence, continuously counting up from 1-9. In both versions there is a requirement to withhold keypress on presentation of the No-go target (the digit 3), however the mechanisms that allow for correct withhold are likely to be quite different between tasks. The unpredictable nature of the random version requires that the prepotent motor response has to be inhibited for a correct withhold to occur. Whereas, a recent ERP study has shown that due to the predictable nature of the fixed SART, participants inhibit the preformed motor response before No-go stimulus presentation occurs, i.e. with the presentation of the digit 2 (Dockree, Kelly, Robertson, Reilly, & Foxe, 2005). Thus, participants are able to circumvent the stimulus-response pairing by sustaining attention on task (Fassbender et al., 2004). Logan and Cowan's (1984) race model suggests that the inhibitive overwriting of the prepotent Go response with the presentation of a No-go target, induces response conflict. Whereby the two processes of "response press" versus "response inhibition" "race" each other to bring about the response

occurrence, commission error[17] versus correct withhold. In such a model, if the Go response is initiated particularly early, maybe even before the presentation of the No-go stimulus, the inhibitive response would have to "run" that much faster in order to win the race, and bring about a correct withhold (Logan, Dagenbach, & Carr, 1994).

Moores and Andrade (2000) found that dyslexic teenagers had significantly higher commission error rates than age-matched controls on the random SART. This is consistent with Smith-Spark et al.'s (2004) findings of increased attentional lapses in adult dyslexics. However, the authors suggested that the increased commission error rate, rather than relating to a sustained attention/inhibitory control deficit, may actually relate to a deficit in the automatic recognition of test stimuli on the part of dyslexic participants (Nicolson & Fawcett, 1990, 2000). That is, dyslexic children simply never get to the stage whereby button press becomes the prepotent response to Go stimuli. To test this hypothesis, they developed a modified version of the task - the scribble SART - in which visual scribbles replaced the normal digit stimuli. The scribbles consisted of abstract doodle patterns which, they hypothesised, would not elicit automatic recognition in any of the participants.

However, Anderson and Marjorie (1998), in their assessment of memory, suggested that poor readers showed a marked preference for pictorial over verbal encoding of information relative to control children, perhaps stemming from their past difficulties with binding verbal labels to visual stimuli. Swan and Goswami (1997) demonstrated that dyslexic children, while impaired in their ability to phonologically represent words, were not impaired in their visual recognition of them, suggesting, the apparent shift in encoding strategy (from verbal to visual) would be less likely to dramatically impair dyslexic children's performance between tasks.

Given Swan and Goswami's findings, there are serious concerns regarding the validity of Moore and Andrade's (2000) experimental premise. Firstly, a number of the scribble stimuli could be easily re-coded in terms of existing visual representations, e.g. the scribble stimuli looked like the letter 'M', the letter 'W', a snake, the Figure '8', which would undermine the purported lack of long-term representations associable with these stimuli. Secondly, as the abstract stimuli were meant to be unverbalisable, the authors seemed to suggest that somehow this would

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[17] Commission error is defined as a response to a No-go target.

prevent automatic visual recognition from occurring. While initially some participants had great difficulties in discriminating the No-go from the Go stimuli, the authors gave these participants repeated practice trials, such that they could then automatically discriminate the No-go from Go stimuli, again undermining the suggested operational manipulation.

Thirdly, while both groups made significantly more commission errors on the Scribble versus the standard SART version, there no longer remained significant between-group differences and the analysis did not indicate a significant interaction between the developmental group and the SART version. This implies that while the Squiggle SART may have acted as a measure of sustained attention or inhibitory response, it was not as sensitive a measure as the standard random SART. Thus, it is unclear why the authors inferred that this lack of interaction between the SART versions and the developmental group supported the hypothesis of a lack of automatic stimulus recognition in dyslexic participants over a sustained attention deficit.

Regardless of the possible over-interpretation of the data, there remains an additional shortfall in the study, that is, a potential sampling flaw, given that 3 out of the 14 dyslexic teenagers were found to be reading at age-appropriate levels or above, and 1 had a reading age 2 years higher than his chronological age. This indicates a possible misdiagnosis of dyslexia for these participants and hence undermines any inferences that can be drawn from the data, even on the standard SART, in respect to dyslexic individuals.

Besides the overt attentional measures of commission and omission error[18] which were analysis in the Moores and Andrade study, there is growing support for the belief that response variability is a valid and highly sensitive measure of attentional control (Bellgrove, Hawi, Kirley, Gill, & Robertson, 2005; Bellgrove, Hester, & Garavan, 2004; Manly et al., 2000; Mullins, Bellgrove, Gill, & Robertson, 2005; Stuss, Murphy, Binns, & Alexander, 2003). Stuss et al. (2003) suggested that impaired top-down attentional control was strongly associated with increased response variability in patients with focal frontal lesions. Extending this position, Mullins et al. (2005) found a similar connection in research with ADHD and control children, arguing that, rather than being irrelevant noise in the analysis, response variability may act as a significant marker of the underlying efficiency of cognitive

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[18] Omission error is defined as a failure to make a response on a Go-target.

processes. Increased variability on motor response tasks has also been linked to poorer academic achievement in reading, spelling and mathematical ability (Waber et al., 2000).

Attentional deployment over time is typically assessed by getting participants to identify 2 targets in a string of distracters. Research involving normal adult readers demonstrated that while the first target (T1) is identified with a high degree of accuracy, the accuracy with which the second target (T2) is identified is directly related to the stimulus-onset asynchrony (SOA) between targets. Shorter SOAs (200ms) lead to the largest level of impairment, with impairment in T2 identification gradually decreasing as SOA increases (Chun, Potter, & Shapiro, 2001; Raymond, Shapiro, & Arnell, 1992). The variability in identification accuracy in T2 relative to SOA has been termed attentional blink (AB). Further research has shown that the intention to attend to or process a target may be a critical factor in AB, given that if participants are instructed to ignore T1, AB does not occur (Raymond et al., 1992). Secondly, it has been shown that the omission of distracters between T1 and T2 does not eliminate AB (Zuvic, Visser, & Di Lollo, 2000). Visser and colleagues (2004) found that dyslexic children were impaired relative to chronological age controls in AB.

It is theorised that AB occurs because the processing of T1 prevents adequate allocation of resources for T2, when T2 occurs within a critical time window within several hundred milliseconds of T1. Visser, Boden and Giaschi (2004) suggested that because T2 is not fully processed it is more vulnerable to rapid decay or subsequent overwriting by the stimuli that follow. Due to the continuous nature of the SART, both digits and response cues could act as either T1 or T2, and their relative positions may swap back and forth as the task progresses. While is seems unlikely that the response cue would overwrite individual digit stimuli, the very process of attending to the response cue could act to dramatically reduce digit recognition and processing. Hypothetically, this processing loss could maximally lead to circumstances where stimuli are processed at such a low level that they effectively do not enter conscious identification. Relating this point to the SART paradigm, the lack of conscious recognition may lead to confusions relating to one's placement in the cyclical sequence e.g. increased omission error rates in the fixed SART for Go-targets that are simply not perceived. Even if one takes a watered down version of this hypothesis, as stimuli approach threshold it is likely that additional attentional resources may need

to be allocated to the identification aspects of the task, leaving fewer reserves which can possibly be allocated towards sustaining attention.

The SART's systematic cycle from digit to mask to response cue to mask for each stimulus sequence may necessitate a high degree of selective attentional processing. Effectively, the children have to selectively attend to both the presented digit and the response cue within an individual trial, while at the same time ignoring the masks in order to efficiently carry out the task. In the SART task, while the response cue would require but minimal processing, dyslexic children due to sluggish attentional shifting (Hari et al., 1999) or a misattribution of attentional processing to the response cue, may have experienced additional difficulties due to the presence of masks and response cue. Thus, the suggested deficits in performance found in the dyslexic children may in fact relate to a deficit in selective (shifting) attention rather than sustained attention. If targets are presented in close temporal succession, both will compete for attentional resources (Hari et al., 1999). In fact, Potter, Staub and O'Connor (2002) demonstrated this attentional resource competition between T1 and T2 in developmentally normal college students for SOAs between 50-150ms. Visser et al. (2004) has argued that the window of competition is likely to be much longer in dyslexic children, which would explain the impairments to both T1 and T2 even when separated by intervals of several hundred milliseconds.

Hari, Valta and Uutela (1999) assessed AB in adult dyslexics and found that attentional dwell time was prolonged by some ~30%, but that for SOAs of 700ms or more identification accuracy was equivalent to control participants. Visser et al. (2004) found similarly that D children demonstrated reduced identification accuracy for T2 relative to control children, even for SOAs as long as 1400ms. Interestingly, Visser also found that D children additionally demonstrated a reduction in stimulus identification rates for T1 relative to identification accuracy when only T1 was required to be identified. This reduction in accuracy again continued to be found in intervals as long 1400ms.

Given these findings it was of particular importance that in the current round of experiments a new version of the SART was developed for both fixed and random tests – which while using a response locked model to reduce speed/accuracy trade-off, removed all visual noise, ensuring that possible differences in AB between groups, would not contaminate the measurement of sustained attention.

If dyslexic children are really achieving the same automatised response style on the SART as their age-matched cohorts, one would hypothesise that there would not be any differences in the RT profiles which lead to correct withholds, commission errors, or errors of omission between groups. For example, if both developmental groups relate to the experimental requirements in a similar fashion, we would expect them both to demonstrate slower RTs before a correct withhold on a No-go target, with RTs speeding up immediately afterwards. Likewise we would expect both groups to experience a quickening in RTs before the occurrence of a commission error in line with previous research (Manly et al., 2000). However, it is expected that dyslexic children will experience more frequent lapses in attention, in line with the research involving dyslexic adults (Smith-Spark et al., 2004). This in turn should lead to a higher response variability (Bellgrove et al., 2004). However, the profile relating to specific response types should be similar between developmental groups.

Experiment 6.1 and 6.2 Method

Participants

The same participants that took part in Experiments 2-4 took part in the current study, (DN n=35, D n=26, DAR n=13, and RA n=35).

Apparatus

The test stimuli were presented on a 17 inch LCD monitor, children were tested individually and sat approximately 60cm from the screen although their position was not restrained. As schools are intrinsically noisy places children wore Sennheiser noise reduction headphones throughout testing as a means of reducing between-setting variation.

Procedure

On the Fixed response-locked version of the Sustained Attention to Response Test (SART) as developed by Bellgrove et al. (2005), participants are presented with a repeating ascending sequence of the digits 1-9. The task is to respond by pressing a response button on the Go trials (the digits- 1, 2, 4, 5, 6, 7, 8, 9) and to withhold key-pressing on the No-go trials (the digit '3'). However rather than responding immediately with the presentation of a go-target, participants are asked to withhold

response until the presentation of a response cue, which was presented 125ms after the digit presentation (see Figure 6.1). The use of a response cue had been shown to reduce speed/accuracy tradeoffs in brain damaged and ADHD populations (Bellgrove et al., 2005; Manly et al., 2000). The Random version of the SART follows an identical procedure except that the sequence presentation of digit stimuli is randomised across the duration of the assessment.

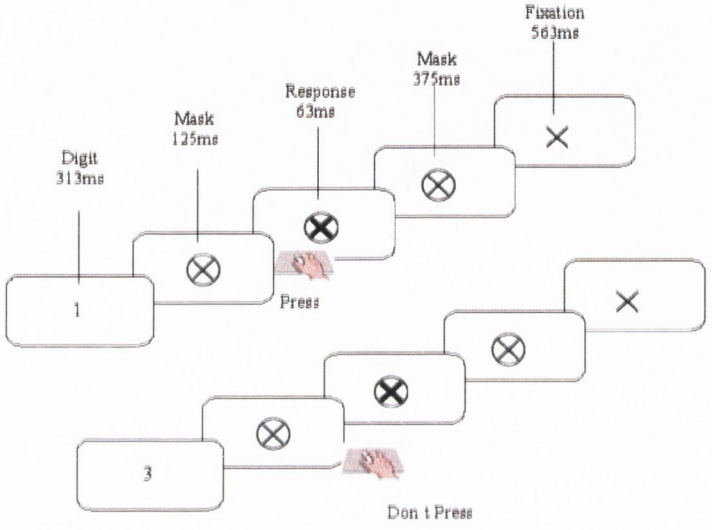

Figure 6.1 Detailed procedural layout for individual stimuli contained within a single trial. Figure (a) illustrates a go trial which would require key press on the response cue. Figure (B) illustrates a No-go trial which requires the withholding of keypress. (From Bellgrove, Hawi, Kirley, Gill & Robertson, 2005, P1851).

Due to possible difference in AB between developmental groups A new version of the response locked SART was developed in which participants were asked to withhold keypress until the go-targets disappeared from the screen. In this way, the cue to response occurs at the same point as the original response locked version (Bellgrove et al., 2004), but it is the absence of visual stimuli that acts as the response cue rather than additional visual stimuli (see Figure 6.2). The inter-stimulus interval between the presentation of one digit and the next was 1438ms. Participants could respond anytime within this presentation window in order for a response to be recorded on the relevant digit.

The order in which children carried out the fixed (Experiment 6.1) and random (Experiment 6.2) versions of the SART was randomised. Each assessment

took 5 minutes and incorporated 25 1 through 9 sequences, which accounted for 225 individual trials, 25 of which were No-go trials. Between the two SART assessments children were given a 5 minute rest period, before starting the second assessment. The task was explained to the children and they were asked to repeat back the instructions in order ascertain procedural understanding, before being given a 36 trial practice run, which contained 4 No-go targets. Once participants were able to carry out the 36 item practice without making any commission errors, the test proper started.

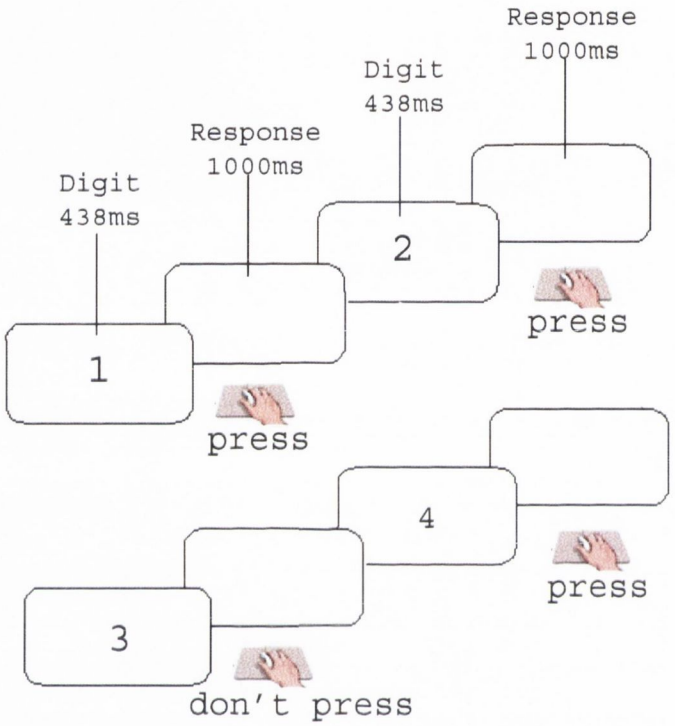

Figure 6.2 Diagram showing the presentation of items for the modified response locked SART. Participants are asked not to respond until the digit disappears from the screen.

Dependent measures were: 1) Commission Errors- a failure to withhold keypress on No-go trials; 2) Omission errors- a failure to respond with keypress on go trials; 3) mean Go Reaction Time for Go trials (Go-RT(ms)); 4) the standard deviation of Go-RT (Go-RT-SD. 5) Response times that preceded or followed a correct withhold response CW-RT; 6) Intra-individual coefficient of variation (ICV), which is calculated by dividing RT standard deviation by the mean RT. Response variability in this way can be compared across experimental and control groups (Bellgrove et al., 2005; Manly et al., 2000; Stuss et al., 2003). 7) the RT profile for a correct withhold response was assessed by looking at the RTs on digit positions immediately proceeding and following a correct withhold, that is RTs for go-targets 2

positions before, 1 before, 1 after and 2 after a correct withhold. 8) the RT profile for a commission error was also assessed by looking at the RTs on digit positions immediately proceeding and following a commission error, that is RTs for go-targets 2 positions before, 1 before, 1 after and 2 after a commission error.

Performance across the individual test measures was predominantly assessed using one-way ANOVAs, but repeated measures analyses were used to assess the RT profile analyses, with all pairwise comparisons using Bonferroni conversions to adjust P-values. Additionally simple linear regression assessed the degree of explained variance which Go-RT-SD could account for in commission and omission error individually.

Experiment 6.1- Fixed SART- Results

Grouping Variables

Participants with omission errors greater than 2 standard deviations (SD) above the mean were removed from all future analysis as such responses were likely to disproportionately skew test results. In this way the sample dropped from 26 in the D group to 25; the DAR group dropped from 13 to 11; the DN group stayed at 38; and the RA group dropped from 35 to 32.

Commission and Omission Errors

A one way ANOVA between the developmental groups was carried out with commission error as the dependent variable. The analysis indicated a significant main effect $F(3, 102)=10.063$, $p < .001$, with Bonferroni planned comparisons indicating that the DN (mean=3.29 [out of 25 possible errors], SD=2.66, 95%CI=2.42-4.16) children had a significantly lower rate of commission errors than D (mean=5.80 [out of 25 possible errors], SD=2.83, 95%CI=4.63-6.97, $p < .05$), DAR (mean=7.36 [out of 25 possible errors], SD=3.44, 95%CI=5.05-9.68, $p = .001$) and RA (mean=6.88 [out of 25 possible errors], SD=3.55, 95%CI=5.59-8.16, $p < .001$) children, with none of the other groups significantly differing from one another.

A second one way ANOVA between the developmental groups was carried out with omission error as the dependent variable. Once again significant differences were found between developmental groups $F(3, 102)=5.570$, $p = .001$, the analysis indicated that DN (mean=5.68 [out of 200 possible errors], SD=6.05, 95%CI=3.70-

7.67) children demonstrated significantly less omission errors than both DAR (mean=11.45 [out of 200 possible errors]. SD=7.50, 95%CI=6.41-16.49, $p = .05$) and RA (mean=11.31 [out of 200 possible errors], SD=6.96, 95%CI=8.80-13.82, $p < .005$) children, with the analysis indicating that the D (mean=8.00, [out of 200 possible errors], SD=4.96, 95%CI=5.95-10.05, $p > .05$) children did not significantly differ from the other 3 groups.

Response Times and Variability

A one way ANOVA was run with Go-RT as the dependent variable between the developmental groups. While a significant main effect was indicated between developmental groups in respect to Go-RT $F(3, 102)=3.718$, $p < .05$, Bonferroni comparisons indicated that none of the groups were significantly different from one another, as DN (mean=567ms, SD=183, 95%CI=507-628), D (mean=466ms, SD=132, 95%CI=411-521), DAR (mean=337ms, SD=151, 95%CI=343-549), and RA (mean=561ms, SD=127, 95%CI=516-607) children's RTs were not sufficiently dissimilar. While no significant differences were found between developmental groups, only the literacy impaired children were found to respond at the offset of the response cue (439ms), while both the DN and RA groups waited some 60ms or so after the response cue before responding. However, given the confidence interval for the DAR children's RTs, this would mean a considerable proportion of key-presses were occurring before response lock.

A repeated measures analysis was carried out across response type (Go-RT versus commission RT) between developmental groups (DN n=34, D n=25, DAR n=11, RA n=31) with RT as the dependent measure. Significant differences were not indicated between developmental groups $F(3,97)=1.786$, $p > .05$, as DN (mean=656ms, SE=21, 95%CI=614-697), D (mean=591ms, SE=24, 95%CI=542-639), DAR (mean=593ms, SE=37, 95%CI=519-667) and RA (mean=602ms, SE=22, 95%CI=558-646) children were responding similarly. Significant differences in RT between response types were indicated $F(3,97)=64.440$, $p < .001$, signifying that Go-RTs (mean=510ms, SE=17, 95%CI=477-543) were significantly quicker than commission RTs (mean=711ms, SE=20, 95%CI=671-750). A significant interaction between response type and development was also found, $F(3,97)=3.312$, $p < .05$. As highlighted in Figure 6.3, in contrast to the DN, D and DAR children, the RA

children did not demonstrate a significantly slower response on commission RT relative to their Go-RT response times, see Table 6.1).

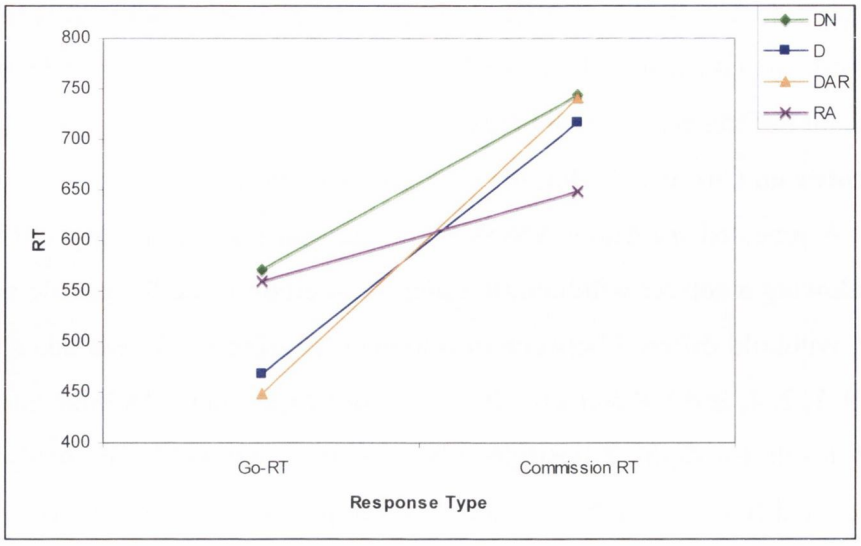

Figure 6.3 Line graph of the interaction between RT response type and developmental group on the fixed SART.

Table 6.1 RT Mean scores, standard error and 95%CI across response type and between developmental group on the fixed SART

Development	Response Type	Mean	Std. Error	95% Confidence Interval	
DN	Go-RT	569	26	517	621
	Commission RT	742	31	681	804
D	Go-RT	466	30	406	527
	Commission RT	715	36	643	787
DAR	Go-RT	447	46	356	538
	Commission RT	739	55	630	847
RA	Go-RT	558	27	503	612
	Commission RT	646	33	582	711

A one way ANOVA was carried out on Go-RT-SD between the developmental groups (DN n=28, D n=25, DAR n=11, RA n=32). The analysis of RT variability suggested significant differences between developmental groups $F(3, 102)=9.350$, $p < .001$, Bonferroni comparisons indicated that the DN (mean=170ms, SE=47, 95%CI=165-195) children were significantly less variable than D (mean=225ms, SE=67, 95%CI=198-253, $p < .05$), DAR (mean=262ms, SE=62, 95%CI=221-394, $p < .001$), and RA (mean=241ms, SE=63, 95%CI=219-265, $p < .001$), but that none of the other groups significantly differed.

A one way ANOVA was carried out on the ICV data which indicated significant differences between developmental groups $F(3,90)=10.233$, $p < .001$, Bonferroni comparisons indicated that DN (mean=.3550, SE=.1596, 95%CI=.3025-.4075) children were significantly less variable than both D (mean=.5035, SE=.1525,

95%CI=.4406-.5665, $p < .05$) and DAR (mean=.6244, SE=.1956, 95%CI=.4936-.7558, $p < .001$) children, but that DN children did not significantly differ from RA (mean=.4493, SE=.1392, 95%CI=3990-4995) children. Additionally, RA children demonstrated significantly less variability than DAR children ($p < .05$), with no other significant differences existing between groups.

RT Profile on Correct Withholds and Commission Errors

A repeated measures ANOVA was carried out on Go-target RTs preceding and following a correct withhold, in order to ascertain if the RT profile surrounding a correct withhold differed between developmental groups. RT was taken for response digits 9, 1, 2, 4, and 5-8 collectively as previous experiments had indicated a return to Go-RT levels for digits 2 positions after a correct withhold. The analysis indicated significant differences in RT between developmental groups $F(3,102)=4.830$, $p < .005$, with pairwise comparisons indicating that DN (mean=556ms, SE=26, 95%CI=505-607) children were responding significantly more slowly than both D (mean=435ms, SE=32, 95%CI=372-498, $p < .05$) and DAR (mean=409ms, SE=48, 95%CI=314-504, $p < .05$) children, while RA (mean=543ms, SE=28, 95%CI=487-599, $p > .05$) children did not significantly differ from any group.

