The Visuospatial Sketch Pad (VSSP): Investigating the Dissociation of Visual and Spatial Imagery and Storage and their Roles in Reading.

By

Jodie Royan
B.A., Carleton University, 2000
M.A., Carleton University, 2001

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Supervisory Committee

Dr. Roger Graves (Department of Psychology)
Supervisor

Dr. Jim Tanaka (Department of Psychology)
Departmental Member

Dr. Dan Bub (Department of Psychology)
Departmental Member

Dr. John Walsh (Department of Educational Psychology)
Outside Member

Dr. Dawn Good (Department of Psychology, Brock University)
External Member

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Abstract

Baddeley and Hitch (Baddeley & Hitch, 1974) have described a model of working memory which explains how information can be temporarily held 'on-line' in order to carry out everyday cognitive tasks such as learning, reasoning, and comprehension. One component of this model, the visuospatial sketchpad (VSSP), has not been as well described as other components of the model and there is some debate over its structure. Furthermore, the everyday cognitive importance of the VSSP has not been well researched. A battery of visual and spatial measures was developed to investigate the structure of the VSSP and its potential role in reading. A principal component analysis on a group of normal, undergraduate participants did not reveal the expected dissociation of visual from spatial processing. However, a dissociation was found in a group of dyslexic individuals. A series of multiple regressions revealed that while neither visual nor spatial processing reliably contributed to reading ability in normals, spatial processing contributed to reading fluency in the dyslexic sample. These findings suggest that while shared variance techniques fail to reveal the visual vs. spatial dissociation in working memory in normals, the dissociation can be revealed by clinical samples. In general, it appears that the ability to maintain visual vs. spatial information in working memory requires distinct cognitive processes. Furthermore, there is a relationship between VSSP processing and reading. This study has opened many doors for future research on the structure of the model and its importance for reading.

Table of Contents

List of Tables

List of Figures

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Introduction

Baddeley and Hitch (Baddeley & Hitch, 1974) have described a model of working memory which explains how information can be temporarily held 'on-line' in order to carry out everyday cognitive tasks such as learning, reasoning, and comprehension (Baddeley, 1996). The model consists of three separate systems: the central executive, the phonological or articulatory loop, and the visuospatial sketch pad (VSSP). The role of the central executive is that of a coordinator, whose responsibility is to focus and switch attention as well as to coordinate the articulatory loop and VSSP. The articulatory loop and VSSP are two specialized temporary memory systems that are responsible for actively maintaining modality-specific memory traces (Baddeley & Logie, 1999b). These two systems are often referred to as 'slave' systems.

The activities of the VSSP have not been as clearly drawn out as those of the phonological loop and there is still some debate over what type of information is primarily processed in this system how it should be fractionated. A growing body of evidence from cognitive psychology and neuropsychology suggests that the system for handling visuospatial information can be sub-divided into separate spatial and visual systems (c.f. Baddeley, 2006; Pickering, 2001; Repovs & Baddeley, 2006). A popular model suggests that the visual subsystem is related to storage while the spatial subsystem is related to manipulation of visuospatial information in working memory. Logie and his associates (Logie, 1986, 1995; Logie & Marchetti, 1991; Logie & Pearson, 1997; Salaway & Logie, 1995) are the main proponents of this visually/spatially dissociated VSSP (see Figure 1). Logie's theory is that the VSSP, much like the phonological loop, can be dissociated into temporary storage and active rehearsal components, a view which is also supported by Baddeley (2003b; 2006; Baddeley & Logie, 1999b).

The purpose of the proposed study is to explore and develop Baddeley and Logie's current model of the VSSP. As shown in Figure 1 (B), one possible development of the VSSP would be to include separate storage and rehearsal mechanisms for each of the visual and spatial subsystems. This model is similar to Logie's (Figure 1 A) in that it includes temporary storage and active rehearsal components. However, unlike Logie who only proposed a temporary passive store for visual information, the proposed model consists of two temporary stores, one for visual information (analogous to the visual cache) and one for spatial information (a completely new module). The proposed model is different from Logie's in that two active rehearsal modules are proposed: one for spatial information (analogous to the inner scribe) and one for visual information (a new module). As discussed in detail in later sections, the temporary visual and spatial stores are proposed to be linked to perception, much like Logie proposed a visual cache/visual perception connection. Also, the rehearsal components are proposed to be linked to visual and spatial imagery.

To examine the dissociation between visual and spatial storage and visual and spatial imagery, relationships amongst measures (immediate recall and mental manipulation respectively) of these behaviours will be examined in a group of cognitively intact individuals. It is expected that: (1) measures of spatial imagery will be more highly correlated to each other than to measures of spatial storage, (2) measures of visual imagery will be more highly correlated to each other than to measures of visual storage, and (3) in general, spatial and visual measures will not be as highly correlated compared to correlations within each dimension.

In addition to examining the relationship between visual and spatial measures in a group of cognitively intact individuals, these individuals were contrasted to a series of individual participants with dyslexia. Given that certain types of dyslexia are associated with spatial, but not visual processing abnormalities, it is expected that these individuals will perform more poorly on spatial than visual measures.

Finally, as discussed in the following sections, there is evidence to suggest that the VSSP might be important for reading. However, there has been no direct research on the functional importance of the VSSP for reading. So, a secondary goal of this study is to examine which components of the VSSP (spatial vs. visual) might be related to reading ability. Given that research from individuals with dyslexia have revealed spatial processing deficits in this group (see discussion below), it is expected that either spatial storage or imagery (or both) will be more highly related to reading ability than visual processing.

Working Memory

The development of Baddeley's working memory model

The history of working memory (WM) can be traced back to when the term working memory was first used (c.f. Baddeley, 2002) in 1960 by Miller, Galanter, and Pribram (1960). At the time Miller and colleague's book was published, research into the separation of short term memory (STM) from long term memory (LTM) had begun to proliferate following Hebb's (1949) proposal for the STM/LTM distinction. Miller and colleagues (1960) suggested that the most forward part of the frontal lobes served as a 'working memory' where plans of action (i.e. plans to execute certain behaviours) could be temporarily retained while being formed, transformed or executed.

Following Miller and colleagues' (1960) introduction of the term WM, Atkinson and Shiffrin (1968) introduced a multi-stage model for short term memory which included a unitary short term store (STS) responsible for the temporary retention of information from all sensory modalities, similar in some ways to the WM described by Miller and colleagues (i.e. temporary retention of information for action on experimental tasks). Around the same time Atkinson and Shiffrin introduced their memory model, Baddeley was conducting research (1966a; 1966b) on the short term retention of verbal information and shortly thereafter published a new model of working memory (Baddeley & Hitch, 1974) which differed from Atkinson and Shiffrin's model in two important ways.

One difference between the models was that while Atkinson and Shiffrin (1980) portrayed WM as just one unitary system of the STS responsible for incoming sensory information from all modalities, Baddeley and Hitch (1974) suggested that WM was a *separate* and multifaceted component of the STS. Not only was it separate from the STS, but there were different subsystems responsible for different types of material. Another difference between the models, is that while Baddeley and Hitch emphasized the functional role of working memory in cognitive activities such as learning, reasoning, and comprehension (Baddeley, 1996), Atkinson and Shiffrin emphasized the role of short term memory in phenomena such as forgetting (Atkinson, 1975).

Baddeley and Hitch described WM as a 3-part system responsible for the temporary maintenance and manipulation of information during various cognitive tasks such as comprehension, learning, and reasoning. The responsibilities of the phonological loop are to hold acoustic or speech-based information in the form of memory traces and to refresh these memory traces through subvocal rehearsal to prevent their decay. Subvocalization is also used to register visually presented material, including words or pictures, in the phonological store (Baddeley, 1992). As mentioned earlier, the activities of the VSSP have not been as clearly drawn out as those of the phonological loop and there is still some debate over what type of information is primarily processed in this system how it should be fractionated. The purpose of the proposed investigation will be to explore a new extension to the current VSSP.

Visual vs. spatial dissociation of the VSSP

A double dissociation (cf. Friedman & Polson, 1981) between visual and spatial processing in working memory has been demonstrated in the past using dual task paradigms (e.g. Friedman & Polson, 1981; Kinsbourne & Cook, 1971) with non-clinical populations. For example, one group of researchers using a dual task paradigm proposed that a system called the visual cache is responsible for the temporary, passive maintenance of visual information such as the properties of objects and scenes including visual form and colour (Logie & Pearson, 1997; Salaway & Logie, 1995). Conversely, they suggested that a more active component of the VSSP, the spatially oriented inner scribe, is responsible for the retention (Logie & Pearson, 1997) of spatial relations amongst objects and movement sequences through rehearsal.

One missing element to Logie and colleagues' research is that they fail to consider possible mechanisms for the active rehearsal of visual information or the passive retention of spatial information. Since the retention and rehearsal mechanisms of the phonological loop serve to support verbal information alone, then perhaps there are also separate retention and rehearsal mechanisms for both visual and spatial information. However, this possibility has not been addressed by Logie's model.