Table 6.2 Mean Go-RT scores and 95%CIs for individual digit positions preceding or following a correct withhold, on the fixed SART.

	Mean	SE	95% CI	Digit 9	Digit 1	Digit 2	Digit 4	Digits 5-8
Digit 9	473	18	438-508		$P < .001$	$p > .05$	$p < .001$	$p = .005$
Digit 1	531	17	497-565	$p < .001$		$p < .001$	$p < .001$	$p = .005$
Digit 2	485	18	448-522	$p > 0.05$	$P < .001$		$p < .001$	$p > 0.05$
Digit 4	438	17	404-472	$p < .001$	$P < .001$	$p < .001$		$p < .001$
Digits 5-8	500	19	461-538	$p = .005$	$P = .005$	$p > 0.05$	$p < .001$	

Significant differences across the RT profile leading to a correct withhold were indicated between the individual digit positions $F(3.458, 352.772)=38.190$, $p < .001$. Pairwise comparisons indicated that RTs on the digit 1 were significantly slower than all other digit RTs ($p < .001$) (see Table 6.2) while children's response to digit 4 was significantly quicker ($p < .001$) than all other stimulus positions, after a correct withhold occurred. Additionally, children responded significantly more quickly to stimuli 3 positions before a correct withhold (digit 9) than across digits 5-8 ($p < .005$). No other significant differences were suggested between groups. A significant interaction was found between developmental type and RT profile for correct withhold responses $F(10.374, 352.772)=3,077$, $p = .001$. As the data from

Table 6.3 highlight, pairwise comparisons found that while for D, DAR and RA children, RTs on digit 4 were significantly quicker than RTs for the digit 1 stimulus ($p < .05$), that for DN children the RTs between stimuli positions did not significantly differ (see Figure 6.4).

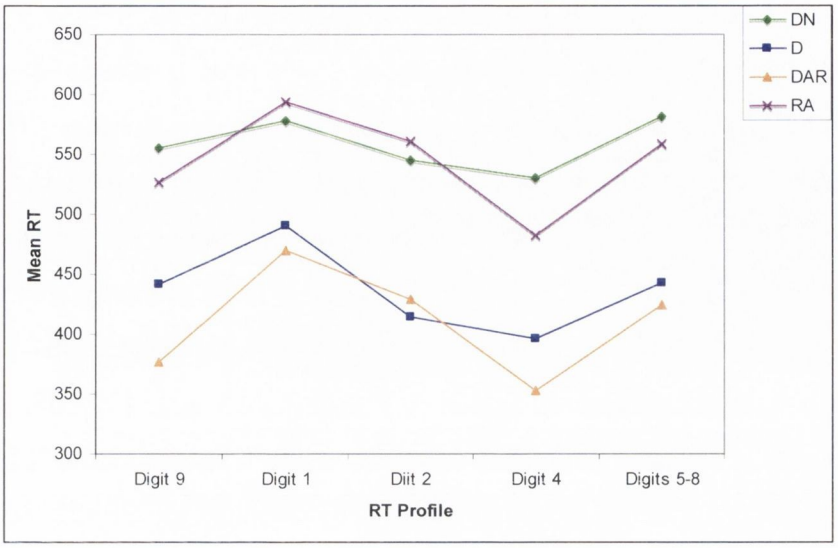

Figure 6.4 Line graph of the interaction between RT profile and developmental groups when a correctly withheld response to No-go stimuli occurs, on the fixed SART

Table 6.3 Mean Go-RT scores and 95%CIs across correct withhold RT profile and between development conditions, on the fixed SART

Development	RT Profile	Mean	Std. Error	95% Confidence Interval	
DN	Digit 9	553	27	500	606
	Digit 1	576	26	525	627
	Digit 2	543	28	489	598
	Digit 4	528	26	478	579
	Digits 5-8	580	29	522	638
D	Digit 9	440	33	375	505
	Digit 1	489	32	426	551
	Digit 2	413	34	345	480
	Digit 4	394	32	331	457
	Digits 5-8	441	36	370	512
DAR	Digit 9	375	49	277	473
	Digit 1	468	48	374	563
	Digit 2	427	51	326	529
	Digit 4	351	48	256	445
	Digits 5-8	423	54	316	530
RA	Digit 9	525	29	468	583
	Digit 1	592	28	537	648
	Digit 2	559	30	499	618
	Digit 4	480	28	425	536
	Digits 5-8	557	32	494	619

A repeated measures ANOVA was carried out on the digit RTs for go targets preceding and following a commission error, in order to ascertain if the RT profile

surrounding a commission error differed between developmental groups (DN n=29, D n=22, DAR n=11, and RA n=30). The assessment layout was identical to the analysis for the correct withhold above. A main effect for development type was again found $F(3, 88)=3.083$, $p < .05$, however, pairwise comparisons indicated that none of the DN (mean=577ms, SE=29, 95%CI=519-636), D (mean=465ms, SE=34, 95%CI=398-532), DAR (mean=454ms, SE=46, 95%CI=360-549) or RA (mean=548ms, SE=29, 95%CI=491-606) children significantly differed from one another. The analysis indicated significant differences in RT between the individual digit positions $F(2.562, 225.426)=22.742$, $p < .001$, with pairwise comparisons finding that the mean RT for digit 4 (mean=619ms, SE=21, 95%CI=557-662) had a significantly slower RT than all other digits ($p < .001$). Digit 1 RT (mean=508, SE=22, 95%CI=464-552ms) was significantly slower than digits 9 (mean=464, SE=22, 95%CI=420-508ms, $p < .05$) and 2 (mean=449, SE=21, 95%CI= 408-490, $p < .001$). Additionally, RT for digit 2 was significantly quicker than RT for digits 5-8 (mean=513, SE=22, 95%CI=469-558, $p < .01$) (see Figure 6.5). No significant interaction was found between developmental type and RT profile when a commission error occurred $F(7.685, 225.426)=.675$, $p > .05$, see Table 6.4.

Table 6.4 Mean Go-RT scores and 95%CIs across commission error RT profile and between development conditions on the fixed SART

Development	RT Profile	Mean	Std. Error	95% Confidence Interval	
DN	Digit 9	533	37	460	606
	Digit 1	565	37	492	637
	Digit 2	546	34	478	613
	Digit 4	683	35	613	753
	Digits 5-8	561	37	488	634
D	Digit 9	436	42	353	520
	Digit 1	443	42	359	526
	Digit 2	394	39	316	471
	Digit 4	569	40	488	649
	Digits 5-8	483	42	399	566
DAR	Digit 9	381	59	263	499
	Digit 1	471	59	353	589
	Digit 2	366	55	257	476
	Digit 4	602	57	488	716
	Digits 5-8	451	59	333	569
RA	Digit 9	508	36	437	580
	Digit 1	554	36	483	626
	Digit 2	492	33	425	558
	Digit 4	627	35	558	696
	Digits 5-8	561	36	490	633

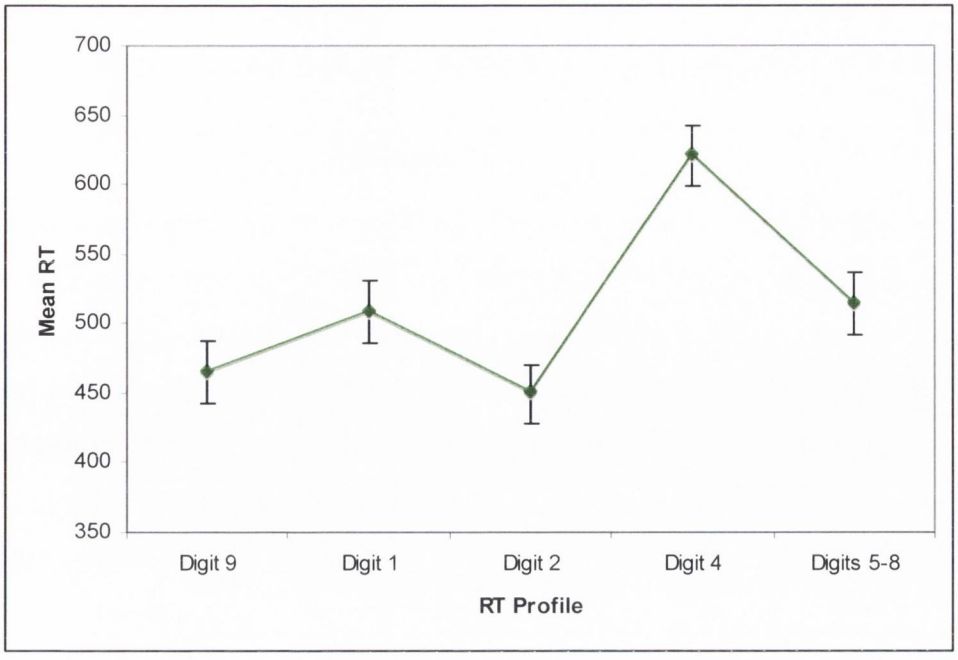

Figure 6.5 Line graph detailing the RT profile across stimuli positions when a commission error occurs on the fixed SART.

Response variability as a predictor of Omission Error

Simple linear regression was carried out to assess the validity of Go-RT-SD as a predictor of omission error variance. For all developmental groups, Go-RT-SD was a significant predictor of omission error: D, β= .025, t(22)=3.017, $p < .01$; DAR, β=.084, t(9)=8.466, $p < .05$; DN, β=.070, t(36)=3.910, $p < .001$; and RA children β=.050, t(30)=2.815, $p < .01$. This indicated that Go-RT-SD was explaining a significant proportion of the omission scores: D, R^2=.26, $F(1,22)$=9,100, $p < .01$; DAR R^2=.42, $F(1,9)$=8.460, $p < .05$; DN R^2=.27, $F(1,36)$=15.285, $p < .001$; and RA children R^2=.18, $F(1,30)$=7.922, $p < .01$.

Response variability as a predictor of Commission Error

The degree of explained commission error variance which Go-RT-SD could account for was assessed across the developmental groups, using simple linear regression. Go-RT-SD significantly predicted commission error for D (β=.022, t(23)=2.967, $p < .01$), DN (β=.033, t(36)=4.27, $p < .001$) and for RA children (β=.039, t(30)=5.307, $p < .001$). Adjusted R squared values for each group were as follows: D, R^2=.245, $F(1,23)$=8.801, $p < .01$; DN, R^2=.318, $F(1,36)$=18.270, $p < .001$; RA, R^2=.467, $F(1,30)$=28.164, $p < .001$. The analysis indicated a non-significant predictive relationship relative to the DAR children β=.029, t(9)=1.860, $p > .05$. However this was likely to be due to the small sample size of this group, as the

suggested proportion of commission error variance explained by Go-RT-SD was very similar to the other groups' adjusted R^2=.197, $F(1,9)$=3.459, $p > .05$.

Discussion

DN children made significantly fewer commission errors than D, DAR and RA children, indicating that they were demonstrating fewer lapses in sustained attention than the other developmental groups. The lack of significant differences between D, DAR and RA children suggests that while dyslexic children make more errors than their chronologically matched cohorts, they perform similarly to their reading age matched cohorts. This suggests that the developmental delay in the ability to sustain attention is no more severe than the delay in literacy ability, but it is one they may potentially may mature out of, given the right circumstances.

Unlike the commission error data, omission error rates did not significantly differ between D and DN groups. It is not surprising that the analysis indicated that DAR children were making significantly more omission errors than DN children given the suggested high risk of ADD or ADHD in these children. DAR children's omission rate was, however, very similar to RA children's error rate. This suggests that while they are experiencing a development delay in the ability to sustain attention relative to age matched cohorts, omission errors do not indicate they experience any additional delay below the ability of their reading age matched cohorts. In line with the previous research it is suggested that omission error may not act as the most sensitive measure of attentional vigilance as, unlike the ICV measure, much of the moment-to-moment fluctuations in sustained attention are not recorded, only those that lead to an error.

The Go-RT-SD data indicated a developmental trend between the experimental groups, with DN children again showing significantly reduced variability relative to the other groups. This decrease in variability likely represents DN children's increased ability to direct attention to task (Manly et al., 2000). While the other three experimental groups didn't significantly differ, the trend again shows D children to be doing comparatively better than the other two, and RA performing somewhat better than DAR children. The considerable similarity between the group's profile on RT-SD and the results discussed above for omission errors further supports the argument that RT variability may act as a more sensitive continuous measure of sustained attention.

In accordance with the Go-RT-SD findings, the analysis of the ICV data also indicated that DN children carried out the fixed SART with significantly less variability than all the other developmental groups. While, no differences in the ICV scores was found between D and RA children, the DAR children were experiencing a significantly more variable response style than their reading age matched cohorts. These findings suggest that DAR children experience an increased ebb and flow in arousal level variance, suggesting an increased demand is placed on top-down executive control in these children (Stuss et al., 2003), above and beyond the demands of their reading age match cohorts. This indicates that DAR children are experiencing an additional delay which is beyond the impaired development of their literacy skills.

In line the suggestion above, the regression analysis indicated that for all groups a significant proportion of omission error was accounted for by RT-SD, however, in the DAR group, RT-SD accounted for 47% of the variance in omission error relative to the other groups: D=25%, DN=27% and RA=18%. In the RA children, the capacity to accurately time motor response with response cue is likely to be slightly less developed than the older developmental groups, as this capacity improves with age (Nicolson & Fawcett, 1994). The lower explained variance in omission error by Go-RT-SD in RA children may relate to a higher degree of variability in RT, which is related to motor timing imprecision. To the same extent the increased explained variance for DAR children would suggest that a higher proportion of their variability is related to lowered executive control rather than motor timing, and hence is more strongly linked to omission errors. The significantly increased variability found in the DAR relative to RA children is consistent with research which found that ADHD children's increased response variability could functionally discriminate their performance from that of their age matched controls (Mullins et al., 2005). This suggests that they are experiencing an additional demand for top-down executive control (Stuss et al., 2003) beyond their low-risk dyslexic cohorts.

Further supportive evidence that the endogenously driven response cue may have affected the individual developmental groups differently according to literacy ability was suggested in the RT data. Only the literacy-impaired children's 95%CI for responses to Go stimuli contained the response cue. However, unlike the D children, the DAR children's SD for Go-RT indicated that a sizeable portion of their responses

were occurring before the onset of response cue, while the DN and RA children's mean intervals were some 50 ms after the cue to response lock. Effectively, the data suggests at least 2 possible scenarios. Firstly, one could argue that the dyslexic children are adhering more stringently to the stipulated task instructions. That is to "keypress" after the digits disappear. Secondly, that the cue to response was simply too early, and that while it constituted a delay in response, for children at this age range, it still incurred a relative speed/accuracy trade off, with the dyslexic and particularly the DAR children taking a more error-prone approach. That is, they were strictly adhering to the response cue, while the DN and RA children were electing a more conservative approach, one that reduces the likelihood of error by delaying keypress response so that more on-task monitoring can occur. As a means of answering this question, it is suggested that the timing of response cue could be delayed further, to somewhere between 500-550ms. This would allow one to ascertain with a higher degree of certainty if these differences are due to deviations in strategy use or if they actually relate to differences in the ability to endogenously response lock.

Interestingly, there is some support for the argument that literacy-impaired children are less able to generate a lasting endogenous response lock. This support comes from the interaction between developmental group and RT profile when a commission error occurs. Given that the RT analysis indicated that while D, DAR and DN children significantly slowed their RTs following a commission error, RA children did not demonstrate such a markedly slowed performance. This may indicate that RA children are less likely to endogenously modify response style following error occurrence. The literacy-impaired children were shown to delay RTs on the next Go-stimulus which immediately followed a commission error to a level which matched DN children. This finding would suggest that while D, DAR and DN children are equally aware that their quicker response speed heightens the likelihood of error occurrence, both D and DAR children are unable to maintain the endogenously set delayed response style in contrast to DN children.

The regression analysis suggested that while there is an association between failure to withhold keypress and Go-RT-SD, the strength of the suggested relationship indicates that it may not be the core factor leading to commission failure on the fixed task, at least for the older children. As the analysis indicated that there was a stronger relationship for the RA children (47%) relative to the other children

D(25%), DAR(20%ns) and DN(32%), there may be a developmental increase or shift in strategy between the younger and older children. In fact, Kontos and Nicholas (1986) found that there was a significant increase in meta-cognition and strategy use as children got older. That is the D, DAR and DN children are more likely to monitor their position within the fixed nine-item cycle, as a pre-emptive cue to withhold keypress before the presentation of the No-go target, than the RA children. Thus, due to their more efficient use of strategy, the older children are less dependent on the moment-to-moment fluctuations in executive control than the RA children, explaining their higher explained variance due to RT-SD (Dockree et al., 2005).

Summary

The commission error data indicated that while D and DAR children were making the same number of errors as RA children, they were significantly more error prone than DN children. This indicates that the literacy-impaired children are experiencing a delay in development relative to the normative increases that literacy-unimpaired children experience in sustained attention ability. Interestingly, the ICV data indicated that the responses of DAR children were significantly more variable than those of RA children, indicating that RA children were having to exert a greater degree of top-down executive control than the RA children to maintain these performance levels (Stuss et al., 2003). Similarly, while D children showed increased individual variation relative to DN children, the data support the position that even with increasing levels of top-down control, they were making more commission errors than DN cohorts. However, both D children's ICV and commission error did not differ from RA children. This suggests that the delay in sustained attention is comparable to that experienced in relation to literacy development.

Experiment 6.2- Random SART- Results

Grouping Variables

Participants with omission errors greater than 2 standard deviations (SD) above the mean were removed from all future analyses as these participants are likely to disproportionately skew test results. In this way the DN sample dropped from 38 to 37, the DAR group dropped from 13 to 11, and the RA dropped from 35-31, while the D group stayed the same with 26 children.

Commission and Omission Errors

A one-way ANOVA was carried out on the commission error data between developmental groups. There was a significant main effect for commission error between developmental groups $F(3,101)=7.760$, $p < .001$. Bonferroni comparisons indicated that DN (mean=5.11, SD=4.42, 95%CI=3.64-6.58) children had significantly less commission errors than D (mean=9.92, SD=5.62, 95%CI=7.65-12.19, $p < .001$), DAR (mean=11.64, SD=5.22, 95%CI=8.13-15.14, $p < .001$), and RA (mean=8.32, SD=4.61, 95%CI=6.63-10.02, $p < .05$) children, with none of the other groups significantly differing.

Another one-way ANOVA was carried out on the omission error data. The analysis found significant group differences in omission error $F(3, 101)=4.175$, $p < .05$, with Bonferroni comparisons indicating that DN (mean=4.43, SD=5.50, 95%CI=2.60-6.26) children were making significantly fewer omission errors than RA (mean=9.03, SD=6.19, 95%CI=6.76-11.30, $p = .001$) children, with neither D (mean=7.73, SD=6.15, 95%CI=5.25-10.21) children or DAR (mean=9.73, SD=7.53, 95%CI=4.67-14.78) children significantly differing from either group.

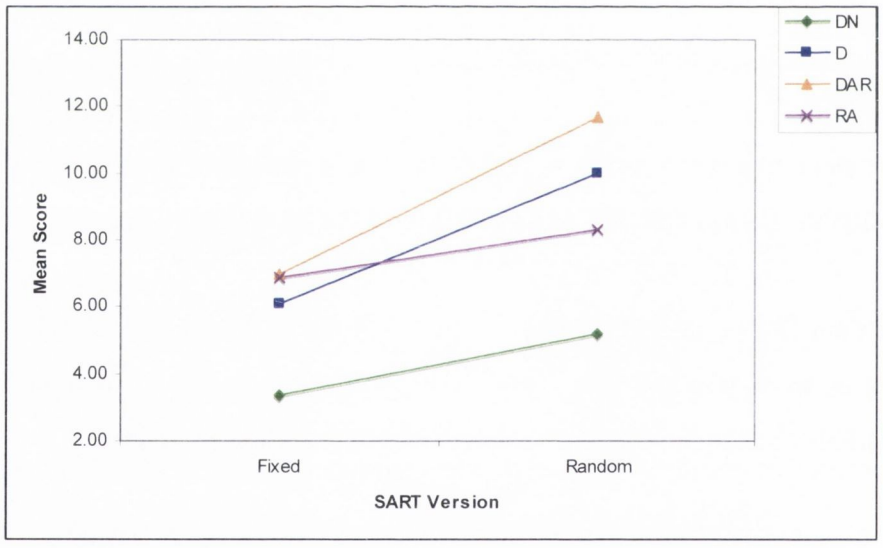

Figure 6.6 Line graph of the interaction between SART presentation versions and developmental groups with commission error as the dependent measure

A repeated measures ANOVA was carried out across fixed and random commission errors between developmental groups. Significant main effects were suggested in respect to development $F(3,100)=9.728$, $p < .001$, which was due to DN children (mean=4.20, SE=.583, 95%CI=3.04-5.37) making significantly less commission errors than D (mean=7.98, SE=.695, 95%CI=6.60-9.37, $p < .001$), DAR

(mean=9.27, SE=1.069, 95%CI=7.14-11.40, $p < .001$) and RA children (mean=7.53, SE=.647, 95%CI=6.25-8.82, $p < .001$) across tests. Children were also experiencing significantly more commission errors $F(1,100)=41.904$, $p < .001$, on the random SART (mean=8.73, SE=.533, 95%CI=7.68-9.72) than on the fixed (mean=5.76, SE=.345, 95%CI=5.08-6.45) version. The analysis also suggested a significant interaction between test version and developmental group $F(3,100)=2.885$, $p < .05$, as Figure 6.6 highlights while all developmental groups experienced a slight increase in commission error on the random relative to the fixed tests, DAR children demonstrated a much greater increase in commission error, given that while DAR and RA children preformed similarly on the fixed version of the SART, DAR children had significantly more commission errors on the random version of the SART than RA children (see Table 6.5).

Table 6.5 Commission error mean scores, standard error and 95%CI across SART version and developmental group

Development	SART Version	Mean	Std. Error	95% Confidence Interval	
DN	Fixed	3.30	0.520	2.26	4.33
	Random	5.11	0.805	3.51	6.71
D	Fixed	6.04	0.621	4.81	7.27
	Random	9.92	0.961	8.02	11.83
DAR	Fixed	6.91	0.955	5.02	8.80
	Random	11.64	1.477	8.71	14.57
RA	Fixed	6.80	0.578	5.65	7.95
	Random	8.27	0.894	6.49	10.04

When omission errors were assessed across SART presentation versions and developmental groups, the analysis indicated that children made significantly more omission errors $F(1,103)=6.853$, $p = .01$, on the fixed version (mean=9.69, SE=.786, 95%CI=9.12-11.24) than the random version (mean=7.71, SE=.666, 95%CI=6.39-9.04). Significant differences were also indicated between developmental groups $F(3, 103)=5.944$, $p = .001$, with DN children (mean=4.97, SE=.943, 95%CI=3.102-6.84) experiencing significantly lower omission errors than both DAR (mean=11.46, SE=1.730, 95%CI=8.02-14.89, $p < .01$) and RA children (mean=9.93, SE=1.047, 95%CI=7.86-12.04, $p < .01$). While D children (mean=8.423, 95%CI=5.414-11.132) did not significantly differ from any other group. No meaningful interaction was indicated between test version and development $F(3, 100)=.366$, $p > .05$, see Table 6.6.

Table 6.6 Omission error mean scores, standard error and 95%CI across SART version and developmental group

Development	SART Version	Mean	Std. Error	95% Confidence Interval	
DN	Fixed	5.51	1.186	3.16	7.87
	Random	4.43	1.006	2.44	6.43
D	Fixed	9.12	1.415	6.31	11.92
	Random	7.73	1.200	5.35	10.11
DAR	Fixed	13.18	2.176	8.86	17.50
	Random	9.73	1.845	6.07	13.39
RA	Fixed	10.90	1.318	8.29	13.51
	Random	8.97	1.117	6.75	11.18

Response Times and Variability

A one-way ANOVA was carried out on Go-RT between the developmental groups, the analysis indicated significant differences in RT $F(3, 101)=8.159$ $p < .001$), with pairwise comparisons indicating that both groups of the literacy impaired children D (mean=510ms SD=116, 95%CI=462-557) and DAR (mean=476ms, SD=108, 95%CI=404-550) had significantly quicker RTs than both groups of literacy unimpaired children, DN (mean=641ms, SD=156, 95%CI=589-693, $p = .001$ and $p < .005$ respectively) and RA (mean=601ms, SD=101, 95%CI=563-638, $p < .05$ and $p < .05$ respectively).