A survey of clinical evidence does provide evidence for a double dissociation of visual and spatial rehearsal (via imagery performance) as well as for visual and spatial storage processes (via recall performance). In the following examples, the functional independence of visual and spatial subsystems is implied by the fact that each one can continue to function the absence of the other (Farah & Hammond, 1988). Evidence for a double dissociation of visual and spatial imagery comes from the patients LH (Farah & Hammond, 1988) and EP (Luzzatti, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998). LH had impaired visual but spared spatial imagery (Farah & Hammond, 1988) while EP had impaired spatial but spared visual imagery (Luzzatti et al., 1998).

Evidence for a double dissociation of visual and spatial storage processes comes from the patients LE (Wilson, Baddeley, & Young, 1999) and MV (Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001). The patient LE (Wilson et al., 1999) had impaired storage processes in visual working memory but preserved storage processes in spatial working memory. Conversely, in the case of MV (Carlesimo et al., 2001), visual recall performance was spared, while spatial recall was impaired. Furthermore, in the case of LE, visual imagery was impaired while spatial imagery was spared while MV had impaired spatial imagery but spared visual imagery.

Taken together, the impaired and preserved functioning in these brain damaged individuals speaks against Logie's proposal that there is a visual cache responsible only for storage of visual information and an inner scribe responsible for only the rehearsal of spatial information. For example, damage to neither the inner scribe nor to the visual cache would explain MV's loss of the ability to store spatial information. Similarly, damage to either of these two systems would not explain LE's inability to manipulate visual information. What might be needed then, is a modification to Logie's theory whereby the visual cache and the inner scribe are each responsible for both the maintenance and rehearsal of information via distinct cognitive systems (Morton & Morris, 1995; Pickering, 2001).

Passive vs. active dissociation of the VSSP

As other authors have pointed out (e.g. Baddeley, 2003b; Pickering, 2001), Logie's challenge of a unitary VSSP is not the only one. Another model differentiates not only between both the nature of the information being processed (i.e. visual or spatial), but also whether the processing of this information is passive or active (Cornoldi, Rigoni, Venneri, & Vecchi, 2000; Vecchi & Cornoldi, 1999; Vecchi & Girelli, 1998; Vecchi, Monticellai, & Cornoldi, 1995). According to the passive/active model, passive processing includes the retention of visuospatial information without alteration in a passive visual store. An example of a passive task is the presentation of a pattern of black squares within a matrix, which a participant must memorize and reproduce on a blank matrix. At the other end of the spectrum, active processing involves the initiation of imagery operations when visuo-spatial information needs to manipulated or re-organized (Vecchi et al., 1995). An example of an active task is one that is similar to the passive task except that the pattern to be retained by the participant is an imagined pattern within a matrix constructed according to verbal statements of direction provided by the examiner.

Using tasks similar to those just described, researchers have found that passive and active processing abilities vary with age (Vecchi & Cornoldi, 1999) and can also differentiate subtypes of nonverbal learning-disabled children (Mammarella et al., 2006). Based on their findings for differences in passive and active processing of visuo-spatial information, the proponents of the passive/active theory suggest that a modified model of the VSSP should involve more than a simple division according to the intrinsic nature of the information being processed (Vecchi & Cornoldi, 1999; Vecchi & Girelli, 1998; Wilson et al., 1999). Instead, the VSSP should be dissociated into a passive store responsible for retaining visuospatial information without performing any modifications and an active process required for manipulating or re-organizing visuospatial information (Vecchi et al., 1995). However, as Pickering points out (2001) a major methodological problem in the passive/active research is that the tasks used to assess active processing might actually involve the central executive, which would account for the dissociation from the passive tasks which do not involve the central executive. Alternatively, the differences in the preceding tasks could actually reflect a dissociation between storage and imagery, which as outlined below, could be incorporated as a further dissociation of visual from spatial processing in the VSSP.

A revision of the VSSP

Baddeley and Hitch's original working memory model could be altered to include four rather than three separate subsystems: the phonological loop for on-line retention and manipulation of auditory information, a spatial system for retention and manipulation of spatial information (imagined or physical movements as well as imagined or actual relations between objects or object localization), a visual system for visual information (physical properties of objects such as shape and colour), and the central executive for co-ordination of the modality-specific systems and allocation of attentional resources. Like the phonological loop, both the visual and spatial subsystems could have separate storage and rehearsal functions. Thus, the original, unitary VSSP would be dissociated into 4 subcomponents: visual storage, visual rehearsal, spatial storage, and spatial rehearsal. As illustrated in Figure 1, this proposed model differs from that proposed by Logie which included only 2 subcomponents: visual cache (i.e. passive visual storage) and inner scribe (i.e. active spatial rehearsal).

The mechanisms for the storage of visual and spatial information might be related to visual and spatial perceptual processing, which seem to be subserved by separate cortical pathways (Mishkin, Ungerleider, & Macko, 1983). Following Wernicke's (1874) theory that different perceptual processes can be localized to different areas of the cortex and that these sensory perceptions can last longer than the stimuli themselves in the forms of memory images, then perhaps the separate visual and spatial perceptual processes provide mechanisms for the dissociated storage of visual and spatial material.

This hypothesis for the link between perceptual processing and memory is implied in Craik and Lockhart's levels of processing theory (Craik & Lockhart, 1972), which specifies that the analyses (including sensory processing) of incoming stimuli form the basis of awareness of the stimuli and provide a source for short-term memory (Craik & Jacoby, 1975). Furthermore, there is evidence to suggest that short-term memory is linked to the identification of stimuli (Graves, 1973) that forms part of sensory processing and storage (Graves, 2001). While the research from Craik and Lockhart and from Graves refers to short term memory, the link between perception and storage could also apply to working memory where perceptual analysis of visual and spatial stimuli is tied to storage in separate visual and spatial systems.

Logie and Marchetti (Logie & Marchetti, 1991) have illustrated a link between visual perception and storage in working memory. These researchers presented participants with a series of colour hues to be retained and then recalled, at the same time, irrelevant pictures of common objects were presented as an interference task. The idea was that the pictures were simply being perceived, but not processed in any meaningful way. The results indicated that the perceptual interference reduced the participant's ability to accurately retain and recall the colour hues. On the other hand, Logie and Marchetti (1991) found that a secondary spatial task did not interfere with the ability to retain colour hues. Based on these results, it appeared that there was a common cognitive system for the storage and perception of visual input.

In terms of visual rehearsal, imagery processes may be used to rehearse visual information (or images) in a system analogous to Kosslyn's visual buffer (Kosslyn, 1991).

Visual images can be described as representations that encode the literal appearance of objects including properties not available from modalities other than vision (Farah, Levine, & Calvanio, 1988). As Kosslyn states "Image maintenance can be considered as a special case of image generation, with the generation mechanisms simply being used repeatedly to refresh an existing pattern of activation in the visual buffer." (Kosslyn, 1991). If visual imagery (i.e. mentally 'viewing' and manipulating images of objects or scenes) is the mechanism for refreshing stored memory traces, then there should be evidence for impaired maintenance of visual information when visual imagery processes are impaired. One case, LE (Wilson et al., 1999) had deficits in both visual imagery and storage of visual information, which suggests that this hypothesis could be true.

If the visual processing system has its own rehearsal mechanism in the form of visual imagery, then the spatial system could also have its own rehearsal system for spatial representations. Spatial representations can be described as the representations of the layout of objects in space, or the relations between different parts of a visual scene, with respect to the viewer and to each other (Farah et al., 1988). The types of imagery tasks that are typically referred to in the literature with respect to spatial representations include mental scanning and rotation of images (with respect either to each other or to the viewer). The evidence to support impaired maintenance of spatial information when imagery processes are impaired is not as straightforward as that for the visual system. In some patients with spatial imagery deficits, there is preserved storage of spatial information (e.g. MG: Morton & Morris, 1995; LE: Wilson et al., 1999). Yet, another case, MV (Carlesimo et al., 2001), has both impaired spatial imagery and impaired storage of spatial information. Thus, it seems that impaired spatial imagery ability can possibly lead to problems with maintenance, as the case of MV demonstrates. However, it also seems that imagery or rehearsal is not always necessary for maintenance, as the other two cases demonstrate. This finding is consistent with Baddeley and Logie (1999c) who suggest that while initial activation of a memory trace (either through visual or spatial perception) is necessary for processing in working memory, active rehearsal is considered an optional means of enhancing performance and is not obligatory.

Give the preceding findings, a re-evaluation of new the VSSP is in order. The evidence speaks to a dissociation of spatial storage and rehearsal from visual storage and rehearsal, however; to date these dissociations have not been investigated together in one investigation. As previously indicated, one purpose of the proposed investigation is to examine the pattern of relationships amongst visual and spatial imagery and storage measures within the context of a revised VSSP.