One-way ANOVA indicated no significant differences between developmental groups in respect to commission error RT $F(3, 95)=.931$, $p > .05$, as RTs for DN (mean=512ms, SD=206, 95%CI=437-588), D (mean=468ms, SD=136, 95%CI=413-523), DAR (mean=436ms, SD=125, 95%CI=352-521) and RA (mean=508ms, SD=126, 95%CI=462-554) children were largely similar.

A one-way ANOVA was carried out on Go-RT-SD between developmental groups, the analysis of RT variability indicated a significant main effect $F(3, 101)=4.377$, $p < .01$. Pairwise comparisons indicated that only DN (mean=171ms, SD=50, 95%CI=154-188) children had significantly lower variability than RA (mean=216ms, SD=45, 95%CI=200-233, $p < .001$) children, while both D (mean=199ms, SD=59, 95%CI=175-223) and DAR (mean=200ms, SD=64, 95%CI=158-243) children did not significantly differ from any of the groups.

A one-way ANOVA of ICV (Go-RT-SD/Go-RT) data across developmental groups demonstrated a highly significant main effect between groups $F(3, 101)=12.733$, $p < .001$. Pairwise comparisons indicated that the DN (mean=.2761, SD=.091, 95%CI=.249-303) children were significantly less variable than the D

(mean=.394, SD=.097, 95%CI=.355-.432, $p < .001$), DAR (mean=.419, SD=.108, 95%CI=.346-491, $p < .001$) and RA (mean=.368, SD=.090, 95%CI=.335-.00, $p < .001$) children, with none of the other groups significantly differing from one another.

Variability across the modified fixed and random SART versions was assessed on the ICV measures with a repeated measures analysis between developmental groups (DN n=37, D n=26, DAR n=11, RA n=30). The analysis indicated that children were significantly less variable $F(1, 100)=72.965$, $p < .001$, on the random SART version (mean=.364, SE=.010, 95%CI=.344-.384) than the fixed version (mean=.491, SE=.017, 95%CI=.458-.525). Significant differences were also indicated between developmental groups $F(3,103)=14.893$, $p < .001$), with Bonferroni comparisons indicating that DN children (mean=.317, SE=.018, 95%CI=.282-352) were significantly less variable than D (mean=.450, SE=.021, 95%CI=.408-.491, $p = .001$), DAR (mean=.532, SE=.032, 95%CI=.467-.596, $p < .001$), and RA children (mean=.412, SE=.202, 95%CI=.373-451, $p < .001$). Additionally, RA children were found to be significantly less variable than DAR children ($p < .05$), with no other significant differences being found between groups. Interestingly, a significant interaction between development and test version was also suggested $F(3,100)=3.347$, $p < .05$. As highlighted in Figure 6.7, though all children were demonstrating a significantly lowered variability on the random SART version, DAR children showed an additional drop in variability such that, in contrast to the fixed version, their ICV scores no longer significantly differed from those of RA children (see Table 6.7).

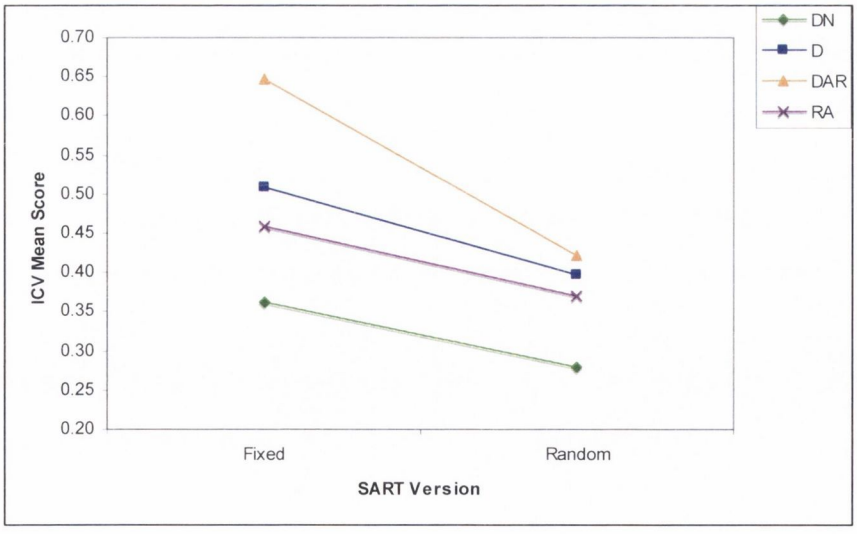

Figure 6.7 Line graph depicting the interaction across SART versions between developmental groups with ICV as the dependent measure.

Table 6.7 ICV mean scores, standard error and 95%CI across SART version and between developmental groups.

Development	SART Version	Mean	Std. Error	95% Confidence Interval	
DN	Fixed	0.36	0.026	0.31	0.41
	Random	0.28	0.015	0.25	0.31
D	Fixed	0.51	0.030	0.45	0.57
	Random	0.39	0.018	0.36	0.43
DAR	Fixed	0.64	0.047	0.55	0.74
	Random	0.42	0.027	0.36	0.47
RA	Fixed	0.46	0.028	0.40	0.51
	Random	0.37	0.017	0.33	0.40

RT Profile on Correct Withholds and Commission errors

A repeated measures analysis was carried out on the RT profile on Go-targets leading up to a correct withhold for Go-target stimuli 2 before, 1 before, 1 after and 2 positions after a correct withhold, with development (DN n=37, D n=26, DAR n=11, RA n=31) as a between subjects factor. Significant differences were suggested between developmental groups $F(3, 101)=7.288$, $p < .001$, indicating that D (mean=521ms, SE=21, 95%CI=467-574) children were responding significantly more quickly overall than were DN (mean=647ms, SE=23, 95%CI=602-691, $p < .01$) and RA (mean=614ms, SE=25, 95%CI=565-663, $p < .05$) children. Additionally, DAR (mean=472ms, SE=41, 95%CI=390-554) children were found to be responding significantly more quickly than both DN ($p < .005$) and RA children ($p < .05$), with no other significant differences existing between groups. Significant main effects were again found across RT profile $F(2.689, 279.699)= 45.510$, $p < .001$. Bonferroni comparisons indicated the familiar trend of a significantly slowed RT before a correct withhold followed by a speeded-up RT immediately afterwards was found. That is, RTs for stimuli immediately following a correct withhold (mean=494ms, SE=17, 95%CI=461-529) were significantly quicker than RTs for all other positions i.e. for stimuli 2 positions before (mean=590ms, SE=15, 95%CI=561-621, $p < .001$), stimuli 2 positions after (mean=564ms, SE=17, 95%CI=531-597, $p < .05$), and stimuli immediately preceding a correct withhold (mean=604ms, SE=15, 95%CI=574-635, $p < .001$). In addition stimuli immediately preceding a correct withhold were significantly slower than stimuli 2 positions afterwards ($p < .001$). A significant interaction between RT profile and development type was found $F(7.868, 264.878)=2.362$, $p < .05$, as highlighted in Figure 6.8 DN children were not showing

a significantly faster RT with the shift from Go-target stimuli positions immediately before to immediately after a correct withhold, in contrast to the other developmental groups which all demonstrated a significant decrease in RT on Go-targets immediately after a correct withhold relative to stimuli immediately before a correct withhold, see Table 6.8.

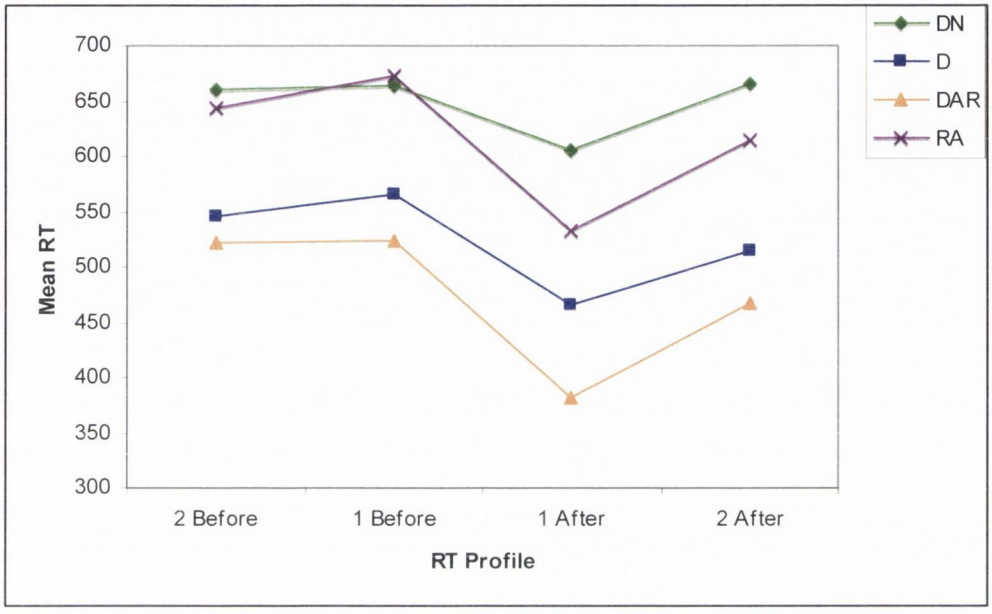

Figure 6.8 Interaction between developmental groups and RT profile when a correct withhold occurs, on the random version of the SART

Table 6.8 RT mean scores, standard errors and 95%CI across RT profile and between development conditions when a correct withhold occurs on the random SART version

Development	RT Profile	Mean	Std. Error	95% Confidence Interval	
DN	2 Before	657	23	612	703
	1 Before	662	23	616	708
	1 After	604	26	552	655
	2 After	663	25	613	713
D	2 Before	544	27	489	598
	1 Before	563	28	508	619
	1 After	464	31	402	525
	2 After	513	30	453	574
DAR	2 Before	520	42	436	603
	1 Before	522	43	437	607
	1 After	380	48	286	475
	2 After	466	47	374	559
RA	2 Before	642	25	593	692
	1 Before	670	25	620	721
	1 After	530	28	474	587
	2 After	613	28	558	668

A repeated measures ANOVA was carried out across RT profile positions when a commission error occurs, between developmental groups (DN n=28, D n=25,

DAR n=11, RA n=31). A significant main effect was indicated between developmental groups $F(3, 91)=3.571$, $p < .05$, however pairwise comparisons indicated that none of the DN (mean=596ms, SE=29, 95%CI=539-654), D (mean=491ms, SE=30, 95%CI=430-551) DAR (mean=489ms, SE=45 95%CI=399-581) or RA (mean=594ms SE=27, 95%CI=541-649) children significantly differed from any of the other groups. Significant differences in RT were indicated across the RT profile positions $F(2.546, 231.668)=10.585$, $p < .001$, Bonferroni-adjusted means indicated that RTs for stimuli 1 position before a commission error (mean=494ms, SE=18, 95% CI=438-530) were significantly quicker than for stimuli 2 positions before (mean=544, SE=20, 95%CI=504-584, $p < .005$), 1 after (mean=574ms, SE=19, 95%CI=536-612, $p < .001$) and 2 after (mean=558ms, SE=19, 95%CI=529-597, $p = .001$). For stimuli immediately following a commission error a trend of slowing RTs was indicated, however this trend was not significant nor were there any other significant differences between stimuli positions, see Figure 6.9. There was no significant interaction found between RT profile and developmental group, $F(7.637, 231.668)=1.137$, $p > .05$, see Table 6.9.

Table 6.9 RT mean scores, standard error and 95%CI across RT profile and development conditions for when a commission error occurs on the random SART version

Development	RT Profile	Mean	Std. Error	95% Confidence Interval	
DN	2 Before	587	34	519	655
	1 Before	548	31	487	610
	1 After	631	33	567	696
	2 After	619	33	553	684
D	2 Before	497	36	425	569
	1 Before	457	33	392	522
	1 After	519	34	451	588
	2 After	489	35	420	558
DAR	2 Before	514	55	406	623
	1 Before	453	49	356	551
	1 After	496	52	393	599
	2 After	495	53	391	599
RA	2 Before	579	33	514	643
	1 Before	519	29	461	577
	1 After	651	31	589	712
	2 After	631	31	569	693

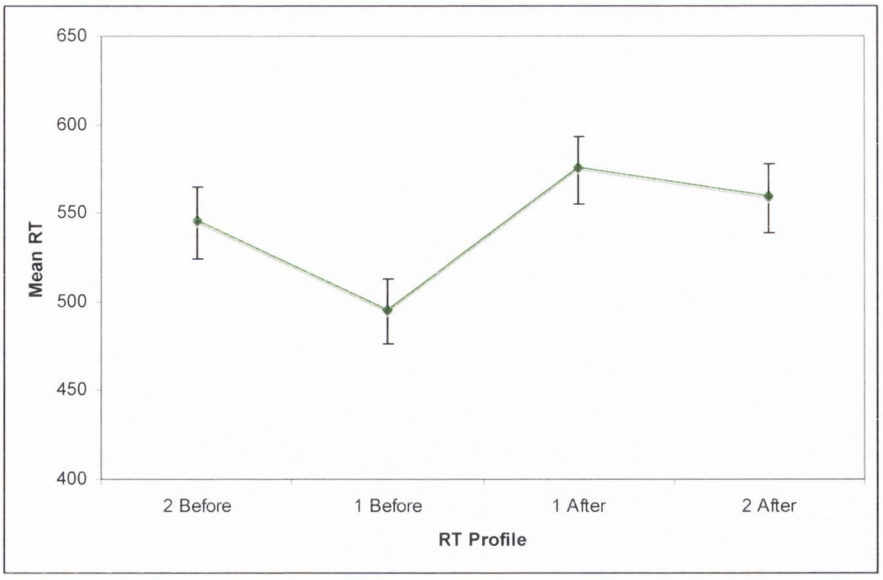

Figure 6.9 Line graph depicting the RT profile when a commission error occurs on a No-go stimuli, for the random SART version.

Response variability as a predictor of Omission Error

Simple linear regression was used to assess the predictive power between Go-RT-SD and omission error across the individual developmental groups. Go-RT-SD significantly predicted omission errors for DN children (β=.047, t(2.799), $p < .01$), D (β=.064, t(24)=3.887, $p = .001$), DAR (β=.084, t(9)=2.915, $p < .05$) and RA children (β=.064, t(29)=2.855, $p < .01$). This indicates that a significant proportion of the omission error variance was explained by Go-RT-SD. The adjusted R squared for each group was as follows: for DN children: R^2=160, $F(1,35)$=7.836, $p < .01$, D children: R^2=.361, $F(1,24)$=15.109, $p = .001$, DAR children: R^2=.428, $F(1,9)$=8.495, $p < .05$ and RA children: R^2=.193, $F(1,29)$=8.153, $p < .01$.

Response variability as a predictor of Commission Error

In the random version of the SART task there seems to be a disassociation between response variability and commission error as simple linear regression indicated that Go-RT-SD did not significantly predict commission error for any of the groups: DN, β=.020, t(35)=1.418, $p > .05$; D, β=.006, t(24)=.301, $p > .05$; DAR, β=.030, t(9)=1.524, $p > .05$ and RA children, β=.029, t(29)=1.595, $p > .05$, with Go-RT-SD accounting for no significant variance in commission errors. Adjusted R squared for each group are as follows: for DN children R^2=.027, $F(1,35)$=2.011, $p > .05$; D R^2=-.038, $F(1,24)$=.090, $p > .05$; DAR R^2=.117, $F(1,9)$=2.322, $p > .05$ and RA children R^2=.049, $F(1,29)$=2.545.

Relationship between Commission Errors across SART versions

Commission error on the fixed test was entered as a predictor of commission error on the random test. Fixed error was a significant predictor of random commission error for both D (β=1.093, t(23)=1.337, p = .005, adjusted R^2=.266, F(1,23)=9.705, p = .005) and RA children (β=.728, t(28)=3.650, p = .001, adjusted R^2=.298, F(1,28)=13.323, p = .001). However, for both the DN and DAR children fixed commission errors did not significantly predict random commission error: DN, β=.452, t(31)=1.027, p > .05, adjusted R^2=.002, F(1,31)=1.056, p > .05, and DAR, β=.305, t(7)=.568, p > .051, adjusted R^2=-.092, F(1,7)=.323, p > .05.

Discussion

The lowered commission errors of the DN children again indicated that they were demonstrating a developmental increase in ability relative to the other children, indicating greater inhibitory control in the DN children. This is in keeping with research which has shown both inhibitory response and the ability to sustain attention continue to show a maturational increase in capacity well into adolescence and early adulthood (Klenberg, Korkman, & Lahti-Nuuttila, 2001; Lin, Hsiao, & Chen, 1999). In line with this argument, recent research has found that the largest improvements in response inhibition and vigilance occur between the ages of 8 and 10 years of age (Klimkeit, Mattingley, Sheppard, Farrow, & Bradshaw, 2004). Omission errors suggested that DN children were again performing with fewer errors than RA children, with neither D nor DAR children differing from any of the other groups. However, it is important to note that DAR children actually had a higher mean error rate than their RA cohorts, so this lack of significant differences, rather than suggesting similar performance between DN and DAR children, likely relates to DAR children's higher variability due to the smaller sample size in this group.

It was argued earlier that omission error may act as a relatively crude measure of executive functioning, one that requires a breach in performance thresholds before an error can be recorded and that response variability may act as a far more sensitive measure of executive control. Regression analysis offered further support for the suggested relationship between response variability and errors of omission. The analysis of intra-individual variability suggested that, in line with the commission error findings, DN children were significantly less variable than all other groups. Bellgrove et al (2004) found that intra-individual variability was strongly associated

with increased frontal lobe activation, which Stuss et al, (2003) suggested was likely to reflect a disruption within the mechanisms of top-down control. The increased variability on the part of RA children relative to the DN children would suggest that this disruption or lack of efficiency in top-down control can be maturational in origin. The similarity in ICV between RA and literacy-impaired children in Experiment 6.2 might suggest that their impairment likewise is developmental in origin. However, as both Dyslexia and ADHD are seen as life-long disorders, coupled with the existing research linking dyslexia with continued increased frequency of attentional slips (Smith-Spark et al., 2004), it is unlikely to be one they will ever fully grow out of.

The significant interaction between SART presentation version and developmental group in respect to commission errors suggests that the literacy-impaired children were demonstrating an additional impairment in inhibiting prepotent response presses when the order of presentation was random. However, this increase may actually relate to the quicker response style demonstrated in these children. In Logan et al.'s (1994) terminology, rather than constituting a deficit in inhibitory control in respect to the literacy unimpaired children, the response style of literacy-impaired children may simply constitute a relay "race" in which response press is simply given too much of a head start, which even an equivalently trained inhibitory control mechanism is unlikely to successfully "catch-up" with. This hypothesis of course would need to be assessed further, perhaps by modifying presentation time of response lock, before any firm conclusions can be drawn.

Interestingly, while the number of commission errors increased on the random version of the SART relative to the fixed version, omission errors demonstrated the opposite profile, being significantly lower on the random version. Intuitively this makes relative sense as, given the increased processing demands in the random version, children most likely don't have to work quite so hard to sustain attention. That is, as the presentation of No-go stimuli is unpredictable, children are required to process all stimuli and as such are less likely to fall into the same rhythm of inattentive responses as the fixed SART. Additionally, the unpredictable presentation of No-go stimuli is likely to act to a greater effect as an exogenous cue to re-engage attention in the random version. Further support for the position that children were not finding it as difficult to sustain attention on the random SART comes from the ICV data, which suggested that all the developmental groups were experiencing a reduction on the random SART in terms of response variability. Secondly, the

analysis also indicated a significant interaction between SART presentation type and development. Of note is the additionally improved performance on the part of the DAR children who, in contrast to Experiment 6.1, were no longer demonstrating a significantly impaired performance relative to the RA children. This suggests that, in line with Manly et al.'s (2003) findings with TBI patients, the apparent reduction in difficulty or challenge in the fixed version of the SART actually enhanced discriminative ability between TBI and control participants. In the current round of experiments, we found a similarly impaired performance in DAR children.

Once again the RT profile for responses connected to a correct withhold indicated a slowing of RT before No-go targets, indicating effective response monitoring due to the anticipation of No-go target presentation. Unusually, the significant interaction between RT profile and developmental group suggested that DN children were not demonstrating a significantly faster keypress on stimulus items immediately following a correct withhold in contrast to the other developmental groups. Robertson et al. (1997), looking at TBI patients, found that unlike age matched controls the TBI patients did not show a RT change in reaction to either a correct withhold or commission error. Unlike Robertson et al.'s findings, the profile plots between groups (Figure 6.8) are largely similar.

Shallice et al. (2002) found that ADHD children's RT slowed down significantly less after a commission error than their matched controls, which, he argued, demonstrated that while ADHD children undoubtedly adapt to error, their reaction to error detection is less developed. In contrast to Shallice's findings, there were no significant interactions between developmental groups and RT profile when a commission error occurred. Instead all groups were demonstrating a significantly quicker RT immediately preceding commission error, with a slowed RT immediately afterwards. As the interaction between RT profile and developmental groups was identified on correctly withheld stimuli trials, and given that RT profile was similar between groups when commission errors did occur, it seems somewhat puzzling that DN children should react differently. Previous research suggested that RT speeds up preceding a commission error (Robertson et al., 1997), which is suggested to imply a lowering of executive control. While all groups show a temporary relaxing of vigilance immediately following a correct withhold, the lack of a significant difference between stimuli immediately following a correct withhold and those stimuli which immediately precede a correct withhold might suggest that DN children

are simply able to maintain a constant level of vigilance, one that does not require temporary breaks in which to re-exert executive control after a relatively successful completion of task requirements.

In opposition to the existing body of research (Bellgrove et al., 2004; Fassbender et al., 2004; Manly et al., 2000; Mullins et al., 2005), the regression analysis suggested that none of the developmental groups demonstrated a significant relationship between Go-RT-SD and commission error, implying that in this version of the random SART response variability is largely unrelated to response inhibition. There are a couple of possible explanations for this finding. Firstly, it is suggested that due to the lack of visual noise in the study, coupled with the slower RT across groups, this response style allows No-go targets to act more efficiently as exogeneous inhibitory cues even if sustained attention is somewhat reduced. Thus, even with a lower state of awareness the visually clean presentation of a No-go targets may be sufficient to re-engage attention and initiate a successful inhibitory response. A second suggestion is that given the random placement of No-go targets, participants simply elect to allocate more attentional resources to readiness for response inhibition. That is, they place a higher emphasis on the withholding response, rather than the accurate keypress element of this task. However, if participants were trying to maintain a stance of prepared response inhibition, this would likely have elevated response variability due to top-down control (Stuss et al., 2003), which was not the case given the reduction in response variability in Experiment 6.2 relative to 6.1. It is suggested that in this version of the SART, given the uncluttered presentation style, commission errors are not as closely dependent on maintained vigilance as in previous versions. Instead, commission error is likely to primarily relate to inhibitory dysfunction. Further research is needed to answer this question decisively. This would likely involve secondary physiological or anatomical measurements of executive control.

In line with the argument above, fixed commission errors were found to explain a significant proportion of random commission error variance in both the D (27%) and RA (30%) children. No significant relationship was suggested between these variables in the DN children. This suggests that at least in the DN children there is some evidence of a separation in function between sustaining attention and response inhibition relative to the random SART. Shallice et al. (2002), in line with Kontos and Nicholas' (1986) findings of maturational increase in strategy use, found

that ADHD children were impaired relative to age matched cohorts not only in strategy production but in its application as well. It is advocated that the split in relationship between commission errors across tests is due to the fact that, unlike the RA and D children, DN children may apply meta-cognitive and strategy use during the fixed SART. As such, their inhibitory control is never really challenged by the fixed version of the SART, as the application of strategy and conscious keypress suppression circumvents the need for inhibition. It is suggested that like Shallice et al's ADHD children, D and RA children may simply be less efficient in their maintenance of meta-cognitive strategy. On the fixed SART measures, they may be more prone to drift in and out of within task monitoring while nonetheless maintaining adequate levels of sustained attention. Thus, even on the fixed SART, there is an occasional need for genuine inhibition of the prepotent response to an "unexpected" No-go stimuli, as these children may simply have lost track of their position with in the cyclical progression. It is likely that the lack of significant effects in the DAR children between fixed and random versions rather than relating to the relatively small sample size in this group, relates to their fundamentally improved performance on the random version over their ability to sustain attention on the fixed as indicated by the ICV analysis between tests. The answers to the questions raised by these findings will need to be assessed with larger group sizes in the future, before any clear inferences are drawn from the findings however.