Neuroanatomical dissociations of visual and spatial processing in working memory

Neuroimaging research

In line with the preceding suggestion for separate visual and spatial perceptual processes and storage mechanisms, a number of neuroimaging studies have likewise examined the neuroanatomically distinct correlates of visual and spatial processing in working memory. While some authors feel that there is a lack of consensus regarding the neuroanatomical correlates for visual and spatial processing in working memory (Baddeley & Logie, 1999a), the pattern of results from several neuroimaging studies reveals some noticeable trends. While early research focused more on the lateralization of visual and spatial working memory (1975) to left and right cerebral hemispheres respectively, more recent research reflects the findings of Mishkin and colleagues (1983) for two separate pathways for vision.

For example, a number of neuroimaging studies provide evidence for the localization of spatial processing to dorsal areas. As Table 1 illustrates, the dorsal areas that are consistently activated in studies using spatial processing tasks include parts of the striate cortex (Broadmann's area 17), the prestriate cortex (Broadmann's areas 18 and 19) and the posterior parietal cortex (Broadmann's areas 40 and 7). Of course, there are other areas activated in most of these studies. One reason for this is that the tasks are not exactly the same from one study to the next. For example, Smith et al.'s (1993) spatial memory task involved retaining the location of three dots presented on a computer screen while Courtney et al. (1996) used a task that involved retaining the location of several faces presented on a computer screen. In addition to differences in the tasks used, many of the spatial processing tasks involve the central executive for processes such as encoding (Owen, Milner, Petrides, & Evans, 1996). Consequently, frontal areas are often activated in addition to the occipital and parietal areas.

While the neuroimaging evidence suggests a relation between spatial processing and dorsal activation, it also suggests a relation between visual processing and ventral activation. As Table 2 illustrates, these areas of activation include the striate (Broadmann's area 17) the prestriate (Broadmann's areas 18 and 19), and inferior temporal cortex (Broadmann's areas 37 and 20). There are a number of other areas activated in the neuroimaging studies; however, these are likely due to the different tasks used in each case.

Based on the neuroimaging evidence, the areas that Mishkin and colleagues (1983) proposed to be important for object and spatial perception might also be important for the storage of visual and spatial information (Goldberg, Berman, Randolph, Gold, & Weinberger, 1996; Mishkin et al., 1983). That is, ventral areas including the inferior temporal cortex and dorsal areas including the posterior parietal cortex seem to be involved in the perception and maintenance of visual (or object) and spatial information respectively.

While there is a rather large body of research concerning the neuroanatomical correlates of visual and spatial perception, there is more speculation regarding the areas responsible for imagery. According to some research, the occipital areas (e.g. areas 18 and 19) could be responsible for visual and spatial imagery (Goldberg et al., 1996). However, this is not consistent with the theory that visual and spatial rehearsal processes are separate since these areas are activated for both visual and spatial processing in working memory.

Findings from patient studies seem to provide more support for dissociable imagery correlates than the neuroimaging research. For example, a double dissociation from the cases described earlier does support the dissociation of visual and spatial rehearsal processes. Some patients had impaired visual imagery but preserved spatial imagery; including LH (Farah & Hammond, 1988), and LE (Wilson et al., 1999) while others had impaired spatial but preserved visual imagery; including MG (Morton & Morris, 1995), EP (Luzzatti et al., 1998), and MV (Carlesimo et al., 2001). One way to determine the localization of visual and spatial rehearsal processes would be to use neuroimaging methods to determine which areas are activated specifically for the visual and spatial imagery tasks used in the cognitive and case study literature.

The VSSP and reading

In addition to developing a new model of visual spatial processing in working memory, this study also seeks to investigate the potential functional importance of the VSSP in everyday life. The importance of the VSSP, whether unitary or divided, has not been extensively discussed or studied. There has been one study on the role of visual-spatial processing in chess

(Saariluoma, 1991); however, there have been no studies for its role in common everyday activities. Baddeley (2006) has suggested that spatial processing in WM might predict success in occupations such as architecture or engineering and may be related to everyday activities such as way-finding. Furthermore, Baddeley and Logie (1999c) have suggested that the VSSP might be important for reading by holding and maintaining some type of VSSP framework; but, the nature of this framework or how it is held and maintained was not discussed. One clue towards the potential role of the VSSP in reading might come from individuals with a specific reading disability (SRD), or dyslexia, who have demonstrated specific spatial processing, but not necessarily visual processing, abnormalities.

Some researchers propose that part of the dorsal pathway for spatial processing, the magnocellular pathway, might be damaged in people with SRD (Graves, Frerichs, & Cook, 1999; Livingstone, Rosen, Drislane, & Galaburda, 1991; Lovegrove, 1996). In line with this proposal, research has shown that individuals with SRD have difficulty with a magnocellular function, visual localization (Graves et al., 1999), when compared to a group of non-Dyslexic individuals. Other researchers (von Karolyi, 2001; Winner, 2001) have shown that spatial imagery deficits are common in dyslexia. Given these findings, it is possible that a spatial deficit might be a mechanism for reading disability in dyslexia.

Given that spatial processing functions might be impaired in dyslexic individuals and perhaps contribute to reading difficulties, then perhaps spatial processing skills, such as those controlled by the VSSP, are related to reading ability in general. One way to investigate the importance of the VSSP's spatial processing functions in reading would be to examine the relationship between reading ability and spatial processing in non-dyslexic individuals. The present study seeks to do this by looking at how much spatial processing in working memory (storage and manipulation) can explain variations in reading ability (beyond visual processing). It is expected that spatial processing will account for a significant amount of the variability in reading when the variation accounted for by visual processing has already been considered.

In summary, the primary purpose of the present research is to investigate the dissociation of spatial storage and rehearsal from visual storage and rehearsal in the VSSP by examining the pattern of relationships amongst visual and spatial imagery and storage measures. Another purpose is to explore whether the spatial components of the VSSP might play a role in reading, which would shed some light on one of the everyday functions of this system.

Method

Participants

111 adult participants were recruited from the University of Victoria Psychology 100 participant pool. These participants were initially divided into two samples: (1) 101 'normal' participants, and (2) 10 'dyslexic' participants. A third sample included the 10 dyslexic participants and 20 participants randomly selected from the original normal sample. This third sample was created for some of the analyses that are described, along with the method for selecting the normal subset, in the results section. Results for demographic measures on all three samples (and the subset of 20 normal participants) can be found in Table 3.

Normal participants

Participants were excluded if they:

1. Had a history of attention deficit disorder or a learning disability other than dyslexia.
2. Had experienced moderate to severe head injuries at any time or mild head injuries in the past year.
3. Were not proficient in English.

Dyslexic participants

Ten individuals reporting a history of reading difficulties (detected from questions on their background, see Appendix A) participated in the study. Participants were excluded from this group if they had a previous diagnosis of attention deficit disorder (with or without hyperactivity).

For individuals to be classified as dyslexic, they had to meet the criteria for a 1 SD discrepancy between their IQ score (as estimated by the Vocabulary subtest of the WAIS) and at least one reading test (c.f. Eden et al., 1996; Graves et al., 1999; Gross-Glenn et al., 1995). Based on the discrepancies, 10 participants were identified as dyslexic (3 males and 7 females). Table 4 gives the z scores and discrepancies for these 10 participants. None of the participants reported a history of attention deficit disorder.

For simplicity, the term dyslexia or dyslexic is used to describe the reading impaired group as a whole; however, individuals in this group were further classified using the Adult Dyslexia Test (ADT: Griffin, Christenson, & Walton, 1995) as the literature indicates that certain types of dyslexia (i.e. dysphonesia and dysphoneidesia, Borsting et al., 1996) might be associated with spatial perceptual deficits, while other types might not (i.e. dyseidesia). Table 4 identifies each participant's ADT classification. Based on ADT results, two cases of dysphoneidesia (JS and RD) and three cases of dyseidesia (AB, LM, and OS) were identified. Some participants were classified as 'normal' according to the ADT, however, given that they met the 1SD reading/IQ discrepancy criteria, they were kept in the analyses.

Materials

A test battery consisting of a total of 11 measures, including new research and standardized psychological tasks, was created for the current study. Two of the tests (VSMT and

BVRT) yielded 2 scores resulting in a total of 13 variables for the study. A detailed description for each measure is provided below. Test reliabilities are presented later in the results section.

Intelligence Quotient (IQ)

An estimate of IQ was obtained from all participants in order to screen for individuals with dyslexia in the sample as indicated above. IQ was estimated using the Vocabulary subtest of the Wechsler Adult Intelligence Scale -III (WAIS-III: Wechsler, 1991).

Reading

All participants completed two reading tests so that t e relationship between reading and visual vs. spatial processing could be examined. These tests were also used in conjunction with IQ estimates to screen for dyslexia in individuals with a history of reading difficulty. Two measures were used to measure different aspects of reading ability.

Woodcock Johnson Tests of Achievement (Woodcock & Johnson, 1990): (1) *Word Attack subtest*. This subtest is designed to assess phonic and structural analysis skills and has been frequently used to differentiate dyslexic from non-dyslexic individuals (e.g. Edwards, Hogben, Clark, & Pratt, 1996; Graves et al., 1999; von Karolyi, 2001). For this test, the subject is required to read nonsense words aloud and is given a score out of 32 based on the number of correctly pronounced words. (2) *Reading Fluency sub-test*. This test provides a measure of timed reading fluency. Three minutes are given to read and determine whether a maximum of 95 individual sentences are true or false (e.g. "A cup may be full.").

Spatial Processing

Two aspects of spatial processing in working memory, storage and manipulation (i.e. imagery), were measured.

Spatial storage was measured in terms of the ability to maintain spatial information (physical movements or relations between objects) in memory for a short period of time. Three measures of spatial storage were used.

Wechsler Memory Scale – III (WMS-III: Wechsler, 1997): The *Spatial Tapping* subtest of the WMS-III was used to assess the number of spatial movements (blocks tapped sequentially) that could be recalled. This test has been used in case studies for dissociating the VSSP (e.g. Wilson et al., 1999).

Visual Spatial Memory Test (VSMT): This computerized test was developed specifically for the current study. Similar tests have been used in neuroimaging research to dissociate visual from spatial memory. The test measures both visual and spatial storage, providing separate scores for each. A total of twelve shapes were created so that they did not resemble common objects such as circles or squares and could not be easily named (c.f. McCarthy et al., 1996). The shapes were randomly presented in some of 12 different locations on a computer screen. In series one of the test, participants are shown 2 shapes in 2 locations on the screen for 2 seconds. Next they are presented with 2 probes (one for shape and one for location) and asked to indicate whether (1) the shape is one they just saw and (2) if the location is one previously occupied by a shape (but not necessarily the probe shape) (see Appendix B for a sample trial). Participants respond 'yes' or 'no' to each probe and the experimenter records their response. This process is repeated for a total of 12 trials in the series. For the next 3 series (12 trials each), the participant is shown one additional shape per series. The participant is thus given a total of 48 trials: 12 with 2 shapes/locations (series 1), 12 with 3 shapes/locations (series 2), 12 with 4 shapes/locations (series 3) and 12 with 5 shapes/locations (series 4). There is only one probe for shape and one probe for location for any given trial. This test is scored on the total number of correct 'shape' and correct 'location' responses out of a possible 48. The number correct 'location' score on the VSMT was used as spatial storage measure (VSMT location) while the correct 'shape' score was used as a visual storage measure (VSMT shape).

Benton Visual Retention Test (Benton, 1991): The BVRT is a standardized psychological test originally designed to measure visual memory. However, early results in the present study demonstrated that it correlated highly with other spatial processing measures. Since this test appeared to have a strong 'spatial' memory component, the standardized scoring criteria were modified to yield separate spatial and visual storage scores. Participants were briefly (10 seconds) shown 10 pictures. Each picture consisted of 3 geometric shapes in various configurations on one page. Once the image was covered, the participants were asked to reproduce the image as accurately as possible. Traditional scoring involved recording the number of correct designs reproduced (maximum of 10) and the number of errors per design.

Scoring was based on 6 error categories: Omissions, Distortions, Perseverations, Rotations, Misplacements, and Size errors. Since 'Rotations' and 'Misplacements' appeared to be more spatial than visual errors, the number of 'spatial' errors in these categories was scored separately from the number of 'visual' errors in the other 4 categories. This scoring method yielded two scores for the current study: a spatial storage score based on the number of 'spatial' errors ('Rotations' and 'Misplacements') across all 10 designs and a visual storage score described later. Appendix C provides more detail on the scoring procedures and test reliabilities are presented in the results section.

Spatial imagery, or mental manipulation of spatial information, was measured in terms of an individual's ability to rotate objects with respect to each other and to mentally rotate themselves with respect to visually presented objects. Three measures of spatial imagery were used:

Revised Vandenberg and Kuse Mental Rotations Test (MRT-form A: Peters, 1995): In this task, referred to as 'MRT', the test-taker is presented with a target drawing of a 3 dimensional, geometric form along with 4 similar forms, 2 of which are the same of the target but have been rotated and 2 of which are similar to but do not match the target. The goal is to identify which of the 4 forms match the target, a process that requires mentally rotating the forms for comparison. The participant completes twenty-four trials and a score out of 24 is obtained. This test is a revised version of the original Vandenberg Test of Three-Dimensional Spatial Visualization (Vandenberg, 1971). The stimuli are the same as those used for the Vandenberg test but have been redrawn for clarity. This test is frequently in case studies demonstrating visual vs. spatial dissociations (Farah & Hammond, 1988; Hanley, Young, & Pearson, 1991; Morton & Morris, 1995).

Brooks Letter Task (Brooks, 1968): This task was originally used by Brooks (1968) and has since been modified and used in many studies including those dissociating visual and spatial processing (e.g. Farah & Hammond, 1988; Morton & Morris, 1995). The participant is asked to imagine a block, capital letter (F and then E) and to imagine traveling from the bottom left hand corner in a clockwise direction around the perimeter of the letter indicating whether they are turning left or right at each corner. The final score represents the total number of correct turns across both letters.

The Standardized Road-map Test of Direction Sense (Money, Alexander, & Walker, 1965): For this test, the individual mentally orients themselves in space and translates this to a flat surface as they follow a route traced out on a map. The test requires the person to follow the route on the map and to indicate at each turn (without rotating the map itself) whether they are turning left or right. The total number of correct turns as well as the time taken to complete the map was recorded. The final measure used in the analyses was an 'efficiency score' computed as the percent of correct turns divided by the number of seconds taken to complete the entire map.

Visual Processing

As with spatial processing, both storage and manipulation of visual information (i.e. physical properties of objects) were measured.

Visual storage was measured in terms of the ability to maintain visual information in memory for a short period of time. Two measures of visual storage were used.

BVRT Visual (Benton, 1991): The general BVRT procedure was described earlier and as previously mentioned, a second score from this test was used as a measure of visual storage. This score was based on the number of visual errors across all 10 designs. Errors were based on 4 categories including 'Omissions, Distortions, Perseverations, and Size' errors.

VSMT Shape: The number correct score for 'shape' as described earlier was used as a second measure of visual storage. This measure was included because, unlike the BVRT and most other standardized tests of visual memory, objects in the VSMT are not easily named, a process that might interfere with the measurement of visual storage per se.

Visual imagery was measured in terms of an individual's ability generate and process or manipulate the physical properties of mental images. Two measures of visual imagery were used.

Animal Tails: this common research task (e.g. Farah & Hammond, 1988) involves asking the participant to visualize an animal (e.g. an elephant or a monkey) and indicate whether the tail is short or long relative to the body size. The number of correct responses for 20 animals is recorded.

Emergent Forms Task (Burton & Fogarty, 2003; Finke, Pinker, & Farah, 1989): This task was originally developed by Finke and colleagues (1989) and modified for the present with the assistance of Burton and Fogarty (2003) who also modified Finke and colleague's original test. For this task, participants are first shown two forms, either capital letters, numbers, or basic shapes (e.g. the letter 'Z' and 'M'). Then they are asked to imagine placing one shape on top of the other such that all their end points and edges matched up. Next, the participants are asked to describe all of the emerging forms theycan 'see' (e.g. Z+M = a 'bowtie', or two triangles, their points meeting in the middle). In order to ensure all participants 'imagined' the same forms, the forms were first presented one at a time on a computer screen. Following their description, participants were asked to draw the image they visualized.

When designing this task, Finke et al (1989) recorded the number of correctly reported emergent patterns detected for each pair of stimulus patterns. They distinguished the patterns as being either geometric (e.g. 'two adjacent squares') or symbolic (e.g. the 'number eight') (Finke et al., 1989). Burton and Fogarty (2003) scored their task as the total number of symbolic and geometric forms detected from imagery. For the present study, the dependent variable was similar to Burton and Fogarty (2003) and included the total number of correctly identified symbolic/geometric forms across each of the eight 'patterns' they were asked to visualize. The drawing were used to help interpret any vague descriptions, however, the drawings themselves were not scored.

Procedure

The entire testing session took approximately one and a half to two hours. The nature of the study and tasks were first explained to participants before obtaining informed consent (see Appendix D). Next, participants were asked a number of background questions (Appendix A) regarding the exclusionary criteria discussed above. Then the tasks were administered in the following order: Brooks, Animal Tails, Word Attack, VSMT, MRT, Emergent Forms, (ADT: for dyslexic participants only), Vocabulary, Spatial Span, Road Map, BVRT, Reading Fluency. All participants completed these tasks in the same order. This order was chosen so that measures of each construct were not completed consecutively, which could result in carry-over effects. Instead, visual and spatial tests were alternated. Upon completion of all the tasks, participants were debriefed (see Appendix E).