General Discussion

The similarity between D and RA children on fixed and random ICV measures, and their higher variability in respect to the DN children, is a strong indication that the increased variability in respect to age for the D children may constitute a developmental delay, rather than a strict deficit, at least at this stage of development. In contrast, DAR children, in line with their additionally impaired performance on the fixed version of the SART, may be experiencing an additional developmental deficit beyond that related to their literacy impairment given they are demonstrating impaired functioning relative even to the RA children's performance levels. However, on the random SART, DAR children's ICV performance was highly similar to RA children's, suggesting that additional difficulty in sustaining attention is only demonstrated on tasks that are particularly unchallenging for these children. As D children did not demonstrate increased ICV scores on the fixed SART, these

findings may have particular relevance as to the effectiveness of remedial intervention for D and DAR children. Unsurprisingly, given their heightened risk of ADHD/ADD the DAR children will experience greater difficulties in remaining attentive unless they are suitably challenged by the task, however even on challenging tasks both the high and low-risk children will experience increased difficulty in sustaining attention relative to their age matched cohorts. This may suggest that remedial intervention would work best if instruction was given in short, frequent bursts, rather than prolonged remedial classes.

The D children in this age range were not experiencing additional developmental delays in their capacity to sustain attention beyond their delay in literacy ability. However, it seems doubtful that they will experience the same maturational increase in inhibitory control and vigilance as their reading age matched cohorts given the existing research, which demonstrates continued attentional deficit in adult dyslexics (Smith-Spark et al., 2004). The maturational increase in sustained attention and inhibitory control in these children requires further investigation, perhaps through the use of longitudinal studies.

Across the two separate SART versions, there has been a consistent relationship between omission error and Go-RT-SD, indicating that at least part of inter-item variability is due to our attention to task. Overall, the D children have demonstrated a stronger suggested relationship between Go-RT-SD and omission errors across tests and versions than DN children, which is likely due to an increased proportion of D children's response variability originating in fluctuations in sustained attention, rather than motor response timing precision. This explains why there is a closer link between the response variability and the registered breaks in attention in the form of omission errors in dyslexic children.

In the introduction it was proposed that the particular visual schematic of Bellgrove et al.'s (2004) response locked version of the SART may have constituted an unequally challenging paradigm for the dyslexic children. The findings of the above experiments would suggest that this proposal can be largely rejected. In the current studies version of the SART, children were required to identify stimuli every 1438ms. Existing research has suggested that both RA and D children would have demonstrated a similarly impaired performance if AB was affecting their capacity to perform the task relative to DN children (Visser et al., 2004). In Experiments 6.1 and 6.2, the D children did not demonstrate a significantly different performance relative

to DN children in terms of omission errors and Go-RT-SD (in experiment 2.4), while the RA children showed a significant impairment relative to DN children on these measures. It is highly unlikely that the differences in performance ability between D and DN can be attributed to differences in AB. The strong claim that differences in AB do not exist between D and DN children cannot be supported in the current research project, as the lack of effects between groups may possibly relate to the lack of storage demands required in the task (Isaak, Shapiro, & Martin, 1999). However, it is suggested that in tasks of this nature, differences in the ability to temporally orientate attention did not significantly affect performance levels.

In the fixed and random SART, an identical positional RT profile was found when a commission error occurred; namely, the speeding of RT prior to an error and a dramatically slowed response immediately after. This commission error RT profile was consistent across all the development groups, indicating that they were reacting similarly to task demands. On the random SART there was a consistent positional RT profile relating to when a No-go target was correctly withheld. That is, a slowed response prior to the No-go target was followed by a quicker response immediately after, which reversed the profile found on commission error RTs. Looking at the positional RT profile on the fixed version of the SART, we find that while an overall speeding up of RT prior to correct withhold, RTs are actually found to speed up further following a correct withhold. This deviates from the profile found in previous response locked research we carried out (Allman, 2007), which found that RTs return to baseline levels for stimuli immediately after a correct withhold on the Fixed SART. The change in RT profile is likely to be due to the extra demands of an endogenous driven response lock, as children lacking an externally driven cue to response simply respond as soon as they perceive they have successfully withheld the response long enough to avoid commission error.

The lack of meaningful interactions between developmental type and RT profiles for either commission errors, CWs or omission errors across SART assessments strongly supports the argument that dyslexic children were performing the SART task similarly to their chronological and reading age matched cohorts, albeit a more error prone performance in comparison to DN children. As such there is little evidence to support Moores and Andrade's (2000) hypothesis that dyslexic children failed to reach a state of automatic performance in the task. The same profile of speeding up in RT before a commission error, or directly after a CW was

consistently found in all groups. Likewise a slowing down in RT before a correct withhold or directly after a commission error indicated that all groups were reacting to success or failure in much the same way. What is suggested instead from the present study's findings is that the differences in ability simply relate to sustained attention and inhibitory function.

The question as to why the dyslexic groups consistently responded more quickly on this version of response lock than either the DN or RA children is somewhat unresolved. One possibility is that the present version just didn't work as a response lock. However, if one compares the Go-RT-SD data from a previous study (Allman, 2007) which used Bellgrove et al's (2005) response locked version of the SART with Experiment 6.1's version of response lock, we find that Go-RT-SD is largely similar between fixed SART versions: ±195ms and ±243ms for DN and D children in Allman's (2007) study and ±179ms and ±236ms for Experiment 6.1. This would suggest that if anything there was a slight though non-significant decrease in response variability with the response lock version of the SART used in the current study. Looking at the random SART data from Allman's (2007) study, the mean SD between groups is ±173ms and ±221ms for DN and D children respectively while using Experiment 6.2's version, we find ±171ms and ±202ms respectively. As variability did not significantly differ between response lock versions on either the fixed or random tests, this would suggest that both versions were acting equally well as response locks. The second suggestion is to argue that somehow the developmental groups have interpreted the task instructions differently, and in this way are response locking to different points in the task. However, as all groups were given identical instructions (i.e. *"You are going to see numbers flash up on the screen, what you have to do is wait for each number to disappear, and then click on the mouse. You have to click after every number except if the number is a 3. So if you see the number 3, don't click"),* this suggestion seems unlikely.

While the differences in RT were highly consistent across individual item profiles, it is unlikely that the literacy-impaired children simply took a different point at which to response lock relative to the literacy unimpaired children. Instead, it is suggested that DN and RA children were able to set and maintain an endogenously driven response lock which decreased the likelihood of error. In contrast the literacy-impaired children seem to lack this capacity to "maintain" an endogenously driven response locked temporal key press. This position is supported by the significant

interaction between commission error RT profile and developmental groups. This indicated that, while both D and DAR children slowed their RTs to a level equivalent to that of DN children, all groups were equally aware that quicker RTs increased the risk of response error, but the literacy-impaired children were simply not able to maintain slower RTs.

Summary

Overall, it is suggested that dyslexic children do suffer from a deficit in sustained attention relative to their aged matched cohorts. Commission error performance on the random SART would support the position held in existing research that dyslexic children also suffer from a secondary deficit in inhibitory control (Reiter et al., 2005; van der Schoot et al., 2000). It is tentatively argued that dyslexic children may also experience a developmental delay in the maintenance of meta-cognitive strategy, in line with findings that suggested ADHD children experience a similar delay (Shallice et al., 2002). Due to the similarities in response profiles across tests, it is argued that there is little evidence for a task automatisation deficit in dyslexic children (Nicolson & Fawcett, 1990), at least in respect to the SART methodology. Instead, it is advocated that dyslexic children's performance, like that of their developmentally normal chronological and reading age matched cohorts, is primarily related to the core abilities of sustaining attention and inhibitory response.

Chapter 8

General Discussion

Across the six experimental chapters, dyslexic children's capacity to orientate, focus and sustain attention within the visual domain was examined, as well as their ability to encode, retrieve and learn spatial, visual and visuospatial information. A new model of dyslexia will first be tentatively proposed. Than we shall turn to the findings that relate to attentional capacity, before turning to the implications for WM. Avenues for future research will then be considered in conjunction with the limitations of the present study. Finally, some general conclusions will be offered, drawing together the connective threads that pervade the research as a whole.

Yet another hypothesis for dyslexia?

The previous six experimental chapters have offered evidence that dyslexic children demonstrate impaired performance in sustaining attention, spatial focus, visual, spatial and VSWM tasks, relative to age-matched developmentally normal children. However, while differences in performance were found between developmental groups, it must be acknowledged that there were always dyslexic children whose individual performance on individual test measures was better than the average DN child. Likewise, there were literacy-unimpaired children whose individual performance on individual test measures was below the average dyslexic child. This is simply to highlight that while the average dyslexic may have difficulties with performing all manner of tasks, individual dyslexic children may show no impairment or even an enhanced ability relative to the average child.

In the general introduction, a modified version of the cerebellar/automaticity hypothesis was suggested. This argued that, while it is likely dyslexic individuals will present with additional difficulties in reaching automatised skill levels in other tasks outside the domain of literacy, it is highly unlikely any individual will demonstrate an impairment in automatising all tasks.

The cerebellar theory of dyslexia (Nicolson et al., 2001) argues that dyslexic individuals will experience difficulties developing any skill, particularly in developing skills to the level of automaticity. Tønnessen (1997) remarked that when using any definition or working hypothesis of dyslexia, we should ask the question: is

this a meaningful distinction to make and does it have value? Coltheart and Jackson (1998) in the discussion of proximal versus distal causes of dyslexia suggested that we must move away from definitions of exclusion. It is suggested here that the blanket requirement that all dyslexic individuals will demonstrate an automaticity deficit in all tasks, is in and of itself an exclusionary definition and one that is not really helpful for our understanding of dyslexia, as it poses the question of classification in the form of *"is this child 'dyslexic enough' to be considered dyslexic?"*

In the course of reviewing the literature related to implicit learning in developing Experiment 5, it was noticed that a considerable volume of this research has investigated the role of sleep in memory and implicit learning. The following paragraphs amount to something of a bold conjecture arising from this research, offering a completely novel and as yet untested avenue for future dyslexia research.

Any hypothesis which hopes to offer a worthwhile causal foundation for dyslexic functioning needs to account for at least four key elements, which have become well established findings within dyslexia research: 1) the heritability of dyslexia (DeFries, Fulker, & LaBuda, 1987; Stevenson, Graham, Fredman, & McLoughlin, 1987), 2) impaired initial learning, (Nicolson et al., 2002; Sperling et al., 2004) 3) impaired functioning in the subsequent reactivation of overlearned skills (Nicolson & Fawcett, 2000; Vicari et al., 2003), and 4) abnormal brain activation and brain growth (Galaburda, Duane, & Gray, 1991; Nicolson et al., 1999). The purpose of the following account is to draw the reader's attention, by drawing parallels with the existing sleep and memory/learning research, to the possibility that the processes which underlie sleep may offer a new causal account of dyslexia. To this end, a brief account will be given relating sleep research to each of these four key elements.

Existing research has indicated that genetic influences play a significant part in sleep-wake patterns (de Castro, 2002). Indeed, research has even suggested that genetic heritability plays a significant role in sleep-related breathing disorders, accounting for some 37% of the variability in elderly male twins (Carmelli, Colrain, Swan, & Bliwise, 2004). Interestingly, research has indicated that certain sleep disorders have been associated with a particular abnormality on the short arm of chromosome 6 (Parkes & Lock, 1989), which has also been heavily connected with reading disabilities (Grigorenko, 2003; Stein, 2004).

As introduced earlier in the thesis, memory can be divided into two distinct types, declarative and non-declarative (Tulving, 1985), although in actuality they seldom operate in total isolation from one another. As detailed in the introduction to chapter 6, the first process of memory consolidation involves the stabilisation of memory encodes (Walker et al., 2003), which primarily helps to strengthen the memory against decay and interference. Memory stabilisation is primarily associated with our waking states, and has been shown to occur within a timeframe of 10 minutes to 6 hours depending on the task involved (Walker & Stickgold, 2006). A second phase of consolidation involves the offline enhancement of a memory code or skill, which appears to occur almost exclusively during sleep (Walker et al., 2002). Further processes related to the enhancement and stabilisation of memory include the integration of new information with existing memory representations, the translocation or anatomical relocation of memory representations, and the active erasure of representations (Walker & Stickgold, 2004).

Sleep research with developmentally normal individuals who have been sleep deprived has found deficits in the initial learning process (linked to inadequate pre-training sleep), and the subsequent reactivation of these over-learned skills (linked to post-training sleep deprivation). This pattern of deficits, induced by sleep deprivation, corresponded to the deficits identified in dyslexic individuals by Nicolson, Fawcett and Dean (2001).

Nicolson and Fawcett's (2000) "square root rule" argues that dyslexic children show a slowed ability when required to learn new tasks. In fact, they suggest that dyslexic children will take longer to acquire a task by a factor of the square root of the time it takes a developmentally normal child to acquire the task. A recent study tested the ability to demonstrate a classically conditioned eyeblink response related to the presentation of a tone (which on 70% of the trials was followed by a corneal airpuff). It found that 85% of young dyslexic adults had an abnormally poor conditioned response or poor tuning of the orienting eyeblink response (Nicolson et al., 2002). In the same year, a second study compared three groups of developmentally normal young adults on the same classical eyeblink conditioning paradigm, but assessing the effects of selective sleep deprivation (Ohno, Urushihara, Sei, & Morita, 2002). The groups were divided according to three sleep conditions; a control group which was allowed to sleep normally the night before conditioning, a second group whose members' REM sleep stages were selectively disrupted and a

third group whose members' slow wave sleep[19] (SWS) was selectively deprived. While the non-sleep deprived and SWS-deprived participants did not differ from one another, the REM-deprived participants demonstrated a significantly lowered capacity to acquire conditioned eyeblinks. Ohno and colleagues, in line with Nicolson et al.'s position, suggested that conditioned eyeblink response is closely related to the cerebellum, but also added that this learning function is disrupted by REM sleep deprivation.

Research which assessed implicit learning on serial response tasks indicated that dyslexic children have a lower rate of learning relative to age-matched cohorts. The dyslexic children did not demonstrate an equivalent reduction in RTs to literacy unimpaired children, with repeated exposure to pseudo-random sequences (Vicari et al., 2003). A reduced rate of implicit sequence learning has also been related to sleep deprivation, as research with literacy-unimpaired adults who had been sleep deprived before training on the serial response task also demonstrated impaired implicit sequence learning (Heuer, Spijkers, Kiesswetter, & Schmidtke, 1998).

A further study, which investigated the effects of 35 hours of sleep deprivation on performance on a verbal memory task, indicated that verbal learning was significantly lower in sleep-deprived individuals relative to those who had slept normally (Drummond & Brown, 2000). Interestingly, this study, used functional magnetic resonance imaging during the encoding phase, and found increased activity in the prefrontal cortex only in sleep-deprived individuals. This suggested that sleep-deprived individuals may have had to consciously compensate for their impaired learning ability, in line with the position put forth by Nicolson and Fawcett (1990) in relation to dyslexics.

Direct evidence that dyslexic children, unlike their reading age matched control cohorts, do not show an offline enhancement in performance post-training related to sleep effects was found in a recent study of mirror drawing ability (Vicari et al., 2005). Additionally, dyslexic children also demonstrated a slower initial drawing speed in the first assessment phase and continued to demonstrate a slower rate of operationalisition in mirror drawing relative to their age matched cohorts.

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[19] Stages 3 and 4 of NREM sleep are sometimes collectively referred to as slow wave sleep, due to the predominance of low-frequency 0.5-4 Hz as registered by EEG.

Research assessing the importance of sleep on memory enhancement on a visual texture discrimination test (Stickgold, Whidbee, Schirmer, Patel, & Hobson, 2000). Found a post-training improvement following a night's sleep, but not after an equivalent period of wakefulness. Of particular interest to the current thesis the non-sleep-deprived participants, when retested 1-7 days after the first night's sleep, continued to show offline improvement in visual discrimination ability relative to the first night, while the sleep deprived participants even after 7 days of normal sleep did not demonstrate any significant improvement in performance. This indicates that a requirement for initial offline enhancement and the subsequent enhancement in trained abilities is undisrupted sleep on the first night after encoding.

Galaburda et al. (1991) reported that the brains of dyslexic individuals, in contrast to literacy-unimpaired individuals, demonstrated symmetry in the planum temporale cortical language areas, indicating anatomical differences in the brain between literacy impaired and unimpaired individuals. A PET imaging study by Nicolson et al., (1999) which assessed dyslexic and literacy unimpaired individuals, involving a motor sequence learning task found significantly lower brain activation in the cerebellar cortex and the left cingulate gyrus when executing pre-trained tasks, but lower right cerebellar cortex activation when encoding new sequences in the literacy impaired individuals. The creation of memories is dependant on brain plasticity, which refers to changes that occur in the brain, which can be of either a structural or functional nature in response to environmental or cognitive stimulation. In a recent sleep study, participants were trained on a motor tapping sequence task, followed by an interval of twelve hours, during which participants either remained awake or slept before being retested on the task during FMRI scanning (Walker, Stickgold, Alsop, Gaab, & Schlaug, 2005). The findings indicated that for the sleep participants there was an increase in activation in the motor cortex, medial prefrontal lobe, hippocampus and the left cerebellum. Interestingly, the patients who had been allowed to sleep also demonstrated reduced activity in the parietal cortices, left insular cortex, temporal pole and fronto-polar region, relative to the non-sleeping participants. The authors suggested these differences were related to reduced conscious monitoring and the emotional task burden in the participants who had been allowed to sleep.

Further support for the position that sleep plays a role in offline reprocessing of learned material was found by Maquet et al. (2000). Investigating brain activation

during a serial reaction time task using PET, Maquet found that several of the same areas which showed increased activation during task learning were significantly more active during REM sleep in trained participants compared with untrained participants. In a second study, this time using a pursuit task, participants had to track the movement of a target using a joystick. The target's movement was highly regular on the horizontal but difficult to predict on the vertical axis, with participants having to learn the relative target trajectory (Maquet, Schwartz, Passingham, & Frith, 2003). Participants were trained on the pursuit task, with half of the participants then being sleep-deprived on the night after training, following 2 subsequent nights in which all the participants were allowed to sleep normally. They were retested on the original trained trajectory and an untrained trajectory. FMRI scanning was used to track brain activity and found that several of the areas were significantly more active in the group that had been allowed to sleep normally on the learned trajectory, but that neither group differed in terms of brain activation on the untrained trajectory. These findings offer strong evidence that sleep may mediate plastic changes within the brain. For a more in-depth review of sleep related changes in brain activity and plasticity (see Walker & Stickgold, 2004).

As highlighted in the general introduction, fluency in reading, spelling and particularly the development of literacy require more cross-communication and smooth interconnectivity between brain areas and processes than perhaps any other activity (Stein & Walsh, 1997). Impaired functioning on any point in this connective network may lead to greater difficulties in carrying out the task as a whole. If the syndrome of dyslexia relates to abnormal sleeping patterns in the form of selective sleep (stage or cycle) disruption, this would effectively entail a double deficit in learning as the disruption would occur both in the pre- and post-learning. Which would affect not just the initial acquisition but the later reactivation of previously learned material, both of which would intimately interact with brain plasticity and thereby brain development.

As this brief review of the findings in sleep research illustrates, striking parallels are found across all four of the key characteristic elements of dyslexia highlighted above - the heritability of dyslexia, impaired initial learning, impaired functioning in the subsequent reactivation of overlearned skills, and abnormal brain activation and brain growth. An extreme interpretation of this striking parallel is that a highly selective disruption within particular sleep stages or particular sleep stages

within individual sleep cycles during the night, offers not only a new causal model of dyslexia, but possibly a new means of dyslexia "prevention" and remediation in the future.

A more cautious interpretation would be that sleep deprivation in non-dyslexic individuals, indices functional information processing deficits equivalent to the normal functioning of the brains of dyslexic individuals. In other words, the brains of sleep-deprived non dyslexics function like the brains of dyslexic individuals. Even with this weaker interpretation, this hypothesis may help to increase our understanding of dyslexic brain processes through systematic exploration of how processes change as a function of sleep-deprivation. Furthermore, in effect, 'dyslexia' becomes a potential independent variable that can be manipulated in an experimental context using participants as their own controls.

Review of thesis findings- Attention

The data from Experiment 1.2 suggested that D children's ability to inhibit task-irrelevant stimuli and therefore to spatially focus attention (Cepeda et al., 1998; Facoetti, 2001; Facoetti & Molteni, 2000) relative to that of DN children was impaired such that they were demonstrated significantly lower recall span on VSWM tasks with interference stimuli. Given that spatial focus is suggested to rely partly on inhibitory mechanisms, the findings that the literacy-impaired children demonstrated increased commission error rates in Experiment 6.2 supports the position that dyslexic children experience inhibitory control difficulties (Bellgrove et al., 2005; Fassbender et al., 2004). Interestingly, in terms of commission errors, the literacy-impaired children were comparable to their reading age-matched cohorts, indicating that they were demonstrating a delay in inhibitory control equivalent to that shown in the development of literacy ability. In addition, on the random SART, DAR children's ICV performance was highly similar to RA children's, suggesting that the additional difficulty in sustaining attention is only found on tasks that are particularly unchallenging for these children. This indicates that in line with Manly et al.'s (2003) findings with TBI patients, the apparent reduction in difficulty or challenge in the fixed version of the SART actually enhances discriminative ability between literacy impaired children with a high risk of ADD/ADHD and their developmentally normal reading age-matched cohorts, relative to the random version of the task.

The findings from Experiment 1.3 indicated that, on the backwards-recall task, which requires a greater degree of CE resources than simple forwards-recall tasks (Vandierendonck, Kemps, Fastame & Szmalec, 2004), DN children also demonstrated a significant drop in recall span due to task-irrelevant interference. Given that the D children demonstrated a significantly larger drop in recall span on the backwards-recall tasks than the DN children, it is suggested that either they are less efficient at directing CE resources or have a lower overall resource pool from which to draw than the DN children. However, since there was no additive effect between backwards-recall and interference effects on the backwards-recall task in D children (although this was possibly due to a floor effect), the findings point towards D children being simply less able to direct the attentional resources available to them.

The data from Experiments 6.1 and 6.2 suggested that, in line with the adult research (Smith-Spark et al., 2004), D children demonstrate significantly more lapses in sustained attention than age-matched literacy-unimpaired children. In contrast to previous research using the SART paradigm (Moores & Andrade, 2000), there was no evidence that dyslexic children were demonstrating a lack of task automaticity. Indeed the profile of responses leading up to or following a commission or correct withhold did not differ between developmental groups. The possibility that the more frequent lapses in attention were actually due to differences in attentional dwell time (Hari et al., 1999) was not supported in the data. The literacy impaired children's ability to sustain attention was largely equivalent to that of the RA children, suggesting they were demonstrating an equal impairment in both sustained attention and literacy development. The DAR children were demonstrating an increased ICV variability relative to the RA children. This indicated a greater ebb and flow in arousal level variance in DAR children, suggesting an increased demand for top-down executive control in these children (Stuss et al., 2003), which is above and beyond the demands required by their reading age matched cohorts.

The findings from Experiments 1.2 and 1.3 suggested that if dyslexic children are suffering from a left mini neglect (Hari et al., 2001), this impairment did not mar their ability to spatially orient attention. D children did not demonstrate an impaired ability to recall spatial sequences which required visual field bisection, relative to sequences which were presented in a column in the centre of the visual field. Indeed, in opposition to the notion of a left mini neglect, D children (like their DN

counterparts) actually demonstrated a significantly higher recall span in horizontal placements, relative to vertical placements.

Experiments 3.2 and 3.3 sought to further extend the understanding of dyslexic children's ability to selectively attend to one aspect of a stimulus while simultaneously suppressing task-irrelevant aspects. The task was designed such that spatial representations were present at the encoding stage of the visual WM task, but were removed when sequence retrieval was required. The idea was that if children did process the spatial representations this would detract from the resources which they could direct towards rehearsing the visual aspects, thereby reducing recall span relative to tasks that did not allow for spatial encoding. However, due to an oversight in the test methodology, the experiment may equally have incurred visual interference effects due to flanking stimuli. While it is unclear whether the interference effects in the task were visual, spatial or combined visual-spatial in nature, the results indicated that the literacy-impaired and indeed the literacy-unimpaired children demonstrated a highly similar drop in recall span on the interference tasks relative to the serial presentations.