Data analyses

Using SPSS (Norusis, 1999), two major analyses, a principal components analysis (PCA) and a stepwise multiple regression were conducted. These analyses were selected given that the sample size was fairly large (*N*=101) and since a relatively large number of measures were used in the study, they would more accurately reveal the relationships amongst measures than simple correlations.

Visual vs. spatial storage and imagery

A PCA was conducted in order to explore the potential structure of the VSSP. This type of analysis was expected to reveal whether the measures representing each dimension (spatial storage, spatial imagery, visual storage, visual imagery) produced the expected factors or 'components'. A PCA was chosen over simple correlations for the main analysis given the relatively large number of measures used in the design and its ability to reduce the large number of observed variables (i.e. each of the measures of spatial and visual processing) into a smaller number of factors. The factors expected to emerge were those for spatial storage, spatial imagery, visual storage, and visual imagery. Once identified, the components would be used to interpret the underlying processes within the structure of the VSSP.

Visual vs. spatial processing and reading

A stepwise, multiple regression was conducted to determine the contributions of visual and spatial processing to reading ability. The dimensions of interest expected to be included were: reading (Word Attack and Reading Fluency: criterion variables 1 and 2), visual storage (predictor variable 1), visual imagery (predictor variable 2), spatial storage (predictor variable 3), and spatial imagery (predictor variable 4). In order to reduce the chance of Type I error, the number of predictor variables entered into the regression was not equal to the number of tasks given, but to the number of factors revealed by the PCA (c.f. Forsythe, May, & Engelman, 1971). Scores for the predictor variables were composite scores based on the factors revealed by the PCA. More details on these scores are provided in the results section.

According to the hypotheses, it was expected that spatial processing would be more highly related to reading ability. However, given a lack of previous research in this area, it was not known which aspect of spatial processing, storage or imagery, would be the more important predictor of reading ability.

Individual differences

In addition to the major analyses described above, any identified SRD individual's spatial processing scores, visual processing scores, IQ scores, and reading scores were compared to the general sample using Crawford and Garthwaite's (2002) abnormality of test score procedure. In-line with previous research, dyslexic individuals were expected to have significantly lower spatial processing (storage and imager) and reading scores than the normal sample. Visual processing (storage and imagery) was not expected to be abnormal.

The difference between spatial and visual processing scores for dyslexic individuals were also compared to differences in the non-dyslexic group. This approach was taken as a means of providing a more stringent test for the presence of a dissociation (Crawford & Garthwaite, 2002) between spatial and visual processing in working memory. If there was an abnormality in spatial processing, but not visual processing, in dyslexic individuals; then, there should be greater differences between visual and spatial processing in this group (i.e. lower spatial processing scores) than in non-Dyslexics.

The methods used to find these abnormalities and differences are applicable to the current study as they are designed for comparisons between individual cases and a control sample of a small or moderate N (Crawford & Garthwaite, 2002). Unlike other methods (e.g. Payne & Jones, 1959), the Crawford and Garthwaite (2002) methods do not treat the statistics of the control sample as if they were population parameters but as sample statistics. As a result, an overestimation of the abnormality, or difference between, test scores is not as likely as with other methods (Crawford & Garthwaite, 2002).

Results

Descriptive statistics

Means and standard deviations for each of the study variables for the normal and dyslexic participants are shown in Table 5. Table 5 also shows the descriptive statistics for the combined dyslexic/normal group as well as for the subset of 20 individuals randomly selected from the group of 101 normals.

Test reliabilities

Published reliabilities and computed reliabilities for the experimental measures and research measures are reported in Table 6. Measures with no published values were computed (Cronbach's α and test-retest reliability for some measures) using the non-dyslexic sample (N = 101). Cronbach's α could not be computed for some measures and instead their published reliabilities were used. However, there is a chance that the published reliabilities may not reflect the reliability in this sample given that the reliability of a test is not a property of a test per se; rather, the reliability is a property of a test administered to a particular population of examinees under certain conditions (Miller, 1995).

As discussed later, some of the reliability values were quite low (Animal Tails, VSMT Shape, and BVRT) but not as a result of outliers in the sample as α's computed without outliers did not increase and in some cases decreased (see Table 6 for values).

Correlations and PCA

The zero-order order correlations between all measures are presented in Table 7. In addition to the Pearson correlations, Table 7 also presents correlations corrected for attenuation (Lord & Novick, 1968, p.70)[1]. These corrected values were computed in order to provide a more accurate index of the true relationship between the variables of interest if the scores were measured without measurement error.

The dissociation between visual and spatial processing in working memory was investigated with a principal components analysis (PCA). PCA without rotation was first performed on the 101 normal participants. The factors, factor loadings, eigenvalues, and percent

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[1] $\hat{r}_{true1-true2} = \dfrac{r_{obs1-obs2}}{\sqrt{r_{11}}\sqrt{r_{22}}}$

of variance accounted for by each factor are shown in Table 8 and the scree plot is shown in Figure 2.

According to the factor loadings and scree plot, only one factor emerged from the analysis (Factor 1: eigenvalue = 2.726, variance explained = 27.26%). While there were three other factors with eigenvalues greater than 1 (factors 2, 3, and 4), these did not appear to be reliable according to the scree plot and the loading matrix. The variables with the highest loadings (>/= .5) on Factor 1 were spatial imagery (Brooks, MRT, Road Map) and spatial storage (Spatial Span, BVRT Spatial). One test designed to measure visual imagery (Emergent Forms) also loaded on Factor 1. However, this is not surprising given the high zero-order correlations with spatial imagery and storage tasks. When examining the remaining factors, they were not well defined by the variables and a consistent pattern could not be interpreted.

The lack of factor structure in the preceding PCA might reflect a lack of variation in the sample of 101 normal, university student participants. Given the lack of factor structure and variability, a second PCA was performed with a sample that included the 10 dyslexic and 20 normal participants (10 males and 10 females[2]) selected from the original sample using random sampling procedures in SPSS. The 10 dyslexic participants were expected to show some differences from the normal participants. However, had the dyslexics simply been added to the entire sample of 101 normal participants, their variability would likely have been masked. Thus, the 10 dyslexic participants were combined with the reduced subset of 20 normal participants for the second PCA.

The results from the second PCA are shown in Table 9. As seen in the factor loadings and scree plot (Figure 3), two factors emerged from this analysis (Factor 1: eigenvalue = 3.39,

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[2] Since the original sample included a nearly equal ratio of males to females, an equal number of each gender was included in the second PCA.

variance explained = 33.9%; Factor 2: eigenvalue = 1.64, variance explained = 16.4%). The variables with the highest loadings (>/= .5) on Factor 1 were spatial imagery (Brooks, MRT, and Road Map), spatial storage (VSMT Location and Spatial Span) and visual imagery (Emergent Forms, which actually correlated highly with spatial imagery tasks). While one visual storage measure (BVRT Visual) did have a fairly high loading on Factor 1 (-.59), it had a higher loading on Factor 2 (-.65) and was included with Factor 2 in subsequent analyses. The variables with the highest loadings on Factor 2 were visual storage (VSMT visual and BVRT Visual) and visual imagery (Animal Tails). Factor 3 was not reliable as it was only defined by one variable, BVRT spatial.

Regressions

The importance of the VSSP for reading was investigated with stepwise multiple regressions guided by the second PCA findings. Based on the pattern structure of the second PCA, two composite z-scores were created and used as predictors in stepwise multiple regressions on reading ability. A total of four stepwise regressions were conducted, two with the normal sample (*N*=101) and two with the dyslexic/normal combined sample (*N*=30). The criterion variable for the first regression in each group was reading performance on the WJ Word Attack subtest. The criterion variable in the second regression for each group was performance on the WJ Reading Fluency subtest.

The predictor variables for each regression were created based on the results from the second PCA described above. The predictor scores were the sum of z-scores from variables with loadings greater than .5 on Factors 1 and 2 in the second PCA. Predictor 1 was a composite z-score based on Brooks, MRT, Road Map, Emergent Forms, VSMT Location and Spatial Span z-scores. This was considered to be a 'spatial' predictor variable. BVRT Visual z-scores were not included as this variable had a higher loading on Factor 2. Predictor 2 was considered a 'visual' predictor and consisted of z-scores from BVRT Visual and VSMT Shape.

None of the variables entered into the stepwise regressions for the 101 normal participants were significant predictors of performance on the Word Attack subtest (see Table 10 for correlations). Using the Bonferroni correction of .05/2, predictor 2 (the 'visual' predictor variable) just failed to reach significance ($p < .025$) as a predictor of Reading Fluency performance: $r = .178$, $t(1,99) = 1.60$, $p = .038$ (1-tail).

For the dyslexic/normal combined sample; predictor 1 (spatial) reached the significance criterion of $p < .025$ as a predictor of Reading Fluency: $r = .414$, $t(1, 28) = 2.40$, $p = .012$ (1-tail). Neither the visual nor spatial variable was a significant predictor of performance on Word Attack. However, as Table 11 illustrates, the zero-order correlation between the visual predictor and Reading Fluency was only somewhat lower ($r = .335$) than the zero-order correlation for the spatial predictor ($r = .414$). There was also a significant correlation between the visual and spatial predictors suggesting collinearity was present in this analysis ($r = .445$).

To investigate the issue of collinearity, a series of regressions were run to determine the total variance accounted for by each predictor alone (i.e. when entered first) the unique variance accounted for by each predictor (i.e. when the other predictor was already accounted for), and the variance accounted for by the linear combination of the variables. These regressions revealed that the spatial predictor accounted for 14%[3] and the visual predictor accounted for 8% of the variance when entered alone. The spatial predictor accounted 6% for and the visual predictor accounted for .1% of the variance when the other variable had been accounted for. The linear combination of the two variables accounted for 14% of the variance in Reading Fluency. Given

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[3] Adjusted variance

these findings, it appeared while the spatial, but not the visual predictor was found to be significant in the stepwise regression, there was more common variance accounting for reading fluency than unique variance due to either variable alone. A larger sample size is needed to further investigate the unique contributions of spatial vs. visual performance to reading fluency.

Identification of dyslexic participants and individual differences analyses

After the dyslexic participants were identified, individual differences in visual and spatial storage and imagery were examined using Crawford and Garthwaite's (2002) abnormality of test score procedure. Table 12 gives the control means and SDs for each test and each dyslexic participant's corresponding score. Composite scores from the two factors detected in the PCA and used in the regression are also included in Table 12.

The abnormality of test score findings did not reveal the predicted pattern of results (impaired spatial, but preserved visual performance). For example, some participants had abnormally low scores on visual *and* spatial measures (JS, NG, EW) and one (OS) had abnormally high visual performance (storage; VSMT Visual). Only one participant (AB, classified as dyseidetic) had exclusively poor spatial imagery performance (Brooks).

In addition to computing abnormality of test scores, the differences between spatial and visual processing scores for dyslexic individuals were also compared to differences in the normal participants. It was expected that relative to visual performance, spatial performance would be abnormally low, however; no significant differences were found in these comparisons. On the other hand, examination of the composite z-scores created for the regressions did suggest some abnormal visual vs. spatial difference might exist (see Table 12). According to these results, the composite z-cores reflecting the 'spatial' variable were generally lower than scores reflecting the 'visual' variable (i.e. AB, LM, RD, SD, OS, EM, NG, EW). However, only two participants had significantly lower than normal spatial composite scores (JS and NG) and in each case the visual composite score was also significantly lower than normal.

To further investigate the overall presence of a spatial vs. visual deficit in the dyslexic group, a group comparison of the spatial and visual composite scores was made between the normals and dyslexics. Because of heterogeneity of variance on the visual variable (Levene's Test: $F = 46.65$, $p <.01$), the data were transformed to ranks and the Mann Whitney test was applied to both the visual and spatial variables. For the spatial variable, the results showed that the dyselxic participants had significantly lower scores ($M = -3.97$, $SD = 4.09$) than the normal participants ($M = -.017$, $SD = 3.72$): *Cohen's d* = .60, W_s=244, $p = .007$. Even though dyslexics had somewhat lower scores ($M = -2.29$, $SD = 5.17$) than normals ($M = -.023$, $SD = 1.39$) on the visual variable, the difference was not significant: W_s=418, $p = .370$.

Discussion

A battery of measures was assembled and used to measure visual and spatial behaviour in normal and dyslexic participants in order to explore the pattern of relationships amongst visual and spatial processes in working memory. In addition to providing new information on the structure of the VSSP and possible revisions, a secondary goal was to determine whether processes within the VSSP might contribute to reading ability. The findings from this research suggest that, pending further investigation, the current conceptualization of the VSSP might need to be changed and that reading ability might rely on some of its subprocesses. The findings also suggest that dissociating visual and spatial processing in humans might be difficult given the complexities in measuring their corresponding behaviours. Each of the analyses will be discussed in terms of their contribution towards a better understanding of measuring visual and spatial processing in humans and how these processes might be described within a working memory model.

Adequacy of the test battery: Reliability measures and inter-correlations

Before discussing the structure of the VSSP, the adequacy of the test battery must first be addressed. Reliability values were provided for all measures used in the test battery (see Table 6). Some values were quite low (Animal Tails, VSMT Shape, and BVRT) and will be discussed next.

BVRT

The test with the lowest reliability value was the BVRT visual (Cronbach's α=.077). BVRT spatial also had fairly low reliability (Cronbach's α= .311). These values could be low due to either an unreliable new scoring method used for the present study and/or the values could be underestimates due to little variability in the sample. The BVRT was scored according to the total number of errors made across 10 design reproductions. The average number of 'visual' errors in the normal sample was .70 (SD = .83, Min = 0, Max = 3) while the average number of spatial errors was 1.57 (SD = 1.38, Min = 0, Max = 7). This very low error rate, or ceiling effect, suggests that the BVRT may not be very sensitive to normal levels of visual and spatial processing abilities. However, even though it has a low Cronbach's, the spatial score on the BVRT does show a little more variability than the visual score suggesting that there may be more individual differences in spatial than visual memory ability in non-impaired individuals.

Inter-rater reliability values were higher compared to Cronbach values (BVRT shape: r = .621, $p < .05$; BVRT spatial: r = .645, $p < .05$). This suggests that the new scoring method is more reliable than suggested by Cronbach's. However, further adjustments to the scoring procedures including more detailed instructions for examiners are required to further increase inter-rater reliability.

VSMT Shape and Location

Following the BVRT visual, VSMT shape had the second lowest reliability value (Cronbach's $\alpha = .214$). However, unlike BVRT visual, VSMT shape did not show a ceiling or floor effect. Out of a possible 48 correct 'yes' or 'no' responses to probe shapes, the normal sample averaged 35.21 correct responses ($SD = 3.23$) with a range of 28 to 43. VSMT location was somewhat more reliable than VSMT shape (Cronbach's $\alpha = .565$) and like VSMT shape, had good variability with no apparent floor or ceiling effects ($M = 40.87$, $SD = 3.64$, $Min = 27$, $Max = 47$).

One reason for the low Cronbach's on the VSMT could have been the scoring method. The score used for the analyses was based on the total number of correct probe responses across each of the 4 series of 2, 3, 4, and 5 shapes/locations (see the preceding procedures section for further description). Using this scoring procedure, Cronbach's α was based on the average inter-item correlation where each 'item' was the total number of correct probe responses for a series. Following the low reliability finding presented earlier, an alternative 'item' score was used to compute Cronbach's. Instead of using the number of correct probe responses for each series, each 'item' used to compute Cronbach's was the number of correctly reported items for each series. This value was computed by dividing the total number of correctly identified probes by the number of trials (12) multiplied by the corresponding number of items presented for that series. Using these new 'item' measures, a Cronbach's α of .205 was found for VSMT shape. Similarly, the new item measures did not increase Cronbach's for VSMT location (.564 vs. the original value of .565). Thus, it did not appear that the scoring method was the reason for a low reliability values on the VSMT.

Another possible reason for low reliability of the VSMT shape in particular, could be individual differences in the ability to 'verbalize' the shapes and/or differences between the shapes' potential to be named. If there was variability in terms of shape verbalization that was unaccounted for, either between individuals or between shapes, it could have been a source of measurement error for the VSMT. While the shapes were designed and selected so that they were not easily verbalized, there was no way of knowing whether some individuals developed good 'verbalizing' strategies to help remember the shapes or whether some shapes were more easily verbalized than others. There was some anecdotal evidence to suggest that some shapes could be named, for example; some participants thought the image in Figure 4.A looked like a 'gun'. Likewise, Figure 4.B could perhaps be identified as a milk pitcher.

The 'verbalization' explanation for low VSMT reliability makes some sense given that the reliability for VSMT shape was lower than location. Also, shapes would be more easily named than the locations as locations were not presented in any easily nameable patterns such as a clock-face (c.f. McCarthy et al., 1996). Perhaps one way to account for verbalization in the future would be to somehow measure how easily each item is verbalized and either keep only items with similar and low verbalization scores in the test or factor the verbalization measure into the overall score. In addition, a measure of individuals' ability to name or verbally describe objects could be included to determine whether this type of ability was in fact related to visual memory performance.

Interestingly, this type of task involving immediate memory for abstract shapes is commonly used in neuroimaging research investigating the correlates of visual memory and/or dissociations from spatial memory but the methods used to prevent shape verbalization are not always discussed. For example, many authors simply report that they used 'unfamiliar' or abstract geometric shapes and do not report reliability values (e.g. Faillenot, 1997; McCarthy et al., 1996; Owen et al., 1998; Smith et al., 1995).