Review of thesis findings- Visual and spatial working memory

Experiment 1.1 involved a modified version of the Corsi blocks task. The results of the analysis indicated that D children did not have a lower VSWM span capacity than DN children. The reliability of the assessment as an accurate measure of VSWM capacity was confounded, however, by two experimental shortcomings. First and foremost there did not seem to be a linear progression between item addition and increased sequence difficulty: failure on a three-item sequence need not have implied that the child would have failed on a four or five-item sequence had testing continued. Second, the test procedure was also constrained by ceiling effects, given that over 10% of children in both developmental groups correctly recalled the highest sequence assessed. In Experiment 2, D children's spatial WM was again assessed on a matrix display using visually indistinct spatial placeholders. As there was no upper limit to sequence length, ceiling effects could no longer occur, with stimulus sequence paths controlled in such a way that easily chunked paths were removed from possible test sequences. Interestingly, the data from Experiment 2, was able to both support and reject previous findings with respect to VSWM in dyslexic children (Jeffries & Everatt, 2004; Kibby et al., 2004; Pickering & Gathercole, 2004). All

previous studies assessing spatial WM have used matrix style presentation displays. The findings from Experiment 2 relating to matrix presentations indicated that whether or not significant effects between dyslexic and their age-matched literacy-unimpaired cohorts were found depended on the scoring method used. That is, while no differences were found using the longest span scoring method, the CRT measure revealed differences between D and DN children. Given that both scoring methods were indicating a similar trend between developmental groups it is suggested that the CRT method simply acts as more sensitive scoring measure of VSWM.

Experiment 1.2 indicated that on a 6-item parallel display, there were no significant differences between D and DN children on standard forwards-recall tasks, but D children were significantly impaired relative to DN children when backwards-recall was required. In Experiment 1.2 the question of whether or not D children were demonstrating age-appropriate VSWM ability was not conclusively unresolved due to potential differences in the use of verbalisation between developmental groups. However, the findings from Experiment 1.2 also indicated that both developmental groups recalled sequences that were presented on a horizontal alignment significantly better than those presented with a vertical alignment. This shift in recall span depending on stimulus alignment offered provisional support for the position that spatial encoding and/or retrieval was occurring, as neither the use of visual or verbal retrieval strategies could account for the shift in recall ability.

In Experiment 2, children's VSWM was again assessed with the use of parallel presentation displays. However, due to the use of visually indistinct stimuli as spatial location placeholders, the procedure removed the possible occurrence of visual or verbal encoding and retrieval strategies. The assessment therefore primarily assessed spatial WM capacity between groups, this time on a 9-item parallel display. The results indicated that regardless of the scoring method used, literacy-impaired children demonstrated a significantly lower VSWM retrieval than the DN children. Firstly, this would indicate that while there was a delay in the development of spatial WM in dyslexic children, the delay was of a similar magnitude to their delayed literacy development. The fact that the literacy-impaired children were now demonstrating an impaired capacity relative to the DN children cannot be accounted for by the suggestion offered in Experiment 1.2, i.e. that this related to the use of a less sensitive scoring method. As the data from Experiment 2 indicated that even on the longest span length measure, DN children were still significantly outperforming

both literacy-impaired groups. The possibility therefore remained that the significant differences between-groups may have related either to the increased difficulty of encoding 9 versus 6 spatial locations (Kemps, 1999), or alternatively to the loss of verbal/visual codes.

The deviation in findings between matrix and parallel presentation types according to scoring method used in Experiment 2 may relate to the increased possibility of scaffolding through a secondary modality CE or LTM etc. in the matrix tasks. This ability to scaffold performance in turn increases the individual variation in span capacity. As the matrix task unlike the parallel is not a "clean" measure of VSWM, deviations in ability are no longer solely attributable to just VSWM ability. That is, by using a single point reference of ability as is the case in the longest span scoring method, D children were found to be performing similarly to DN children as the differences in accuracy levels up until that point are not recorded. In contrast, the CRT scoring method offers a more sensitive measure of recall span, given it is based on accuracy of recall across all the trials in a subtest. The decrease in variability due to multiple points of comparison meant that not only were DN children functionally discriminated from the other 3 developmental groups, but additionally D children were found to have correctly recalled more trials than the RA children. This indicated that while D children were demonstrating a relative impairment in spatial WM, from a developmental perspective, it was not as severe as their literacy impairment.

Serial presentation displays were used in Experiment 3.1 to assess visual WM capacity between developmental groups. The findings indicated that the D and DAR children had a significantly impaired recall span relative to DN children, but a highly similar span to RA children. These differences in ability were consistently upheld across the three visual representation stimuli, even on the animal stimuli. The profile of recall span did suggest that children recalled animal stimuli significantly better than both symbol and face stimuli, and recalled symbol stimuli better than face stimuli. This indicates that while D and DAR children showed a reduced recall span relative to DN children, changes in the ease of encoding stimulus items did not significantly alter the relationship between developmental groups. This finding suggests that the differences in visual WM ability may relate to capacity rather than to encoding and retrieval differences between groups. The finding that D children had a significantly impaired recall span relative to DN children suggests that the results

from Experiment 1.2 on the standard recall task were unlikely to be due to an advantage caused by a shift in retrieval strategy between D and DN children.

In chapter 5, the assessment of VSWM on tasks that allow for combined visual and spatial representations was revisited. In Experiment 4.1, parallel displays presented sequences using the same three types of visual stimuli as chapter 4. The analysis indicated, in contrast to the results discussed in chapters 3 and 4, that when animal stimuli are used as spatial location placeholders, there are no longer any significant differences between D and DN children (although it must be acknowledged that there was a strong trend in that direction). This finding is consistent with the analysis of Experiment 1.2. It suggests that while D children are impaired on tasks that only allow for either spatial or visual recall, significant differences between groups are no longer up held in recall span on tasks that allow for combined verbal/visual/spatial codes.

The increased recall span demonstrated by DN children relative to the other developmental groups does not appear to relate to possible differences in the use of retrieval strategy. Given, the combined analysis of Experiments 4.1 and 4.2 indicated that DN children could have been using visuospatial retrieval, as they demonstrated a significantly lower recall span on parallel as opposed to matrix tasks on all visual representation stimuli types even the verbalisable animal stimuli. This was equivalent to the change in recall span demonstrated by the other developmental groups. In contrast to the suggestion that D children simply have an increased capacity on tasks that allow for a combined visual and spatial representations, the findings from the parallel analysis which used face and symbol stimuli indicated that DN children had significantly higher recall span than D children. Rather than suggesting that D children experience increased difficulty using new visual representations as spatial placeholders relative to DN children, the lack of significant effects on the animal tasks is likely to relate to increased individual variance due to the addition of the verbal modality which some children may use to enhance recall, increasing the variability between developmental groups, as while non-significant the trend still indicated that D children had lower recall span than DN children.

Across the visual representation stimulus types, DN children demonstrated a significantly higher recall span than either DAR or RA children. In contrast to the findings from Experiments 3.1-3.3, Experiment 4.1 indicated that D children had significantly higher recall span than RA children. These findings suggest that while

the D children showed a slightly higher (though non-significant) ability to recall predominantly spatial or visual sequences than RA children, it was only on tasks that used parallel presentation and allow for combined representations that D children perform better.

Experiment 4.2 assessed children's recall span using the same visual representation stimuli but this time on a matrix presentation display. While DN children continued to demonstrate significantly higher recall span than all of the other developmental groups, D children no longer outperformed RA children. One possible explanation for this shift may relate to the degree of interrelatedness between spatial locations. That is, if D children do have an enhanced ability relative to RA children in combining 'what' with 'where' representations, there may be less of a requirement for such an ability on the matrix task owing to the interrelatedness between individual item locations. Alternatively, due to the capacity to scaffold matrix presentations with LTM representations, recall span may be less dependent on core VSWM, relying more on the interaction between LTM and VSWM ability.

As noted earlier, the integrated analysis of Experiments 4.1 and 4.2 indicated that all the developmental groups reacted similarly to the changes in visual representation. Consider that DN children were showing significantly higher recall span on the matrix versus parallel presentations, as well as lower recall span on the vertical alignments in Experiment 1.2. In contrast to previous research, this would strongly suggest that if both spatial and visual codes remain continuously present throughout testing, even on easily verbalisable stimuli, verbal recall will not be the dominant retrieval strategy, at least for children in this 9-11 years age range.

In Experiment 5, the capacity for implicit spatial learning was assessed between developmental groups. This assessment investigated whether children would demonstrate an implicit increase in recall span due to repeated exposures to matrix presentations between the initial and final assessment. Across test sessions the results indicated that there was a significantly higher recall span on the final assessment. No significant interaction was indicated between developmental groups and test session. However, when increases in recall span across test session was further assessed post hoc, only the DN children demonstrated significantly improved recall span on the final assessment. Both DAR and RA children's trend between sessions indicated a slight though non-significant increase in recall span on the final session, with D children demonstrating no change between test sessions. In keeping with the

established pattern from Experiments 2-4, DN children were found to have significantly higher recall span than any of the other developmental groups, with the data indicating that D children had significantly higher recall than RA children. The analysis of Experiment 5 also indicated that children had significantly quicker RTs on the final assessment than they did on the initial assessment. Once again when the developmental groups were assessed individually on RTs across test sessions, significant decreases in RTs were only indicated in the literacy-unimpaired children. Although D and DAR children were demonstrating a trend in the same direction, this was just short of statistical significance ($p < .07$) for D children, but considerably weaker for the DAR children. The recall span and RT data would provisionally indicate that dyslexic children do not demonstrate increases in performance with repeated task exposure to the same degree as their developmentally age-matched cohorts. While both DN and RA children showed significant decreases in RTs, neither of the literacy-impaired groups did. However, since both the recall span and RT findings for each of the developmental groups arose from post hoc analysis, further research would be required before any firm conclusions can be drawn.

Across all the VSWM tasks which have assessed serial position accuracy, the same profile has been consistently found, with primacy items being recalled the most accurately, intermediate items having a significantly lower accuracy and recency items having a significantly lower item accuracy than either primacy or intermediate items. Profiles remain consistent even in DN children on the visual WM tests that used easily verbalisable animal stimuli (as in Experiment 3.1). Thus, it seems likely that DN children do not use verbal retrieval strategies, if the stimuli items are continuously present from the encoding to the recall stage. This is in opposition to existing research which has suggested that verbally dominate retrieval strategies are present from around the age of 8 years (Hitch, Halliday et al., 1989; Hitch et al., 1988; Hitch, Woodin et al., 1989). If verbal retrieval had been taking place, we would have expected a traditional bow effect in recall accuracy (Baddeley, 1986; Brown & Brown, 1982). However, further research would need to be carried out before any firm conclusions could be drawn, perhaps by asking children what processes they were using when recalling sequences. In the current research thesis, this avenue of potential enquiry was not followed up, as it was believed it may have led to a change in recall strategy between children or test sessions. Given that children were often

sampled from the same class, they may have discussed any questions asked during the course of testing.

Future Research and Limitations of the Current Thesis

Further research is required to uncover the underlying mechanisms involved in backwards-recall on VSWM tasks. Above and beyond any possible diagnostic potential these tasks have in relation to dyslexic functioning, the exact nature of the possible interplay between individual memory components of WM needs to be elucidated before it is used in clinical settings. Existing research has suggested that even backwards-recall on spatial WM tasks may require verbal working memory support (Vandierendonck, Kemps, Fastame & Szmalec, 2004). Even if children are primarily using visual and spatial codes at the retrieval stage in tasks of this nature, it is unclear whether the significantly lower backwards-recall performance in D children indicated in Experiment 1.3 relates to an inefficient use of or lower CE resources, or if it simply relates to the requirement to scaffold VSWM with verbal WM. In Experiment 1.3, when digit span was entered into the analysis as a covariate, significant differences were no longer found between developmental groups. This may suggest that the differences in backwards-recall between groups could largely be accounted for with reference to both phonological and CE resources. However, due to the possible confound in using easily nameable shape stimuli, further research using non-verbalisable stimuli is needed to elucidate this relationship.

Another avenue for future research suggested in the current thesis relates to the finding that DN children only experienced significant interference effects from task-irrelevant stimuli when backwards-recall was required. This may suggest that the same attentional mechanisms that underlie spatial focus are taxed by reverse recall tasks. Alternatively, this may simply relate to increased difficulties experienced when having to divide attention between the two tasks. In attempting to answer this question it is recommended that children are sufficiently practised to reach a level of fluency, such that there is no longer a drop in VSWM span capacity when backwards-recall is required relative to forward span (Vandierendonck et al., 2004). If DN children still demonstrate task interference effects on the backward but not the forward recall tasks, then it seems likely that same attentional processes are involved in both tasks.

Arising from the assessments of VSWM carried out in chapter 2, a number of methodological suggestions were made. Firstly, though involving a longer assessment, it was suggested that children should get an identical number of sequence trials (at least 3 or 4) at each span length according to their ability. This is suggested to replace test procedures that automatically increase task difficulty if a child gets a particular span length correct, as in Experiment 1.2 and 1.3. The reasoning behind using such a procedure is that while some children may attain the same highest span length score, they may demonstrate very different assessment profiles, such as in terms of the number of incorrectly recalled trials. Furthermore, it is suggested that all future assessments of VSWM should attempt to equate sequence length with task difficulty. Primarily this would involve constraining possible test sequences such that easily chunked sequence paths are removed from the overall assessment as they can lead to highly inconsistent results (Smirni et al., 1983).

The analysis of Experiments 2-5 showed that whether group differences arose between developmental groups depended on the scoring method used. For this reason it is suggested that future assessments should use multiple scoring methods as, by looking at the changes between test measures, it is possible to get a more complete representation of possible differences between groups.

In Experiments 3.1-3.3 and 4.1-4.2, children were evaluated in terms of stimulus familiarity or recognition before VSWM assessment. A further recommendation for future WM assessments would be to use a similar pre-assessment procedure. By assessing individual children's actual familiarity or recognition of test stimuli before assessment, the validity of making assumptions as to a particular stimulus' novelty or supposed automatic recognition is grounded in terms of the individual child. This is important because there was considerable variation between children in respect to which animal, face or symbol stimuli was easily named or was unfamiliar to them. All future assessments should aim to tailor test stimuli to the task and the individual participant.

Systematic variation in the structuring of spatial presentation displays is needed in order to elucidate the conditions under which the degree of impairment between D and DN children is maximised. This should better inform us as to the exact set of conditions in which impairment is occurring and also lead more accurate diagnostic procedures.

In the current research, children demonstrated a poorer performance on the parallel than the matrix spatial WM tasks. It was suggested in Experiment 2 that these differences in recall may relate to the degree of facilitation from pre-existing spatial representations in LTM, in line with Kemps' (1999) research with 9-item structured and unstructured displays. It is possible that the relative degree of facilitation of VSWM capacity from LTM representations experienced by literacy-impaired and unimpaired children differs. If there are differences in the degree to which core VSWM ability can be buttressed with LTM representations, it seems plausible that unstructured displays may have a greater discriminative function than the structured parallel or matrix displays used in the current thesis.

It remains unclear whether the interference effects in Experiment 3.2 and 3.3 are best understood in terms of spatial, visual or combined visual-spatial interference. Experiment 3.2 presented stimuli on a parallel display with a between item distance of ¾cm, while Experiment 3.3 presented stimuli on a matrix presentation with between item distances of 2.5 cm, with the spatial information and visual information between items being rendered redundant at the retrieval stage. This possibility may be further investigated by varying the between-item distances, to ascertain if visual interference effects are occurring in WM tasks, and if so at what distances they are demonstrated in children of this age range. Second, it is suggested that the degree of spatial interference effects could be assessed by varying the degree of spatial structure in the display. The more structure that is freely available in the display, the more likely these spatial representations will induce interference effects, as they will be simultaneously encoded as part of the visual representation. However, in the current thesis, there was little evidence to suggest a developmental increase in the ability to inhibit either the visual or spatial representations that are causing the interference effects in children in this age range.

The analysis in Experiment 5 indicated that there was a significant increase in recall span between the initial and final sessions. On further exploration of the data, post hoc analysis indicated that only DN children demonstrated a significant increase in recall span between sessions. It was suggested that the increased rate of learning may relate to DN children's enriched spatial representations at the start of testing, as demonstrated by their significantly higher recall span. If the rate of implicit learning simply relates to the degree of pre-existing representations (Gombert, 2003), this would explain the non-significant increase in recall span found on the RA and the

literacy impaired children. However, while non-significant, the trend in the data indicated that RA and DAR but not D children had a slight increase in recall span. It seems likely that children may simply not have received sufficient exposure to the test procedure to demonstrate any measurable increases in performance. For this reason it is suggested that future research addressing implicit learning in VSWM should perhaps use unstructured displays (for which no children should have selectively enriched representations) with increased exposure to test displays, using interim assessments to plot the degree of learning over time.

Across Experiments 2-5 no significant interactions between developmental groups and the experimental conditions were indicated, yet the results consistently found that the literacy impaired children had a lower recall span than their developmentally normal age-matched cohorts. The data from the serial presentation experiments found that even on presentations which removed flanking or interference stimuli, dyslexic children were still demonstrating a reduced WM capacity relative to DN children, indicating that their VSWM impairments could not be solely attributed to weakened inhibitory control. The data from the other experiments offers further support for the position that it is unlikely that the dyslexic children's reduced WM capacity is a causal consequence of impaired encoding and/or retrieval of new or pre-existing visual, spatial or combined visuospatial codes. Instead, it is suggested that dyslexic children have a generally lowered VSWM capacity, one which will adversely affect their performance on all tasks that tax or require visual, spatial or combined visuospatial ability.

Another avenue for further research relates to the relationship between dyslexia, mathematical ability and VSWM. While Experiments 2-5 did not find evidence that dyslexic children, separated according to their mathematical ability, significantly differed from one another, the sample sizes were small and therefore may not have been representative.

In Experiment 6.2, D and DAR children showed significantly higher commission errors rates than DN children. Rather than relating to an inhibitory deficit, this difference may relate to the differences in RT speeds between the developmental groups, not to an inhibitory deficit. In Logan et al.'s (1994) terminology, the quicker RTs in the literacy-impaired children may constitute a disadvantage, which even a normally functioning inhibitory control mechanism would have had difficulties overcoming. Future research involving the random SART

with dyslexic children should therefore assess functioning and possible changes in task-related performance by testing children across a range of cue-to-response lock onsets. As children in the 6-11 age range from the literacy-unimpaired groups were responding in around 600-650ms, the response lock could be cued to this point to ascertain if the increases in commission error in the D and DAR children related to an inability to endogenously maintain a response press or if dyslexic children simply do have lowered inhibitory control.

Conclusion

Almost all dyslexia research is directed towards increasing our understanding of dyslexia. Ultimately, though, the primary objective of gaining such an understanding is that this information can eventually serve to enable soft signs of later literacy development to be recognised earlier and as a foundation for early-intervention programmes. Earlier remedial intervention can counteract the development of patterns of secondary difficulties before they become more deeply-entrenched. As was highlighted in the introduction, dyslexia is associated with not just continued difficulties in literacy related tasks, but also continued impairments with sustaining attention, verbal working memory and even speed of processing.

The current body of work has shown that dyslexia is a multi-faceted phenomenon and, particularly from a methodological point of view, must be addressed as such. If we are to gain conceptual clarity, it is vital that the test measures used are explicit and specific in terms of what they purport to assess. By applying a systematic approach, this thesis has shown that the average dyslexic child demonstrates focused, inhibitory and sustained attentional difficulties, and that they have lowered visual, spatial and combined visuospatial working memory ability relative to their literacy unimpaired age-matched cohorts. In the process of discovery, invariably many more questions have been raised. It is believed, however, that only by taking these small and painstaking steps can we acquire a fuller understanding of the nature of dyslexia.

This study is the first to show that that the strength of the demonstrated impairment in spatial WM between literacy-impaired and unimpaired children depends on the spatial presentation of the display. The study also showed that the degree of impairment in visual WM tasks between developmental groups is not modified by previous recognition of visual stimuli items in dyslexic children

indicating an equivalent ability in encoding and retrieving novel versus established stimuli to literacy unimpaired children. It is the first to indicate that dyslexic children's difficulties in inhibitory function can impair functioning on VSWM ability and the first to assess backwards VSWM recall in children. It is also the first study to assess dyslexic children on simple measures of sustained attention, which demonstrated impaired ability in these children. In the case of the 'at risk of ADHD/ADD' dyslexic children, this impairment was of a greater magnitude than the deficits demonstrated in literacy ability.

Lastly, it has been the first to connect the protean findings in dyslexia research with the corpus of sleep deprivation research, leading to the tentative proposal of a "bold hypothesis" which offers at most new a causal explanation for the condition of dyslexia and at least a new method for exploring it. It is believed that this hypothesis may offer a more economical explanation as to the heterogeneity of symptoms beyond literacy difficulties which are found in dyslexic individuals than is currently offered by existing models. While this hypothesis potentially generates a rich source of further research, its validity of course remains as yet, untested.

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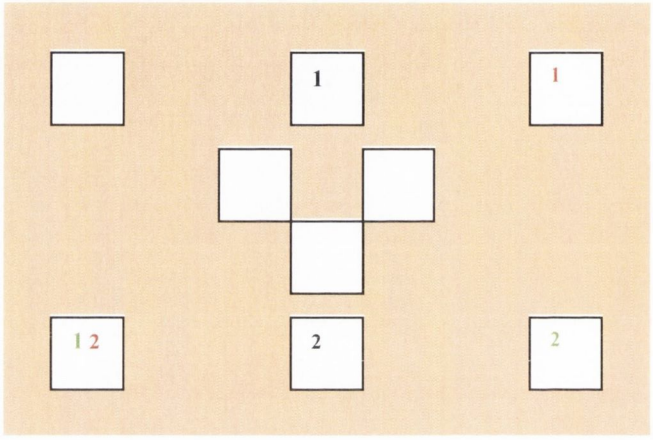
Appendix I Experiment 1.1:

Visual Sequential Memory task

- When presenting sequence, allow 1 second between each square.
- If a child makes a Fails a sequence, say: '*No that's not quite it, lets try this one instead*' and choose another colour sequence.
- Discontinue test after child has had two consecutive failures.

Practice 1:



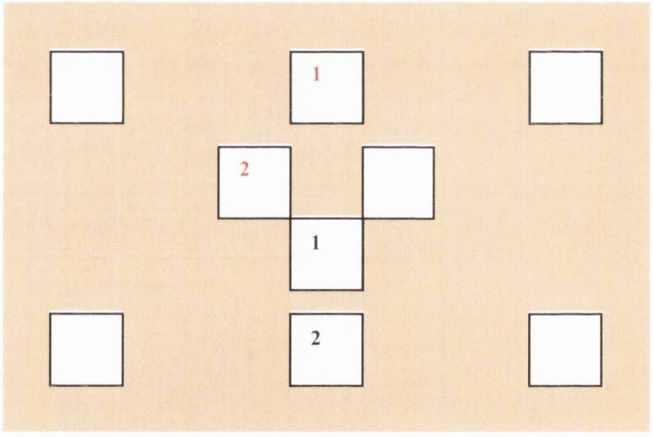
Instructions:

I'm going to touch two squares, one after the other. Like this-

And then you show me what squares I just touched. Like this- now you show me what square I touched- Touch the square I touched first, and then touch the next one.

Yes that's it

Practice 2:

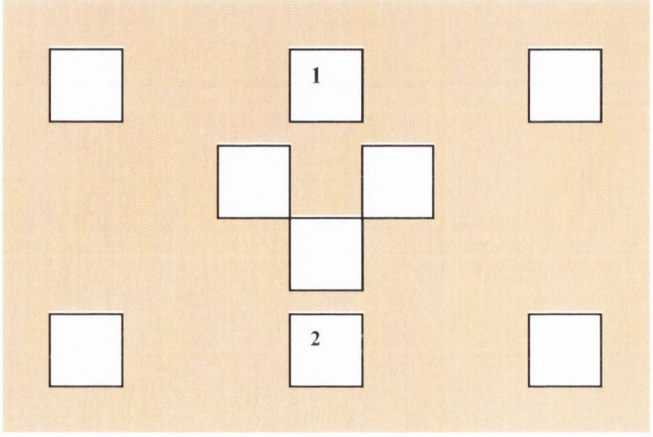


Instructions:

Now I'm going to touch another two squares. Can you show me what square I touched first, and what square I touched next?

Yes that's it

2 item trial 1:

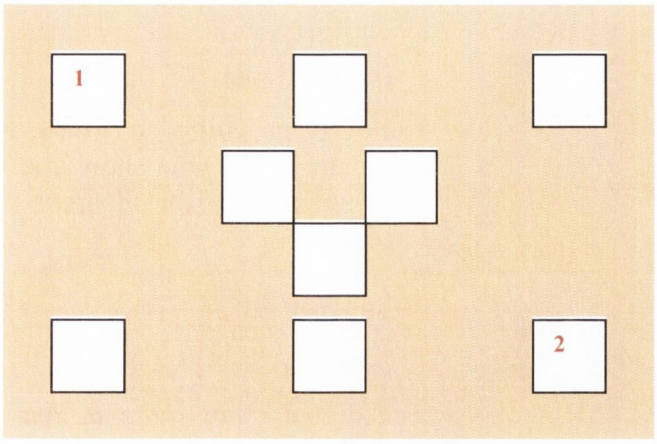


Instructions:

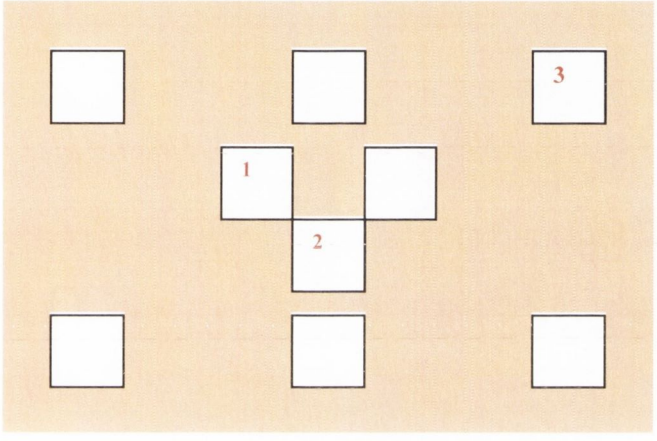
Now let's try it again. Now show me what order I touched the squares.

Yes that's it

'*No that's not quite it, lets try this one instead*'



3 item trial:

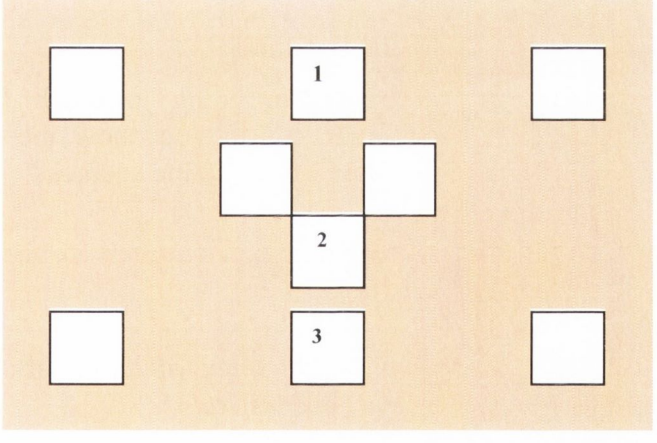


Instructions:

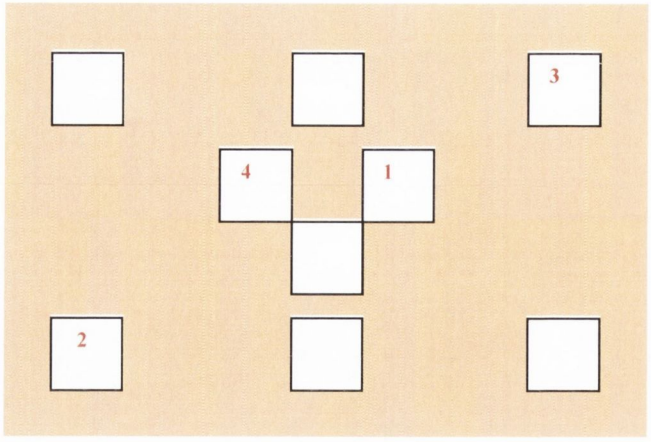
Now this time I'm going to touch three squares. Now you show me the order I touched the squares- which one I touched first, next and last.

Yes that's it

'*No that's not quite it, lets try this one instead*'



4 Item trial:

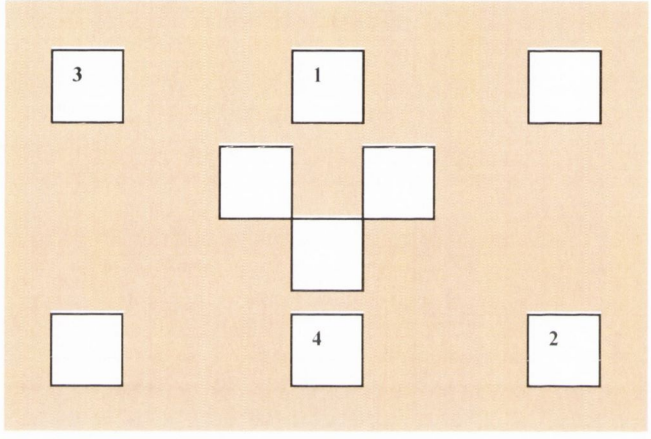


Instructions:

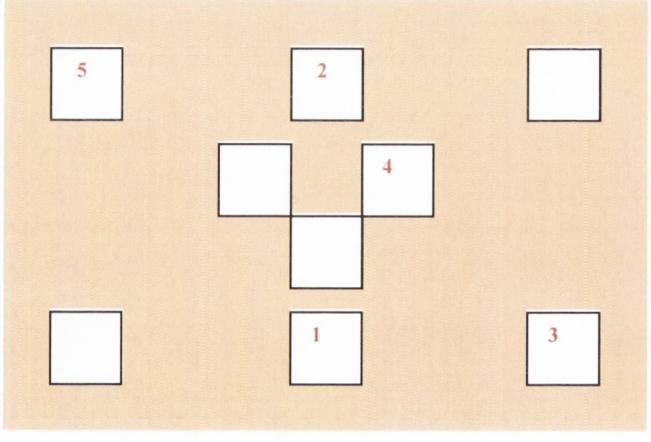
Now I'm going to touch four squares- can you show me the order I touched the squares?

Yes that's it

'*No that's not quite it, lets try this one instead*'



5 Item trial:

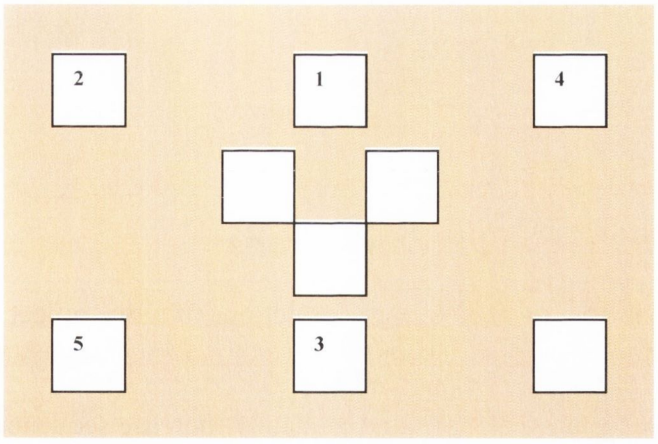


Instructions:

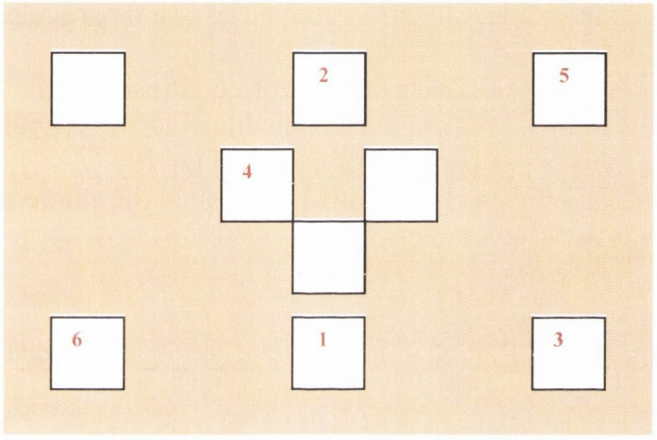
Now I'm going to touch five squares. Can you show me the order I touched the squares?

Yes that right

'*No that's not quite it, lets try this one instead*'



6 item trial:

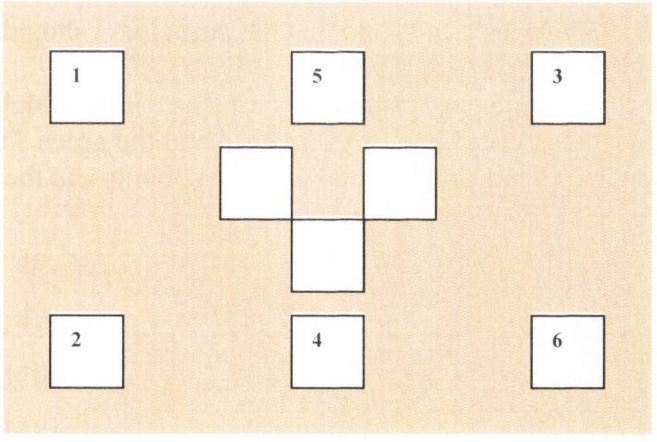


Instructions:

Now I'm going to touch six squares. Can you show me the order I touched the squares.

Yes that's it

'*No that's not quite it, lets try this one instead*'



Appendix II Experiments 1.2 and 1.3:

Procedural Instructions

Common Elements to all the Test Presentations

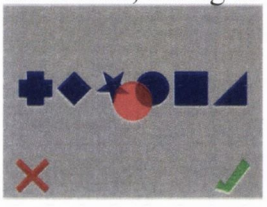
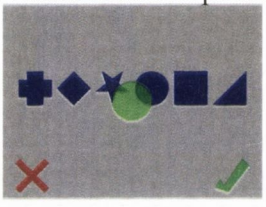
A) All tests will start with a demo, with voice over instructions of a two object sequence, then showing how to copy the sequence correctly, then demonstrate the same for a 3 object sequence.

B) All tests start with 2 sequence presentations and gradually increase sequence length.

C) The participants are given 1 trials at each level of sequence, with a second trial being offered if the child gets the first incorrect. Testing within the individual tests ceases when the participant copies both trials for a particular level incorrectly.

D) For 2 and 3 object sequences if the child gets them incorrect, the test will respond "no that's not quite right, the shapes flashed in this order" and it will show the original sequence then show a hand correctly copying it.

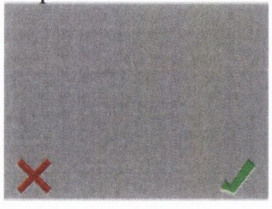
E) Before each trial a transparent red then green circle will flash in the centre of the screen, acting as a visual location prompt.

F) Shapes flash for 500 ms with an interval of 1 sec before the next shape will shape flash.

G) A tone sounds at the end of sequences to indicate that the participant should now copy the sequence.

H) The Background for all the tests displays. The red X is used as a kind of delete key to clear what has already been copied on that sequence and the green Tick as a enter key, which is pressed to indicate one has finished copying out the sequence.



I) Sequence presentation was constrained in such a way as to remove easily chunked sequences from possible test environment. For example removing mirrored sequences form possible test sequences e.g. none of the following could have been presented 131, 2565, 43421. Secondly, consecutive sequences of over 2 items were removed, such that the following could not be presented in the test sequence; 345, 123, 432.

Individual test procedure and instructions

Test 1 forward recall parallel presentation:

Same instructions for both horizontal and vertical tests

Track 1

"In this game you have to follow the order in which the shapes flash. Then you have to copy the order by touching the shapes in the same order they flashed on the screen. So which ever shape flashes first, you touch first, what ever shape flashes second you touch next, and so on." –

Before every sequence even the demos a there is a visual cue of traffic light changing from red to green in centre of screen, which is semitransparent over the original backdrop, after the green traffic light disappears, there is a delay of 2 seconds before the sequence begins.

Track2

"Like this"…

Demo here of a two flash sequence- Track3 *"now look the hand is touching the shapes in the order they flashed, then the you touch the green tick to show you're finished"* With a demonstration hand following the sequence.

Then give a demo of a three sequence with demo hand.

Then play track 21

"If you make a mistake you can delete it by touching the red X. Then just copy the order from the beginning"

Track4

"*If you're not quite sure how to play the game press the Red X, if you know how to play the game press the green tick"*

if the red X is selected, the child gets another 2 demos, before being cued to Track4

If the green tick is selected- the sequence starts with- Track5

"*now you try*"

For the first three attempts if the child makes a mistake, the response Track7"*no that's not quite right, copy the sequence like this*" with the demo hand copying the sequence of flashes again.

After every other sequence the response given is Track19 "*now try this one*"

When the child gets two consecutive failures, game ends, with response Track8 "*well done, let's play a new game*"

Test 2 reverse order parallel presentation:

Track9

In this game you have to follow the order in which the shapes flash. Then you have touch the shapes in reverse order on the screen. So which ever shape flashes last, you touch first, what ever shape flashes second last you touch next, and so on until the shape that flashed first you touch last.

Track2

"Like this"…

Demo here of a two flash sequence- Track10 *"now look the hand is touching the shapes in the reverse order they flashed. Again you touch the green tick to show you are finished"* With a demonstration hand following the sequence.

Then give a demo of a three sequence with demo hand. Here there is a voice over the sequence is triangle star circle. Track11 "*see because the circle flashed last we touch that first, then star as it flashed second last, then the triangle as it flashed first*".

Track4

"*If you're not quite sure how to play the game press the Red X, if you know how to play the game press the green tick"*

if the red X is selected, the child gets another 2 demos, before being cued to Track5 "*now you try*"

If the green tick is selected- the sequence starts with- Track5

"*now you try*"

For the first three attempts if the child makes a mistake, the response Track7"*no that's not quite right, copy the sequence like this*" with the demo hand copying the sequence of flashes again.

After every other sequence the response given is Track19 "*now try this one*"

When the child gets two consecutive failures, game ends, with response Track8 "*well done, let's play a new game*"

Test 3 forward recall Interference presentation:

The same instructions is used for the horizontal and vertical tests, except that the word "column" replaces the word "line" for the vertical tests.

Track13red, track13blue, track13yellow, track13orange, track13green

In this game you have to follow only the centre red/blue/yellow/orange/green/ etc. line of shapes and copy only the order in which the red/blue/yellow/ orange /green shapes flash. Just copy what ever flashes up in the centre line and ignore the others. Then you have touch the shapes in the same order on the screen. So which ever shape flashes first, you touch first, what ever shape flashes second you touch next, and so on." –

The rest of the instructions are identical to test 1

Test 4 reverse order interference presentation:

The same instructions is used for the horizontal and vertical tests, except that the word "column" replaces the word "line" for the vertical tests.

Track31red, track31blue, track31yellow, track31orange, track31green

"In this game you have to follow only the centre red/blue/yellow/orange/green/ etc. line of shapes and copy the red/blue/yellow/ orange /green shapes in the reverse order. So just reverse copy what ever flashes up in the centre line and ignore the others. So which ever shape in the centre line flashes last, you touch first, what ever shape flashes second last you touch next, and so on until the shape that flashed first you touch last."

All the other test instructions are the same as test 2.

Appendix III Experiments 2-5:

Common elements to all the Test Presentations:

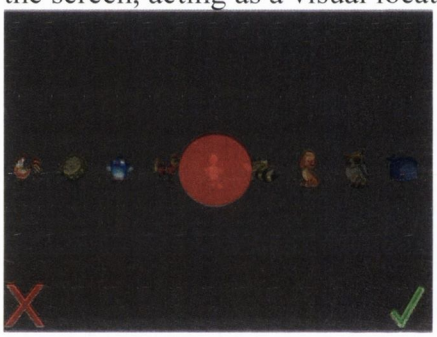
A) All tests will start with a demo, with voiceover instructions of a two object sequence, then showing how to copy the sequence correctly, followed by a demonstration of a 3 item sequence.

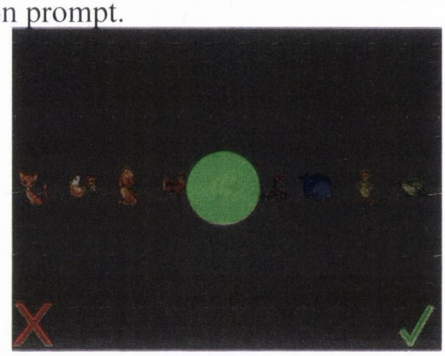
B) All tests start with 2 sequence presentations and will increase sequence length, with no upper limit.

C) The participants are given 3 trials at each sequence length (i.e. 3 trials on a 2 item sequence, 3 trials on 3 item sequences etc). Testing within the individual presentation subtest ceases when the participant fails to get any of the 3 trials for a particular level correct.

D) For 2 and 3 item sequences if the child gets the sequence incorrect, the test will respond "no that's not quite right, the animals flashed in this order" and it will show the original sequence then show a hand correctly copying it.

E) Before each trial a transparent red then green circle will flash in the centre of the screen, acting as a visual location prompt.



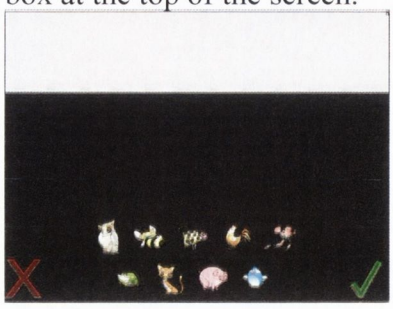


F) Objects will flash for 500 ms with a 1 sec interval before the next item flashes.

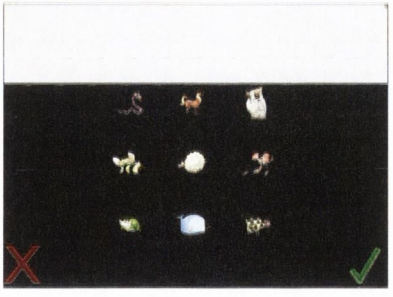
G) A tone and verbal instructions will sound at the end of sequences to indicate that the participant should now copy the sequence.

H) For the parallel and matrix presentations the position of objects is randomly assigned at the start of each test.

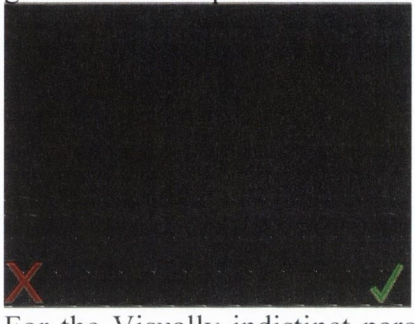
I) For the serial, and spatially redundant parallel and matrix tests- the response screen will looks like this: Each item which is pressed appears in the answer box at the top of the screen.



J) For the spatially relevant Parallel and Matrix Tests the response screen will be identical to the test screens except that an answer box now appears at the top of the screen.



K) The Background for all the tests looks like the image below. The red X is used as a kind of delete key, to clear items from the answer box one at a time. The green Tick is pressed to indicate one has finished copying a sequence.



L) For the Visually indistinct parallel and matrix tests the format is exactly the same as the spatially relevant parallel and matrix tests, except that a single item "a blue square" is used to mark all 9 spatial locations

Serial Presentation

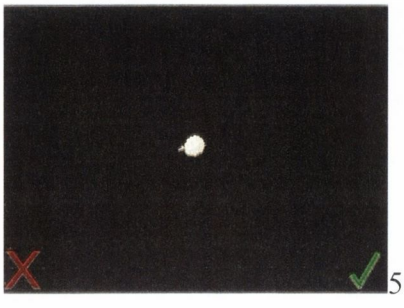
1) Serial presentation consists of the shapes being presented one at a time in the centre of the screen. First just showing the empty background screen, then showing the transparent traffic lights indicating testing is about to begin, then showing something like the following for a two item sequence:



500ms

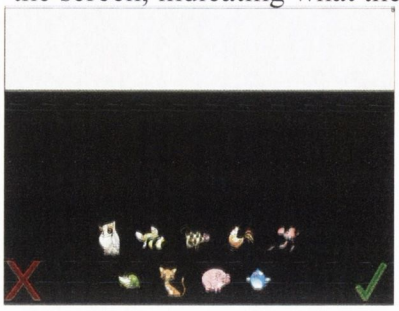


1sec



500ms another 500ms then tone.

2) So the participant would then see the standard response screen with answer box, and would then press the bee followed by the sheep to get the trial correct- A bee and a sheep would then show up in the answer box at the top of the screen, indicating what the response had been.

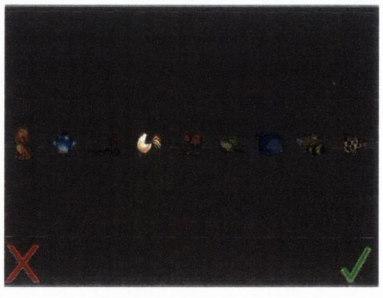


Parallel Presentation Spatially Redundant:

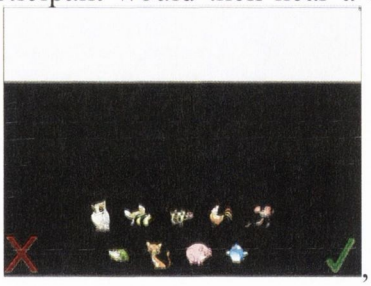
1) the test screen will look something like this, depending on the visual representation stimuli used on the particular subtest:



To indicate which objects are to be remembered the objects themselves will flash. Each trial starts with the traffic light stimuli, than an interval of 2 sec with all stimuli items at the dormant level of luminance, the first item would then flash for 500ms then an interval of 1 sec with all the objects at the dormant level of luminance, than a second item would flash for 500ms, and so on till the required sequence length. The screen shots below demonstrate the hen then bee in the flash level of abrupt luminance change



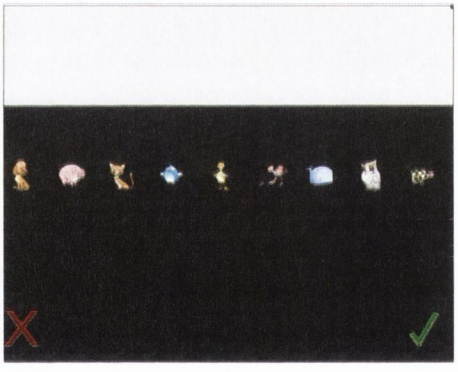


2) The Participant would then hear a tone and be shown the standard response screen. , and obviously have to respond, hen than bee, which would then appear in order at the top of the screen in the answer box.

Parallel Presentation Spatial Inclusion:

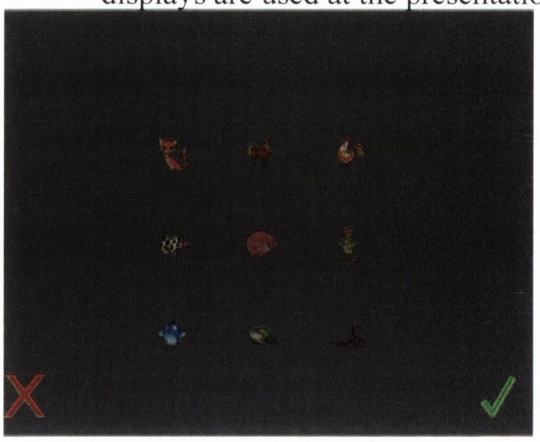
The presentation procedure is the same as spatially redundant Parallel presentations, the distinction between presentation types being the manner in which sequence copying takes place. This time the screen doesn't change to the standard response screen, but maintains all the test stimuli in an identical layout to sequence presentation, the only visual distinction being the addition of an answer box at the top of the screen. With the touched items appearing in the answer box at the top of the screen as per usual.





Matrix Presentation Spatially Redundant:

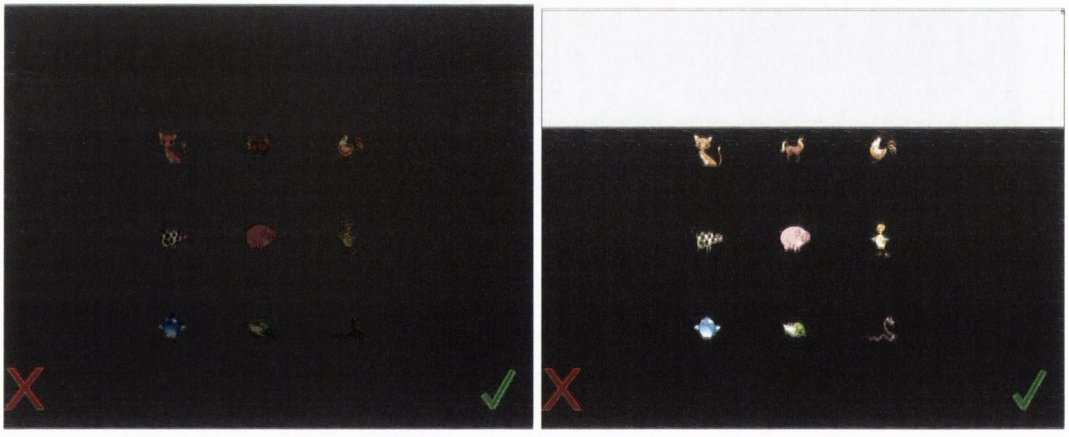
1) The Matrix presentation is 3X3 spatial layout, exactly the same procedure as the spatially redundant parallel presentations is used except that matrix displays are used at the presentation stage.