However, there was one interesting approach to avoid verbal strategies was taken by Owen and colleagues (1996). For their task, pictures of common objects such as a butterfly were presented for retention. For the retrieval phase, the participant had to pick the matching picture from two choices, one that had slightly different features and one that matched the presented picture exactly. Since it would be very difficult to verbally encode all of the details in the image, memory for visually identifying features was thought to be involved. In support of this belief, regions corresponding to perception of object identity were activated during object feature retrieval.

Since verbalization could be an issue for the VSMT shape and other similar tests of visual memory, precaution should be taken constructing these types of measures so that the stimuli are not easily verbalized and are homogeneous in this respect. Furthermore, reliability values should be published.

Animal Tails

Another measure with a fairly low Cronbach's α (.265) was the visual imagery test, Animal Tails. However, the reliability measure might be an underestimate due to little variability and a ceiling effect in this sample. Out of a possible 20 items, the normal sample scored an average of 18.19 correct (*SD* = 1.35, *Min* = 15, *Max* = 20). Given the restricted variability, Animal Tails, like the BVRT, may not be very sensitive to normal levels of visual imagery ability but better suited for clinical samples with visual imagery deficits.

Animal Tails has been frequently used in the past as for case study research dissociating visual from spatial processing (Carlesimo et al., 2001; Farah & Hammond, 1988; Hanley et al., 1991; Morton & Morris, 1995). This suggests that Animal Tails is in fact sensitive in certain populations, however, caution should be taken and reliability values should be provided when this measure is used.

Emergent Forms

This measure was designed as a second test of visual imagery ability for the test battery and was more reliable than Animal Tails, however, Cronbach's α was still somewhat low (.402). Variability on this measure was good. Out a possible score of 21, the normal sample had an average of 15.43 (*SD* = 3.09, *Min* = 8, *Max* = 21). The length of the test could be one reason for the low Cronbach's. Only 8 designs are included since the test takes a fairly long time to complete. However, if the test included 3 times the number of items, the estimated reliability[4] (Lord & Novick, 1968) would be .67 which is just below the usual acceptable reliability value of .70. However, a version of the test with 24 designs would take a considerable amount of time to complete. Furthermore, Burton and Fogarty (2003) report Cronbach's α = .76 for their 6 item version of the test but had a much larger sample of 216 normal participants. Taken together, this information does not suggest a longer version of the test would be more reliable.

The scoring procedure could be an alternative reason for low reliability on Emergent Forms. Scoring involved assigning points for each correctly identified element of a design and it is possible that scoring was inconsistent. However, the inter-rater reliability was very high (*r* =

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[4] Spearman Brown formula (Lord & Novick, 1968, p.115) for a parallel test containing k times as many items:

$$r_{new} = \frac{kr_{old}}{1+(k-1)r_{old}}$$

.956, $p < .01$) which does not suggest inconsistent scoring procedures were the reason for low reliability.

A source of error contributing to low internal consistency as reflected in Cronbach's could come differences between the items in terms of the type of superimposed image formed. For example, item 1 requires participants to place the letter 'N' on top of the letter 'X' and the resulting image looks like a bowtie. On the other hand, item 8 requires superimposing the letter 'M' on the letter 'Z' resulting in a more obscure image consisting of a square with four triangles inside. If image 8 is not as easily recognized as image 1 (the 'bowtie'), then perhaps it requires some additional processing beyond that required for image 1. If there are variations in identification processes used across images, then the Emergent Forms might actually be a multidimensional test and Cronbach's α would be an underestimate of reliability as it measures the interrelatedness of test items, not the homogeneity of the test (Schmitt, 1996).

While all of the preceding measures had low reliability values, the remaining tests met the acceptable criterion of .70. One exception is that no measure of reliability is available for the Road Map test as there is only one trial in this test (c.f. Hegarty & Waller, 2004). However, the Road Map test has been widely accepted as valid measure of spatial imagery or 'transformation' and is often used for both clinical and normal samples (e.g. Hegarty & Waller, 2004; Rainville, Marchand, & Passini, 2002). As will be discussed next, correlations between the Road Map and other spatial imagery tasks suggest that this test is measuring what it is purported to measure. An examination of the inter-correlations between all the measures in the test battery, including correlations corrected for attenuation, also provides more insight into the adequacy of the test battery beyond the alpha levels reported above (c.f. Schmitt, 1996).

Correlations

One way to examine the adequacy of the test battery, or to determine if each test was measuring what it was intended to measure, is to examine the test inter-correlations. Given the four VSSP dimensions of interest for this study, it was expected that: (1) measures of spatial imagery would be more highly correlated to each other than to measures of spatial storage, (2) measures of visual imagery would be more highly correlated to each other than to measures of visual storage, and (3) in general, spatial and visual measures would not be as highly correlated compared to correlations within each dimension. Table 7 illustrates all the test inter-correlations including correlations corrected for low reliability. Inter-correlations with respect to each VSSP dimension will be examined in terms of the adequacy of the test battery and also in terms of a preliminary discussion of the VSSP model.

Spatial measures

As predicted, all of the spatial imagery measures were significantly correlated (*r*'s = .372 to .491). Correlations between spatial imagery and spatial storage tasks (BVRT spatial and Spatial Span) were within a somewhat lower but similar range (*r*'s = .235 to 431). One reason for correlations between spatial imagery and storage could be that imagery techniques were used during recall. Support for this hypothesis comes from research demonstrating links between the neural systems used to retrieve information from memory and those used for imagery, or to 'visualize' an item that has been retrieved (Handy et al., 2004; Sakai & Miyashita, 1994). While research examining the link between retrieval and imagery typically involves visual imagery processes, the same connection could potentially be made between retrieving spatial information and spatial imagery.

In terms of the adequacy of the test battery, correlations between spatial imagery and storage measures do not necessary indicate a problem with the tests, but indicate that measuring the construct of 'storage' using immediate recall might simultaneously take spatial imagery processes into account. This suggests that developing a 'pure' measure of spatial storage might be difficult.

With respect to the structure of the VSSP, the correlation between spatial imagery and storage does not rule out the possibility of separate spatial storage and spatial rehearsal (via imagery) mechanisms. However, it may be difficult to experimentally dissociate these mechanisms in cognitively intact individuals. This problem is analogous to difficulties dissociating subvocal rehearsal from the phonological store as rehearsal is needed to keep information in the store beyond 2 seconds.

One way to demonstrate that spatial storage and imagery mechanisms are independent would be to illustrate a double dissociation from patients with deficits in one but not the other component. Two patients from the literature with impaired spatial imagery but preserved spatial storage (MG: Morton & Morris, 1995; LE: Wilson et al., 1999) present evidence for a single dissociation. However, a literature review revealed no reports of patients with impaired spatial storage but preserved imagery to support the full double dissociation. The evidence for impaired spatial imagery with preserved spatial storage does suggest that these mechanisms might be independent components of the VSSP. However, given that spatial imagery and storage measures are correlated in normals, they are not likely completely independent. Perhaps spatial imagery is used for recall in non-impaired individuals while those with spatial imagery deficits compensate by using some other strategy to recall spatial information.

One unexpected finding from the correlation results was the very low and non-significant correlations amongst the spatial storage tasks (r's did not reach .10). One reason for low correlations between BVRT spatial and the other measures could be low variability; however, this test did correlate significantly with all three spatial imagery tasks and Emergent Forms. Likewise, Spatial Span correlated with all the imagery measures. Furthermore, when corrected for attenuation, spatial storage intercorrelations were still quite low with $r = -.16$ between BVRT spatial and VSMT location as the highest value.

Given the substantial correlations between BVRT spatial, Spatial Span and the spatial imagery measures, it does seem that these two storage tasks are tapping into some common 'spatial' construct. However, the low correlation between the two spatial storage tasks suggests that they reflect different types of spatial storage processes. On the one hand, BVRT spatial requires the retention of unchanging spatial relations within a static image. On the other hand, Spatial Span requires retaining a changing sequence or the order of spatial locations. While both of these tasks involve retaining spatial relations, they may require somewhat different coding processes and perhaps reflect separate mechanisms for retaining topographical vs. spatial 'order' within a spatial store. This could be analogous to Baddeley's recent suggestion for separate item and order mechanisms within the phonological loop (Baddeley, 2003a).

Visual measures

Contrary to the research hypotheses, the two visual imagery measures were not highly correlated ($r = -.07$). One reason for this low correlation could be the low Cronbach's values for these measures, particularly for Animal Tails. When the correlation coefficient was corrected for attenuation however, the value was still low ($r = -.21$).