2) Again objects will flash on the screen one at a time, followed by a sound and verbal prompt, after which participants will be shown the standard response screen to copy out the sequence trial.

Matrix Presentation Spatial inclusion:

Follows exactly the same procedural layout as the spatially redundant matrix presentations, except that like the spatially relevant parallel presentations once again participants copy out sequence trials on a response screen which is identical to the test presentation screen but for the addition of the answer box see below.



Procedure and Test Instructions:

Animal recognition Pretest:

Track A1

"*In this game animals will flash up on the screen one at a time. If you know what the animals name is just say the name out loud, if you're unsure just say your don't know*"

This is the bit were an animal will flash up and stay there until I've indicated if it is recognised or not by typing Y/N on the keyboard.

Symbol recognition Pre-test:

Track S1

"*In this game symbols will flash up on the screen one at a time. If you think you know what the symbols name is or if it reminds you of anything, just say the name out loud, if you're unsure just say your don't know*"

Face recognition Pre-test:

Track F1

"*In this game faces will flash up on the screen one at a time. If you think you know what the face's name is or if it reminds you of anybody, just say the name out loud, if you're unsure just say your don't know*"

For both the symbol and face tests, items where only included in the test proper if child did not recognise them

Voice over for the <u>first round</u> of testing

The Same instructions were given for all representation stimuli, although only the animal voiceovers are presented here, the word animal would have been replaced with symbol, face or square.

Initial instructions:

Track 2

"*In this game you have to remember the order animals flash up on the screen. Then you have to copy the order by touching the animals in the same order they flashed on the screen. So which ever animal flashes first, you touch first, whichever animal flashes second you touch next and so on*"

All that is shown is the standard screen background for the particular test

Track 3

"*Before the start of every round a red circle followed by a green circle will flash up like a traffic light, this tells us the round is about to begin, like this*"

Traffic light moving from red to green on screen.

It then Plays track 4 and carry's out a demo sequence of 2 animals flashing

Track 4:

"*After the traffic light the animals flash up on the screen like this*"

Then the tone should sound, and track 5 should play

Track 5

"*This sound tells you that the animals have finished flashing and you can now copy the order animals flashed up*"

Point *

Ordinary Demo instructions:

For all tests the initial screen is the default dormant luminance level screen, followed by a 2 item sequence flashing up. For serial, spatially redundant parallel and matrix presentations track 6a is played, but for spatially relevant parallel and matrix tests track 6b is played and for the visually indistinct spatial presentations track 6c is played. The demonstration will show the demo hand touching the 2 animals in the order they flashed, with the touched animal stimuli appearing in the answer box, then the demo hand touches the green tick.

Track 6a

"*In this game, after the animals have finished flashing, a copy box will show up on the screen. So which ever animal flashed first, you touch first, whichever animal flashed second you touch next and so on. The animals you touch will then show up in the answer box.*"

Track 6b

"*In this game you will touch the animals where they flashed up on the screen. So which ever animal flashes first, you touch first, whichever animal flashes second you touch next and so on. The animals you touch will then show up in the answer box.*"

Track 6c

"*In this game you will touch the squares where they flashed up on the screen. So which ever square flashes first, you touch first, whichever square flashes second you touch next and so on. Once you touch a square it will then show up in the answer box.*"

Point **

Play track 7 then participants are shown a second 2 item sequence.

Track 7

"lets look at another example"

After the 2 items sequence flash up and tone, when the demo hand starts responding play Track 8.

Track 8

"Now, look the hand is touching the animals in the order they flashed, and the touched animals are showing up in the Answer Box, the hand is then touching the green tick to show it is finished"

This is directly followed by a 3 animal sequence with Demo of hand touching the animals and them showing up in the response field as normal except that when the hand is copying the 3 item sequence it will make a mistake on the last item, but will delete the mistake by touching the red X. Play track as soon as the tone sounds

Track 9

"If you make a mistake when you are copying out the order, you can undo the mistake by pressing the red X, and it will remove the mistake from the answer box, like this."

Hand then completes the order as normal, hitting the green tick etc. while playing track 10.

Track 10

"Then just finish copying the order the animals flashed up on the screen"

Point ***

After the demos have completed, track 11 should play

Track 11

"If you are not quite sure how to play the game press the Red X, if you know how to play the game press the green Tick"

If the red X is selected, repeat demos sequence from point ** above.

If green tick is selected then round of testing starts proper with

Track 12

"Now you try"

After the participant clicks the green tick, track 13 should be played:

Track 13

"Now try this one"

Sequence repeats until the participant fails to get 3 trials correct on a given level of difficulty, at which point track 14 will be played.

Track 14

"*Well done, lets play a new game*"

Possible events during testing that modify above procedure:

When a mistake is made:

IF the participant gets a trail incorrect during the first 2 levels of difficulty (i.e. 2/3 item sequences), Track 15 will play.

Track 15

"*No that is not quite right, copy the order like this*"

Whereby the original sequence repeats, then the demo-hand copies the order of animals flashed, touching the green tick at the end. Then track 13 plays

Track 13

"*Now try this one*"

Additional info on two sequence trials:

During the first level of difficulty, after the tone for each sequence Track 15 is played

Track 16

"*Now you try this one, don't forget to touch the green tick to show you are finished*"

Test rounds after the first:

After the first round of testing each new round will begin at Point*, then immediately go to point *** skipping the demos unless prompted to do so.

e.g.:

Point *

For all tests the initial screen is the default dormant luminance level screen, followed by a 2 item sequence flashing up. For serial, spatially redundant parallel and matrix presentations track 6a is played, but for spatially relevant parallel and matrix tests track 6b is played and for the visually indistinct spatial presentations track 6c is played. The demonstration will show the demo hand touching the 2 animals in the

order they flashed, with the touched animal stimuli appearing in the answer box, then the demo hand touches the green tick.

Track 6a

"In this game, after the animals have finished flashing, a copy box will show up on the screen. So which ever animal flashed first, you touch first, whichever animal flashed second you touch next and so on. The animals you touch will then show up in the answer box."

Track 6b

"In this game you will touch the animals where they flashed up on the screen. So which ever animal flashes first, you touch first, whichever animal flashes second you touch next and so on. The animals you touch will then show up in the answer box."

Point ***

At which point track 11 is played

Track 11

"If you are not quite sure how to play the game press the Red X, if you know how to play the game press the green Tick"

If the red X is selected, repeat demos sequence from point ** above.

If green tick is selected then round of testing starts proper with

Track 12

"Now you try"

So only if the child clicks on the red X will it bother going to Point**

Point **

Play track 7 then shows another 2 animal sequence.

Track 7

"lets look at another example"

After the 2 sequence flash and tone, when the demo hand starts responding play Track 8.

Track 8

"Now look the hand is touching the animals in the order they flashed, and the touched animals are showing up in the Answer Box, the hand is then touching the green tick to show it is finished"

This is directly followed by a 3 animal sequence with Demo of hand touching the animals and them showing up in the response field as normal, no need to show the hand making a mistake.

Individual Stimuli items:

Animals:



Symbols:



Faces:



Appendix IV

Secondary analyses:

Experiment 3.1

Performance of the sub-sample of dyslexic children who had been divided according to their mathematical ability, were assessed across the 3 visual representation conditions with CRT as the dependent measure. No significant differences $F(1, 22)=1.225$, $p > .05$ in recall span were indicated between AMA (mean=4.00, SE=.349, 95%CI=3.28-4.72) and BAM (mean=3.29, SE=.543, 95%CI=2.86-4.41) groups. Nor was there a significant interaction suggested between mathematical ability and visual representation type $F(1, 44)=1.285$, $p > .05$, see Table A.1.

Table A.1 Summary table of CRT mean scores, standard error and 95%CI, on the non-significant interaction between mathematical ability and visual representation.

Mathematical ability	Representation	Mean	Std. Error	95% Confidence Interval	
AMA	Animal	5.24	0.440	4.32	6.15
	Symbol	3.59	0.467	2.62	4.56
	Face	3.18	0.445	2.25	4.10
BAM	Animal	4.29	0.686	2.86	5.71
	Symbol	2.29	0.728	0.78	3.79
	Face	3.29	0.693	1.85	4.72

Experiment 3.2

The repeated measures analysis which was run across the 3 visual representation conditions and between the 2 mathematical ability groups on spatially redundant parallel presentation types with CRT as the dependent measure indicated no significant differences $F(1, 22)=.163$, $p > .05$, between the dyslexic children sorted according to mathematical ability. As AMA (mean=3.71, SE=.307, 95%CI=3.07-4.34) and BAM (mean=3.48, SE=.479, 95%CI=2.48-4.47) children had a highly similar recall span. Visual representation and mathematical ability did not significantly interact $F(2, 44)=.614$, $p > .05$.

Experiment 3.3

The repeated measures analysis which was run across the 3 visual representation conditions and between the 2 mathematical ability groups on spatially redundant matrix presentation types with CRT as the dependent measure indicated no significant differences $F(1, 22)=.887$, $p > .05$, between the dyslexic children sorted according to mathematical ability. As AMA (mean=3.26, SE=.291, 95%CI=2.65-386) and BAM (mean=3.76, SE=.453, 95%CI=2.82-4.70) children had a highly similar recall span. Visual representation and mathematical ability did not significantly interact $F(2, 44)=.514$, $p > .05$.

Experiment 4.1

A repeated measures analysis was run across the 3 visual representation conditions and between the 2 mathematical ability groups on parallel presentation displays that allowed for combined visuospatial encoding and retrieval with CRT as the dependent measure. The analysis indicated no significant differences $F(1, 23)=.126$, $p > .05$, between the dyslexic children sorted according to mathematical ability. As AMA (mean=6.19, SE=.418, 95%CI=5.32-7.05) and BAM (mean=5.91, SE=.671, 95%CI=4.52-7.29) children had a highly similar recall span. Visual representation and mathematical ability did not significantly interact $F(2, 46)=.358$, $p > .05$.

A repeated measures analysis was carried out on the RT data for incorrectly recalled responses across the 3 visual representation conditions and developmental groups (DN n=38, D n=26, DAR n=13, and RA n=35). The analysis indicated that significant differences existed between visual representation stimuli $F(1,780, 192.277)=19.119$, $p < .001$, with pairwise comparisons indicating that children were responding significantly more slowly on incorrectly recalled animal presentation sequences (mean=10282ms, SE=494, 95%CI=9301-11263) than either symbol (mean=7652ms, SE=308, 95%CI=7041-8263, $p < .001$) or face stimulus presentations (mean=8317ms, SE=381, 95%CI=7560-7074, $p < .001$). Children responded similarly to face and symbol stimulus presentations. No interaction was found between visual representation and developmental groups $F(5.341, 192.277)=1.127$, $p > .05$, see Table A.2. Main effect were found between developmental groups $F(3,108)=3.415$, $p < .05$, with planned comparisons indicating that once again D children (mean=7907ms, SE=591, 95%CI=6735-9079) responded

significantly more quickly across trials than RA children (mean=10108ms, SE=509, 95%CI=9098-11118, $p < .05$) but that neither DN (mean=9166ms, SE=489, 95%CI=8196-10135) nor DAR children (mean=7822ms, SE=838, 95%CI=6164-9479) responded significantly differently from any of the other groups.

Table A.2 Mean RT, standard error and 95% CI for incorrectly recalled sequences across visual representation and developmental groups for stimuli displayed on parallel presentation displays

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	10905	778	9362	12447
	Symbol	8644	484	7684	9604
	Face	7949	601	6759	9140
D	Animal	9565	941	7700	11430
	Symbol	6466	586	5305	7627
	Face	7690	726	6251	9130
DAR	Animal	8834	1331	6196	11471
	Symbol	7038	828	5396	8680
	Face	7595	1027	5560	9631
RA	Animal	11827	811	10219	13434
	Symbol	8462	505	7461	9462
	Face	10036	626	8795	11277

Experiment 4.2

A repeated measures analysis was run across the 3 visual representation conditions and between the 2 mathematical ability groups on matrix presentation displays that allowed for combined visuospatial encoding and retrieval with CRT as the dependent measure. The analysis indicated no significant differences $F(1, 23)=2.596$, $p > .05$, between the dyslexic children sorted according to mathematical ability. As AMA (mean=9.04, SE=.403, 95%CI=8.20-9.87) and BAM (mean=7.81, SE=.646, 95%CI=6.37-9.15) children had a highly similar recall span. Visual representation and mathematical ability did not significantly interact $F(2, 46)=2.456$, $p > .05$.

A repeated measures analysis was carried out on the RT data for incorrectly recalled responses across the 3 visual representation conditions and developmental groups (DN n=38, D n=26, DAR n=13, and RA n=35). Analysis indicated that children responded differed significantly in RT across the 3 visual representation stimuli, $F(1.828,197.475)=11.741$, $p < .001$. The effects were due to children responding significantly more quickly on sequences in which trials used symbol stimuli (mean=7031ms, SE=280, 95%CI=6477-7587) than either animal (mean=8779ms, SE=285, 95%CI=8212-9344, $p < .001$) or face stimuli

(mean=8515ms, SE=409, 95%CI=7704-9327, P=.001). Significant main effect were again found between developmental groups $F(1,108)=3.438$, $p < .05$, with post hoc tests indicating that D children (mean=6980ms SE=461, 95%CI=6066-7894) were responding significantly more quickly than RA children (mean=8869ms, SE=397, 95%CI=8081-9657, $p < .05$), with neither DN (mean=8460ms, SE=381, 95%CI=7704-9416) or DAR children (mean=8126ms, SE=652, 95%CI=6834-9419) differing significantly from any of the other groups. No significant interaction was found between visual representation and developmental groups $F(5.485, 197.475)=.401$, $p > .05$, see Table A.3.

Table A.3 Mean RT, standard error and 95% CI for incorrectly recalled sequences across visual representation and developmental groups for stimuli displayed on matrix presentation displays

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	8801	449	7911	9691
	Symbol	7399	440	6526	8272
	Face	9181	644	7905	10457
D	Animal	7940	543	6864	9016
	Symbol	5965	532	4910	7020
	Face	7036	778	5493	8578
DAR	Animal	9021	768	7499	10543
	Symbol	6755	753	5263	8248
	Face	8604	1101	6423	10785
RA	Animal	9354	468	8427	10282
	Symbol	8011	459	7102	8921
	Face	9242	671	7913	10572

Integrating Experiments 4.1 and 4.2

A repeated measures analysis was carried out on the RT data for incorrectly recalled responses across the 3 visual representation conditions, 2 spatial presentation and between developmental groups (DN n=38, D n=26, DAR n=13, and RA n=35). The analysis indicated a significant main effect between developmental group, $F(3,108)=3.703$, $p < .05$, with D children (mean=7443ms, SE=489, 95%CI=6473-8414) having significantly quicker responses than RA children (mean=9488ms, SE=421, 95%CI=8652-10325 $p < .05$). Neither the DN (mean=8813ms, SE=404, 95%CI=8010-9615) nor DAR children (mean=7974, SE=692, 95%CI=6602-9346) significantly differed from any of the other groups. Significant main effect were also found between representation conditions, $F(1.972, 212.976)=22.197$, $p < .001$, with children responding more slowly to animal stimuli (mean=9530ms, SE=353, 95%CI=8134-9367) than both symbol (mean=7342ms, SE=261, 95%CI=6823-7861,

$p < .001$) and face stimuli (mean=8416ms, SE=337, 95%CI=7748-9085, $p < .01$). In addition, children responded more slowly on face than symbol stimuli (P=.001). Significant differences were also found for presentation, $F(1,108)=8.987$, $p < .005$, with parallel displays (mean=8750ms, SE=310, 95%CI=8134-9367) having slower RTs than matrix displays (mean=8109ms, SE=242, 95%CI=7628-8589, $p < .005$). There were no significant interactions involving development, as representation by development was non significant $F(5.591, 201.585)=.316$, $p > .05$ (see Table A.4), and presentation by development was non significant $F(3, 108)=1.807$, $p > .05$, (see Table A.5).

Table A.4 RT mean scores, standard error and 95%CI across visual representation and between developmental groups for incorrectly recalled sequence trials

Development	Representation	Mean	Std. Error	95% Confidence Interval	
DN	Animal	9853	555	8752	10953
	Symbol	8022	412	7206	8837
	Face	8565	530	7514	9616
D	Animal	8753	671	7422	10083
	Symbol	6215	498	5229	7202
	Face	7363	641	6092	8634
DAR	Animal	8927	949	7046	10808
	Symbol	6897	704	5502	8291
	Face	8100	907	6303	9897
RA	Animal	10590	578	9444	11737
	Symbol	8237	429	7387	9087
	Face	9639	553	8544	10734

Table A.5 RT mean scores, standard error and 95%CI across spatial presentation and between developmental groups for incorrectly recalled sequence trials

Development	Presentation	Mean	Std. Error	95% Confidence Interval	
DN	Parallel	9166	489	8197	10135
	Matrix	8460	381	7704	9216
D	Parallel	7907	591	6735	9079
	Matrix	6980	461	6066	7894
DAR	Parallel	7822	836	6165	9480
	Matrix	8127	652	6834	9419
RA	Parallel	10108	510	9098	11118
	Matrix	8869	397	8082	9657

The analysis of RTs for incorrectly recalled trials indicated a significant interaction between representation and presentation conditions, $F(1.972, 212.976)=5.533$, P=.005. As Figure A.1 indicates, this was due to children responding significantly slower on parallel presented animal displays than matrix presented animal displays, while RTs between parallel and matrix displays did not significantly differ for symbol and face stimuli (see Table A.6).

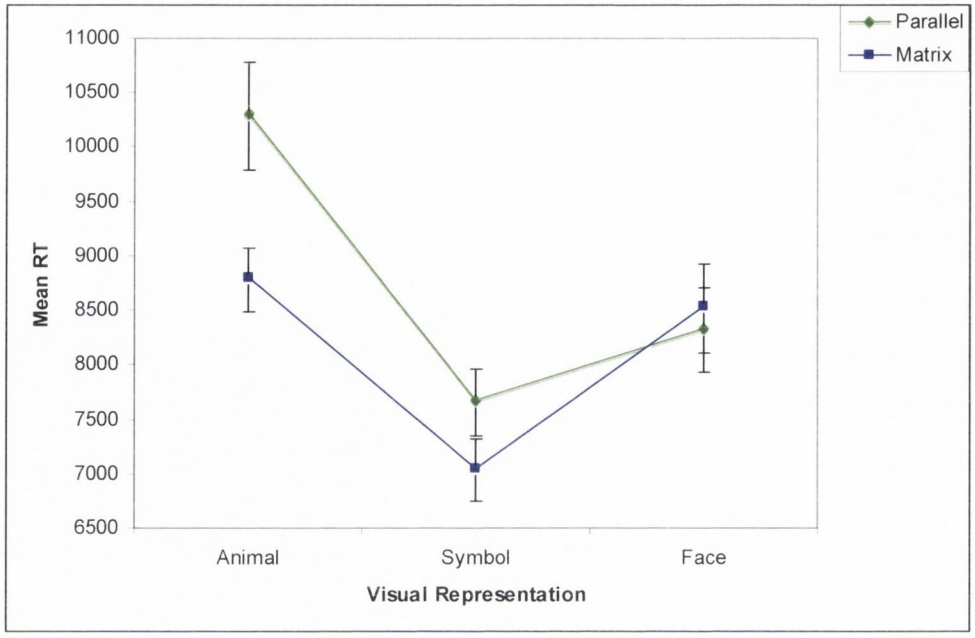


Figure A.1 Line graph of the interaction between presentation and representation conditions for RTs of incorrectly recalled sequence trials.

Table A.6 RT mean scores, standard error and 95%CI for visual representation and spatial presentation conditions for incorrectly recalled sequence trials.

Presentation	Representation	Mean	Std. Error	95% Confidence Interval	
Parallel	Animal	10283	495	9302	11264
	Symbol	7652	308	7042	8263
	Face	8318	382	7561	9075
Matrix	Animal	8779	286	8213	9345
	Symbol	7033	280	6478	7588
	Face	8516	409	7704	9327

Experiment 5

A repeated measures analysis was run across the implicit learning and between the development conditions (DN n=38, D n=26, DAR n=10, RA n=35) with incorrectly recalled sequence trial RTs as the dependent measure. The analysis followed a profile identical to the correctly recalled trials, with development $F(3,108)=2.2257$, $p > .05$, as DN (mean=8256ms, SE=398, 95%CI=7467-9047), D (mean=6889ms, SE=482, 95%CI=5934-7844), DAR (mean=6666ms, SE=681, 95%CI=5315-8016) and RA (mean=7657ms, SE=415, 95%CI=6834-8480) children's RTs for incorrectly recalled sequences trials were very similar to one another. The interaction between implicit learning and development conditions was non-significant, $F(3,108)=.690$, $p > .05$, see Table A.7. Children were once again found to

respond significantly more quickly $F(1,108)=6.191$, $p < .05$, on the final assessment (mean=6953ms, SE=319, 84-7521) than on the initial assessment (mean=7781ms, SE=287, 95%CI=7149-8412).

Table A.7 RT mean scores, standard error and 95%CI for implicit learning and between development conditions for incorrectly recalled sequence trials

Development	Implicit Learning	Mean	Std. Error	95% Confidence Interval	
DN	Initial	8996	501	8002	9989
	Final	7518	451	6624	8412
D	Initial	7251	606	6050	8451
	Final	6528	545	5447	7609
DAR	Initial	7000	857	5302	8698
	Final	6331	771	4802	7859
RA	Initial	7878	522	6843	8913
	Final	7436	470	6505	8368

Appendix V: Consent and Ethics forms

Experiment 1.1 consent forms

Letter to Principal



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Dyslexia Research Unit

Dear Principal (X)

Trinity Early Screening Test for Dyslexia

We are contacting you on behalf of the Dyslexia Research Unit which is based in the Department of Psychology, Trinity College, Dublin. The Unit, at present, is working on the development of a new early screening test for dyslexia, the **Trinity Early Screening Test**. As part of our preliminary research we are carrying out a pilot study to determine whether our set of sub-tests provide a valid and reliable discriminator of dyslexia.

We will be working with two groups, one consisting of 40 dyslexic children aged between 8 and 10, and the other a control group of similar, non-dyslexic children. We are writing to ask whether your school would be interested in helping us by enabling access to a group of your students as participants.

The testing involves pictorial-based recognition, rhyme recognition, word repetition and physical movements. There is no reading or writing involved and all the subtests are non-intrusive. The testing will take a maximum of 45 minutes per child, with each child tested individually. There will be a need to know group variables such as age and IQ, but all information will be completely confidential and will never be associated with a single child. Some of the testing will be recorded by video camera, to allow for accurate test inter-rater reliability scoring, the tapes after scoring will be destroyed, and the child's identity will remain at all times anonymous and confidential.

Research unequivocally demonstrates that the earlier a child with a specific language learning disorder can be identified the better that child's prospects for normal language development. Thus we hope you can help us with our research. Should you wish to get involved, please reply at your earliest convenience, using the SAE enclosed. If you have any further questions, please do not hesitate to contact us (01- 6082095) or Dr Ray Fuller, Project Director (01-6082426).
Yours sincerely,

Justin Allman
Postgraduate student

Erin O'Brien
Student

Parental Consent Form:

DEPARTMENT OF PSYCHOLOGY

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E-mail rfuller@tcd.ie

Dyslexia Research Unit

Dear Parent/Guardian,

We are contacting you on behalf of the Dyslexia Research Unit, which is based in the Department of Psychology, Trinity College, Dublin. The Unit, at present, is working on the development of a new early screening test for dyslexia, the Trinity Early Screening Test (T.E.S.T.). This test is being developed to screen children for specific language learning difficulties - which can arise in reading, writing or spelling.

The trials we are about to carry out are to see if the various elements of the test are reliable discriminators of dyslexia. In order to do this we need to test children who do not have dyslexia as a comparison population. All information will be strictly confidential and at no point will the identity of any participant be revealed.

The test will take about 45 minutes and will not be stressful at all to your child. There will be no need for him or her to read or write anything during the test, which is designed to assess a range of simple skills, including spatial memory, involves pictorial-based recognition, rhyme recognition, word repetition and physical movements. The child will be able to withdraw from participation at any point if s/he expresses a wish to do so. The results from these trials should enable the development of the T.E.S.T. for Dyslexia which will potentially benefit a great number of children. This is because the earlier an accurate diagnosis can be given in relation to the presence of a language learning disability, the earlier the child can receive the specialized teaching required and the better his or her chances of developing normally.

We would very much appreciate your help in this research. Please complete the attached permission form and return it to the school. Incidentally if there is any history of difficulties in learning to read in your child's immediate family (either

parent or a brother or sister), please note it in the space provided. Should you have any further questions, please do not hesitate to contact either the unit at 01 608-2095 or 01 6082426 or the school.

Yours sincerely,

Justin Allman
Postgraduate Student

Erin O'Brien
Student

PERMISSION FORM

Name of your child: _____

Date of birth: _____ Class: _____

I give permission for my child to take part in the trials ☐

Signature of parent _____

Optional Background Information
Completion of this part of the form is optional and contents will be treated as confidential and anonymous.

1. Has your child ever been referred for behavioural problems?

Yes ☐

No ☐

1a. If 'yes' did this led to a diagnosis of 'Dyslexia/ Specific Learning Difficulty'

Yes ☐

No ☐

If "No" please specify what lead to your child's diagnosis? _____

_____

2. Has your child been diagnosed with 'Dyslexia' or 'Specific Learning Difficulty'?

Yes ☐

No ☐ – skip to question 4

3. Who first noticed that your child might have a 'Specific Learning Difficulty'/ 'Dyslexia'

Parent ☐

Teacher ☐

Other (please specify): _____

3a. When was the difficulty first recognised?

1-5 years ☐

6-8 years ☐

8+ years ☐

4. Does your child have or has your child had any persisting motor (movement or co-ordination) difficulties?

Yes ☐

No ☐

If 'Yes' please specify: _____

5. Birth order of your child in the family

First ☐

Second ☐

Third ☐

Other): _____

6. Was your child?

Premature ☐

On-term ☐

Overdue ☐

7. Did your child crawl and if so, at what age?

Yes ☐

No ☐

Age (months): _____

8. Have there been any long-term specific reading, spelling or writing problems experienced by your child's- (tick all applicable)

Father ☐

Mother ☐

Brother ☐

Sister ☐

Grandparent ☐

Other close relative (please specify): _____

None of the above ☐

Thank you for your time and your child's participation

Experiments 1.2-1.3 Consent Forms:

Letter to Principal for control children

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Dyslexia Research Group

Dear Principle (X)

Trinity Early Screening Test for Cognitive Deficit. (TEST-CD)

We are contacting you on behalf of the Dyslexia Research Group which is based in the Department of Psychology, Trinity College, Dublin. The Group, at present, is working on the development of a new early screening test for dyslexia, the **Trinity Early Screening Test for Cognitive Deficit.** As part of our preliminary research we are carrying out a pilot study to determine whether our set of sub-tests provide a valid and reliable discriminator of dyslexia.

We will be working with two groups, one consisting of 100 dyslexic children aged between 8 and 12, and a control group of similar, IQ matched non-dyslexic children. We are writing to ask whether your school would be interested in helping us by enabling access to a group of your students as control participants.

This round of testing will focus on visual working memory as well aspects of visual attention. There is no reading or writing involved and all the subtests are non-intrusive. Participants will also be assessed for IQ using a well recognized standardized procedure. The testing will take approximately of 90-120 minutes per child in three 30-45 minute sessions. Each participant will be assessed individually first for IQ, and then with the TEST-CD. There will be a need to know group variables such as age, years of schooling etc. but all information will be completely confidential and will never be associated with a single child, all participants have the ability to withdraw from testing at any time.

Research unequivocally demonstrates that the earlier a child with a specific language learning disorder can be identified the better that child's prospects for normal language development. Thus we hope you can help us with our research. Should you wish to get involved, please reply at your earliest convenience, using the SAE enclosed. If you have any further questions, please do not hesitate to contact myself Justin Allman (01- 6082095) or Dr Ray Fuller, Project Director (01-6082426).
Yours sincerely,

Justin Allman
Post-graduate student.
Department of Psychology
Trinity College Dublin
Tel: + 353 1 608 2095

Letter to principal for dyslexic children:

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Dyslexia Research Group

Dear Principle (X)

Trinity Early Screening Test for Cognitive Deficit. (TEST-CD)

We are contacting you on behalf of the Dyslexia Research Group which is based in the Department of Psychology, Trinity College, Dublin. The Group, at present, is working on the development of a new early screening test for dyslexia, the **Trinity Early Screening Test for Cognitive Deficit**. As part of our preliminary research we are carrying out a pilot study to determine whether our set of sub-tests provide a valid and reliable discriminator of dyslexia.

We will be working with two groups, one consisting of 100 dyslexic children aged between 8 and 12, and the other a control group of similar IQ matched, non-dyslexic children. We are writing to ask whether your school would be interested in helping us by enabling access to a group of your students as participants for the Dyslexic group.

This round of testing will focus on tests of visual working memory, as well aspects of visual attention. There is no reading or writing involved and all the subtests are non-intrusive. A child's likelihood of suffering from Attention Deficit Disorder (ADD) will also be assessed. The testing will take approximately of 60-90 minutes per child in two 30-45 minute sessions. Each participant will be assessed individually first for IQ, and then with the TEST-CD. There will be a need to know group variables such as age, years of schooling etc. but all information will be completely confidential and will never be associated with a single child, all participants have the ability to withdraw from testing at any time. There will be a need to know group variables such as age and IQ of individual children, but all information will be completely confidential and will never be associated with a single child, all participants have the ability to withdraw from testing at any time.

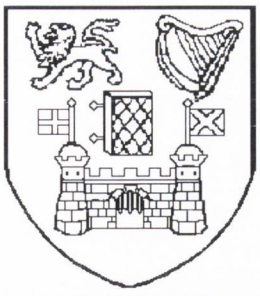
Research unequivocally demonstrates that the earlier a child with a specific language learning disorder can be identified the better that child's prospects for normal language development. Thus we hope you can help us with our research. Should you wish to get involved, please reply at your earliest convenience, using the SAE enclosed. If you have any

further questions, please do not hesitate to contact Justin Allman (01- 6082095) or Dr Ray Fuller, Project Director (01-6082426).

Yours sincerely,

Justin Allman
Post-graduate student.
Department of Psychology
Trinity College Dublin
Tel: + 353 1 608 2095

Letter to parents of control children:



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Dyslexia Research Group,

Dear Parent/Guardian,

I am contacting you as a member of the Dyslexic Research Group, based in Trinity College Dublin. One current aim of the Group is the development of a new early screening test for children at risk for Dyslexia, and I am responsible for the design and assessment of a new computerised component which is designed to identify developmental delay in certain basic cognitive activities such as attention and short-term memory. The participation of your child in this study would be most welcome.

Our prototype tests are about to be assessed to determine if they can reliably discriminate between children with dyslexia and those who are not dyslexic. (Their aim is not to determine if your child has dyslexia.) Any information obtained will be strictly confidential, at no point will an individual's results be presented in any report, and all participants will be anonymous. All participating children will have the right to leave the testing procedure at any time.

Testing will involve firstly an IQ assessment which will take approximately 30 minutes. Children will then be assessed on the new computerised tasks which will take a further 60-90 minutes. The assessment is not stressful at all to your child and will be carried out in three parts. There will be no need for your child to either read or write anything during the test, which is designed to assess aspects of visual and spatial memory and attention. The completed test will be of potential benefit to a great number of children, because the earlier a reliable diagnosis can be given, the earlier a child can receive appropriately targeted teaching and support.

I would very much appreciate the help of your child's participation in this research. Please complete the attached permission and Child Behaviour form and

return them to the school. If there is any history of difficulties in learning to read in the child's immediate family (parents or siblings), please note it in the space provided. Should you have any further questions, do not hesitate to contact me at 01-608-2095 e-mail: allmanjj@tcd.ie.

Yours sincerely,

Justin Allman
Post-graduate Student

PERMISSION FORM

Name of Child: _____

Date of birth: _____ Class:

_____

I give permission for my child to take part ☐

Signature of parent _____

Letter to Parents of Dyslexic children:

DEPARTMENT OF PSYCHOLOGY

TRINITY COLLEGE
DUBLIN 2

Tel + 353-1-6081886 (Department)
Tel + 353-1-6082426 (Direct Personal Line)

Fax +353-1-6712006
E-mail rfuller@tcd.ie

Dyslexia Research Group,

Dear Parent/Guardian,

I am contacting you as a member of the Dyslexic Research Group, based in Trinity College Dublin. One current aim of the Group is the development of a new early screening test for children at risk for Dyslexia, and I am responsible for the design and assessment of a new computerised component which is designed to identify developmental delay in certain basic cognitive activities such as attention and short-term memory. The participation of your child in this study would be most welcome.

Our prototype tests are about to be assessed to determine if they can reliably discriminate between children with dyslexia and those who are not dyslexic. (Their aim is not to determine if your child has dyslexia.) Any information obtained will be strictly confidential, at no point will an individual's results be presented in any report, and all participants will be anonymous. All participating children will have the right to leave the testing procedure at any time.

The test will take about 60-90 minutes, will be split between two sessions. The assessment is not stressful at all to your child and there will be no need to for your child to either read or write anything during the test, which is designed to assess a range of skills, particularly aspects of visual and spatial memory and attention. The completed test will be of potential benefit to a great number of children, because the earlier a reliable diagnosis can be given, the earlier a child can receive appropriately targeted teaching and support.

I would very much appreciate the help of your child's participation in this research. Please complete the attached permission and Child Behaviour form and return them to the school. If there is any history of difficulties in learning to read in

the child's immediate family (parents or siblings), please note it in the space provided. Should you have any further questions, do not hesitate to contact me at 01-608-2095 e-mail: allmanjj@tcd.ie.

Yours sincerely,

Justin Allman

Post-graduate Student

PERMISSION FORM

Name of Child: _____

Date of birth: _____ Class: _____

I give permission for my child to take part ☐

Signature of parent _____

Experiments 2-6 Consent Forms:

Letter to Principal for Age Matched Control Children:



SCHOOL OF PSYCHOLOGY

TRINITY COLLEGE
DUBLIN 2

Tel + 353-1-6081886 (School)
Tel + 353-1-6082095 (Direct Personal Line)
Fax +353-1-6712006
Email: allmanjj@tcd.ie

Dyslexia Research Group

Dear Principal (X)

Trinity Early Screening Test for Cognitive Deficit (TEST-CD)

I am contacting you as a member of the Dyslexia Research Group which is based in the School of Psychology, Trinity College Dublin. I am, at present, working on the development of a new early screening test for cognitive developmental delay which may underpin dyslexia, as well as other difficulties, the **Trinity Early Screening Test for Cognitive Deficit**. As part of the ongoing research I am carrying out a research study to determine whether my set of sub-tests provides a valid and reliable discriminator of dyslexia.

I will be working with three groups, one consisting of 30+ dyslexic children aged between 9 and 11 and two control groups. The control groups consist of developmentally normal individuals which will be matched with the dyslexic children for age, gender and IQ, and a second control group of younger developmentally normal children that are matched with the dyslexic children on their spelling and reading comprehension ability. I am writing to ask whether your school would be interested in helping by enabling access to a group of your students as control participants.

This testing will involve a computer based assessment which focuses on pictorial-based memory tasks, as well as measures of visual sustained attention. The testing will take approximately 95-160 minutes per child and would be carried out in three sessions. Tests are non-intrusive, and participants will be initially assessed using standardized procedures for IQ, Attention Deficit Disorder (ADD) as well as Reading and Spelling ability, as a means of matching them with the Dyslexic participants. This part of the assessment will take approximately 25 minutes. In the Second, Third and Forth session the participants will then be assessed using the TEST-CD which will take approximately 30-45 minutes per session. There will be a need to know information such as the child's age and years of schooling etc. All information, data collected will be completely confidential and will never be associated

with a single child, and will be held in a secure environment, all participants have the freedom to withdraw from testing at any time.

Research unequivocally demonstrates that the earlier a child with a specific language learning disorder can be identified the better that child's prospects for normal language development. Thus I hope you can help me with my research. Should you wish to get involved, please reply at your earliest convenience, or if you have any further questions, please do not hesitate to contact myself Justin Allman (01- 6082095) or Prof. Ray Fuller, Project Director (01-6082426).

Yours sincerely,

Justin Allman

Post-graduate student

Letter to Principal for Dyslexic children:

SCHOOL OF PSYCHOLOGY

TRINITY COLLEGE
DUBLIN 2

Tel + 353-1-6081886 (School)
Tel + 353-1-6082095 (Direct Personal Line)
Fax +353-1-6712006
Email: allmanjj@tcd.ie
Dyslexia Research Group

Dear Principal (X),

Trinity Early Screening Test for Cognitive Deficit (TEST-CD)

I am contacting you as a member of the Dyslexia Research Group which is based in the School of Psychology, Trinity College Dublin. I am, at present, working on the development of a new early screening test for cognitive developmental delay which may underpin dyslexia, as well as other difficulties, the **Trinity Early Screening Test for Cognitive Deficit**. As part of the ongoing research I am carrying out a research study to determine whether my set of sub-tests provides a valid and reliable discriminator of dyslexia.

I will be working with three groups, one consisting of 30+ dyslexic children aged between 9 and 11 and two control groups. The control groups consist of developmentally normal individuals which have been matched with the dyslexic children for age, gender and IQ, and a second control group of younger developmentally normal children that are matched with the dyslexic children on their spelling and reading comprehension ability. I am writing to ask whether your school would be interested in helping by enabling access to a group of your students who could be participants in the Dyslexic group.

The testing will involve computer based assessment which focuses on pictorial-based memory tasks, as well as measures of visual sustained attention. The Assessment is designed to pry apart what differences exist between differing modes of presentation, and if these differences are consistent across developmental conditions. The testing will take approximately 90-160 minutes per child and would be carried out in a 4 sessions. Tests are non-intrusive, will involve standardized questionnaires for Attention Deficit Disorder and a need to know relevant background information such as the child's age, years of schooling, IQ, spelling and reading comprehension as a means of matching dyslexic participants up with developmentally normal participants. All information, data collected will be completely confidential and will never be associated with a single child, all information held will be

stored in a password protected digital environment, with all participants having the freedom to withdraw from testing at any time.

Research unequivocally demonstrates that the earlier a child with a specific language learning disorder can be identified the better that child's prospects for normal language development. Thus I hope you can help me with my research. Should you wish to get involved, please reply at your earliest convenience, or if you have any further questions, please do not hesitate to contact myself Justin Allman (01- 6082095) or Prof. Ray Fuller, Project Director (01-6082426).

Yours sincerely,

Justin Allman

Post-graduate student

Letter to Principal for Reading age matched control children:

SCHOOL OF PSYCHOLOGY

TRINITY COLLEGE
DUBLIN 2

Tel + 353-1-6081886 (School)
Tel + 353-1-6083907 (Direct Personal Line)
Fax +353-1-6712006
Email: allmanjj@tcd.ie
Dyslexia Research Group

Dear Principal,

Trinity Early Screening Test for Cognitive Deficit (TEST-CD)

I am contacting you as a member of the Dyslexia Research Group which is based in the School of Psychology, Trinity College Dublin. I am, at present, working on the development of a new early screening test for cognitive developmental delay which may underpin dyslexia, as well as other difficulties, the **Trinity Early Screening Test for Cognitive Deficit**. As part of the ongoing research I am carrying out a research study to determine whether my set of sub-tests provides a valid and reliable discriminator of dyslexia.

I will be working with three groups, one consisting of 30+ dyslexic children aged between 9 and 11 and two control groups. The control groups consist of developmentally normal individuals which will be matched with the dyslexic children for age, gender and IQ, and a second control group of younger developmentally normal children that are matched with the dyslexic children on their spelling and reading comprehension ability. I am writing to ask whether your school would be interested in helping by enabling access to a group of your students as reading-age matched control participants. We would like access to children aged between 6-8, these participants would have no history of or concerns relating to their reading or spelling ability, and would be considered an average student.

This testing will involve a computer based assessment which focuses on pictorial-based memory tasks, as well as measures of visual sustained attention. The testing will take approximately 95-160 minutes per child and would be carried out in four sessions. Tests are non-intrusive, and participants will be initially assessed using standardized procedures for IQ, Attention Deficit Disorder (ADD) as well as Reading and Spelling ability, as a means of matching them with the Dyslexic participants. This part of the assessment will take approximately 25 minutes. In a Second, Third and Forth session the participants will then be assessed using the TEST-CD which will take approximately 30-45 minutes per session. There will be a need to know information such as the child's age and years of schooling etc. All

information, data collected will be completely confidential and will never be associated with a single child, and will be held in a secure environment, all participants have the freedom to withdraw from testing at any time.

Research unequivocally demonstrates that the earlier a child with a specific language learning disorder can be identified the better that child's prospects for normal language development. Thus I hope you can help me with my research. Should you wish to get involved, please reply at your earliest convenience, or if you have any further questions, please do not hesitate to contact myself Justin Allman (01- 6083907) or Prof. Ray Fuller, Project Director (01-6082426).

Yours sincerely,

Justin Allman

Post-graduate student

Letter Parents of Control children:

SCHOOL OF PSYCHOLOGY

TRINITY COLLEGE
DUBLIN 2

Tel + 353-1-6081886 (School)
Tel + 353-1-6083907 (Direct Personal Line)
Fax +353-1-6712006
Email: allmanjj@tcd.ie
Dyslexia Research Group,

Dear Parent/Guardian,

I am contacting you as a member of the Dyslexic Research Group, based in Trinity College Dublin. One current aim of the Group is the development of a new early screening test for children at risk for Dyslexia, and I am responsible for the design and assessment of new computerised components which are intended to identify developmental delay in certain basic cognitive activities such as attention and short-term memory. To this end the study requires children who are developmentally normal to be matched up with a second group of dyslexic children on a range of attributes such as age, gender, IQ etc. as a means of assessing normal development and ability ranges from potentially abnormal ones. The participation of your child as a developmentally normal control child in this study would be most welcome.

Our prototype tests are about to be assessed to determine if they can reliably discriminate between children with dyslexia and those who are not dyslexic. (Their aim is not to determine if your child has dyslexia.) . The testing will involve computer based assessment which focuses on pictorial-based memory tasks, as well as measures of attention.

Testing will involve firstly an assessment of IQ, Spelling and Reading comprehension which will take approximately 25 minutes. In a second, third and forth session children will then be assessed using the new computerised tasks which will take a further 30-45 minutes per session. The assessment is not stressful at all to your child. The tests are designed to assess aspects of memory and attention, specifically relating to differences between the way in which information is displayed and how this relates to later ease of recall, and whether these differences are consistent across developmental types. Any information obtained will be strictly confidential, at no point will an individual's results be presented in any report, and all participants will be anonymous, with all data collected held in a password protected environment. All participating children will have the right to leave the testing procedure at any time. The completed test will be of potential benefit to a great number of children, as the earlier a reliable diagnosis can be given, the earlier a child can receive appropriately targeted teaching and support.

I would very much appreciate the help of your child's participation in this research. Please complete the attached permission and Child Behaviour form and return them to the school. If there is any history of difficulties in learning to read in the child's immediate family (parents or siblings), please note it in the space provided. Should you have any further questions, do not hesitate to contact me at 01-608-3907 e-mail: allmanjj@tcd.ie.

Yours sincerely,

Justin Allman

Post-graduate Student

Trinity Early Screening Test for Cognitive Development (TEST-CD)

PERMISSION FORM

Name of Child: _____

Please Tick the box to give permission for your child to take part in the TEST-CD study ☐

Signature of parent _____

Date _____

FURTHER INFORMATION:

Date of birth: _____ Class: _____

Teachers Name:_____ Years of schooling: _____

Is there any history of reading/spelling problems in the family? _____

If so please give relevant details. _____

_____

_____

_____

_____

_____

_____

Letter to Parents of Dyslexic Children:



SCHOOL OF PSYCHOLOGY

TRINITY COLLEGE
DUBLIN 2

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Tel + 353-1-6082095 (Direct Personal Line) Email: allmanjj@tcd.ie

Dyslexia Research Group,

Dear Parent/Guardian,

I am contacting you as a member of the Dyslexic Research Group, based in Trinity College Dublin. One current aim of the Group is the development of a new early screening test for children at risk for Dyslexia, and I am responsible for the design and assessment of new computerised components which are intended to identify developmental delay in certain basic cognitive activities such as attention and short-term memory.

The project will be working with three groups, one consisting of dyslexic children aged between 9 and 11 and two groups of control children. The control groups consist of developmentally normal individuals which have been matched with the dyslexic children for age, gender and IQ, and a second control group of younger developmentally normal children that are matched with the dyslexic children on their spelling and reading comprehension ability. The testing will involve computer based assessment which focuses on pictorial-based memory tasks, as well as measures of attention. The tests are designed to assess aspects of memory and attention, specifically relating to differences between the way in which information is displayed and how this relates to later ease of recall, and whether these differences are consistent across developmental types. The participation of your child as a member of the dyslexic group in this study would be most welcome.

The prototype tests are being assessed to determine if they can reliably discriminate between children with dyslexia and those who are not dyslexic. (Their aim is not to determine if your child has dyslexia.) Any information obtained will be strictly confidential, at no point will an individual's results be presented in any report, and all participants will be anonymous, with all data collected held in a password protected environment. All participating children will have the right to leave the testing procedure at any time. Testing will take approximately 95-160 minutes, which will be split across 4 sessions and will not be stressful at all to your child. The completed test will be of potential benefit to a great number of children, as the earlier a reliable diagnosis can be given, the earlier a child can receive appropriately targeted teaching and support.

I would very much appreciate the help of your child's participation in this research. Please complete the attached permission and Child Behaviour form and return them to the school. If there is any history of difficulties in learning to read in the child's immediate family (parents or siblings), please note it in the space provided. Should you have any further questions, do not hesitate to contact me at 01-608-2095 e-mail: allmanjj@tcd.ie.

Yours sincerely,

Justin Allman

Post-Graduate Student

Trinity Early Screening Test for Cognitive Development (TEST-CD)

PERMISSION FORM

Name of Child: _____

Please Tick the box to give permission for your child to take part in the TEST-CD study ☐

Signature of parent _____

Date _____

FURTHER INFORMATION:

Date of birth: _____ Class: _____

Teachers Name:_____ Years of schooling: _____

How many years/months of remedial help has your child received:_____

Is there any history of reading/spelling problems in the family? _____

If so please give relevant details. _____

_____

_____

_____

_____

_____

_____

Department of Psychology
University of Dublin, Trinity College
Dublin 2, Ireland

Tel: +353 1 608 1886
Fax: +353 1 671 2006

Department of Psychology
Ethics Committee

22/07/2005

Dear Justin Allman

The Department of Psychology Ethics Committee met recently to consider your application entitled
Trinity early screening test for cognitive development

I am pleased to inform you that the Committee has approved your application, subject to you making the following changes.

- Provide information on data storage + how long the data will be retained
- Do not use the term 'dyslexics', use an alternative such as 'person with dyslexia'
- 'Principle' change to 'Principal'
- Provide more information on consent form.

Yours sincerely,

Kevin Tierney
Chairperson,
Department of Psychology Ethics Committee

Department of Psychology
University of Dublin, Trinity College
Dublin 2, Ireland

Tel: +353 1 60
Fax: +353 1 67

Head of Department: Professor Ian Robertson

Department of Psychology
Ethics Committee

February 12, 2002

Dear Justin Allman and Erin O'Brien,

The Department of Psychology Ethics Committee met recently to consider your application for approval. The Committee decided to approve your application provided the following conditions are met:

- that Garda clearance is obtained for all research involving children.

- that the nature of the task should be explained to the parents in the information sheet. We also recommend that you obtain consent from the children themselves.

- that the tapes be stored for at least one year, and not destroyed as indicated (see information on the Freedom of Information Act).

- That your names and status (e.g. post-graduate students) are clearly indicated on the information sheet.

Please note that it is not necessary to resubmit the application form to the Committee.

Yours sincerely,

Fiona Newell
(on behalf of the Department of Psychology Ethics Committee)