Another reason the low correlation could be that the Emergent Forms task was in fact measuring some spatial processes. This is possible given that Emergent Forms had low to moderate, significant correlations (*r*'s = .283 to 440) with all three measures of spatial imagery and with one measure of spatial storage (BVRT spatial, *r* = -.253). When these correlations between Emergent Forms and the spatial tasks were corrected for attenuation to compensate for low reliability, they were quite high (*r*'s = .70 to -.72).

The goal for the Emergent Forms task is to identify an image formed by two superimposed symbols. This would theoretically require processing the figurative aspects of the image, a visual imagery process. However, spatial imagery processes such as spatial transformation (i.e. fitting one figure directly on top of the other so the end points and edges match up) and scanning the spatial relations within the image might also be required to identify the image. In other words, this task likely involves both spatial and visual processes to create and identify the images. Given the high correlations with other spatial measures, Emergent Forms might actually be better classified as a spatial rather than visual imagery measure.

Another unexpected result was the low correlation between the two visual storage measures, VSMT shape and BVRT visual (*r* = .01). This small relationship was likely due to low variability in the BVRT and low reliability in VSMT shape for reasons discussed earlier. The low correlation and reliability values illustrate the difficulty in designing good measures of visual storage for use in a sample of normals. If these measures were revised so that the BVRT was more difficult and VSMT shape was more reliable, a higher correlation might be found.

Visual and spatial measures

As previously mentioned, Emergent forms correlated with spatial imagery rather than visual imagery measures. This suggests that Emergent Forms might tap into spatial processing resources in addition to some visual processing resources. Further evidence for this is the significant correlation between Emergent Forms and one measure of spatial storage, BVRT spatial ($r = -.253, p < .01$). This correlation could reflect the role of spatial imagery during recall of spatial properties.

Another significant visual/spatial correlation was found between Animal Tails and Road Map ($r = -.207, p < .05$). This relationship is somewhat difficult to interpret given the low reliability of Animal Tails. However, given the negative correlation, this finding suggests that these two measures require quite distinct cognitive resources. Intuitively, it seems that this reflects a visual vs. spatial imagery dichotomy, however, further testing with a more reliable version of animal tails for normals is required before making this conclusion.

A final unexpected visual/spatial correlation was found between VSMT shape and Brooks ($r = .214,\ p < .05$). This does not represent a very strong relationship, but again illustrates that there is some overlap between visual and spatial processing. Further discussion on reasons for these visual/spatial inter-correlations will be provided in more detail later.

Investigating VSSP structure: PCAs

A series of PCAs was conducted in order to further examine the dissociation of visual from spatial storage and imagery within the VSSP. Four factors were expected to emerge: spatial storage, spatial imagery, visual storage, and visual imagery. However, when the PCA was performed on the 101 normal participants, only one main factor emerged. The highest loadings on this factor came from all of the spatial measures (excluding VSMT location and including Emergent Forms). A reliable ‘visual’ factor did not emerge.

Given the inter-correlations between spatial imagery and storage it is not surprising that these measures were not picked up as separate factors in the PCA. As previously suggested, imagery might be important for retrieving information during recall (Handy et al., 2004; Sakai & Miyashita, 1994) which would explain the correlations between imagery and storage measures found in the current study.

A failure to dissociate visual from spatial processing in the current study mirrors similar difficulties defining cognitive constructs using shared variance techniques in other research. For example, Delis and colleagues (Delis, Jacobson, Bondi, Hamilton, & Salmon, 2003) found that they could not dissociate STM from LTM using typical shared variance procedures (correlations and PCAs) with a normal sample. However, they were able to detect the well-known distinction from clinical samples with specific STM or LTM disruptions.

One reason for the lack of dissociation could be that cognitive measures of visual and spatial imagery/memory share variance in the intact brain (c.f. Delis et al., 2003). In support of this hypothesis, neuroimaging (PET) studies have shown that both the ventral and visual pathways are activated during either visual or spatial imagery and memory tasks in non-impaired individuals (Faillenot, 1997; Mazard, Tzourio-Mazoyer, Crivello, Mazoyer, & Mellet, 2004). At the same time, the studies showed that the spatial tasks were associated with relatively more dorsal than ventral activity and vice versa for object tasks. So, even though there is some distinct neural activity associated with visual and spatial processing, cognitive measures might be reflecting the shared neural activity.

A related reason for overlap between visual and spatial measures could be that it is not possible, or very difficult, to develop tasks that are purely 'spatial' or 'visual'. That is, spatial tasks are not completely void of object feature processing and visual tasks often involve some spatial 'scanning'.

Alternatively, individual differences, rather than the properties of the test, might be masking visual vs. spatial dissociations in working memory. These individual differences might be related to an individual's 'cognitive style' or how they consistently acquire and process information (c.f. Kozhevnikov, Kosslyn, & Shephard, 2005). Recent research (Kozhevnikov et al., 2005) suggests that individuals who prefer using verbal over visual strategies will perform equally well on object and spatial imagery tasks. These 'verbalizers' tend to rely on verbal strategies when performing cognitive tasks. On the other hand, there is a dissociation between individuals who prefer using visual strategies on cognitive tasks. That is, people who do well on spatial imagery tasks ('spatial visualizers'), do poorly on visual imagery tasks and people who do well on visual imagery tasks ('object visualizers') do poorly on spatial imagery tasks.

While research concerning visual vs. spatial *storage* differences in verbalizers and visualizers has not been conducted, it is possible that results similar to the imagery research would be found. With respect to the current study, if verbalizers do perform equally well on visual and spatial imagery *and* storage tasks and if a sufficient number of verbalizers were inadvertently included in the current normal sample; then, the dissociation between object and spatial processing might have been masked. One way to examine this possibility in future research would be to include measures designed to detect cognitive style (e.g. the Object-Spatial Imagery Questionnaire: Blajenkova, Kozhevnikov, & Motes, 2006) and determine whether cognitive style does act as a confound with visual vs. spatial processing in WM.

Given the lack of factor structure in the normal sample, a second PCA was conducted with the dyslexic sample. While four factors representing visual and spatial imagery and storage were not found, two factors did emerge. Factor 1 included loadings from all of the spatial measures (excluding VSMT location and including Emergent Forms). Factor 2 included loadings from some of the visual measures (VSMT shape, BVRT visual, and to a lesser extent Animal Tails). Similar to the normal sample PCA results, imagery and storage did not dissociate.

In general, the visual/spatial distinction was more evident in a clinical sample of dyslexic individuals than in a sample of normals. Perhaps the dissociation was detected in the dyslexic group because brain regions vital for 'spatial' processing were disrupted in some or all of the participants. That is, disruptions in the dorsal pathway for 'spatial' vision which may be responsible for abnormal localization of visual stimuli (Graves, Frerichs, and Cook, 1999) and abnormal spatial imagery (e.g. mental rotation test: Winner et al. 2001) in dyslexic individuals might have contributed to the dissociation detected in the current study. However, further correlational and PCA analyses should be conducted with specific clinical samples to further investigate the potential dissociation of these constructs. For example, groups of patients with ventral/temporal vs. dorsal/parietal lesions could be contrasted to investigate visual vs. spatial processing differences.

While there was some evidence for a visual vs. spatial dissociation from the dyslexic sample, there was still no evidence for an imagery/storage dissociation. One argument for this finding (i.e. only 2 components as opposed to the expected 4) could be that the factor structure in fact represents a model analogous to that proposed by Logie (i.e. Figure 1 A). That is, the 'spatial' variable could reflect the spatially oriented, active inner scribe and the 'visual' variable could reflect the passive, visually oriented visual cache. Logie's visual cache module, responsible for the temporary, passive maintenance of visual information (Logie & Pearson, 1997; Salaway & Logie, 1995), could reasonably explain the visual factor consisting of the two visual storage measures (VSMT Shape and BVRT Visual). However, Logie's model does not explain why measures of spatial storage load on the same variable as spatial imagery. That is, Logie does not specifically indicate that spatial rehearsal (i.e. the inner scribe) and spatial storage are in fact one in the same module. Rather, the inner scribe is proposed simply as a spatial rehearsal mechanism for visual information.

Despite the lack of findings for an imagery/storage distinction in the current results, there is evidence for this dissociation from other sources that support the model proposed in the current study. For example, there are two clinical cases with impaired spatial imagery but preserved spatial storage (MG: Morton & Morris, 1995; LE: Wilson et al., 1999). While not as well studied, a single dissociation between visual imagery and storage has been also been reported (Frick, 1987). Frick (1987) found two college students with an impaired ability to form conscious visual images but a preserved ability to retain visual information for short periods of time. Together, these cases suggest that spatial storage and imagery and visual storage and imagery are not necessarily synonymous. However, further evidence for a full dissociation is needed.

In addition to evidence from clinical cases, an experimental dissociation of imagery from storage in both modalities would lend further support for the four-component VSSP model. A dual task paradigm would be one way to show a double dissociation between imagery and storage experimentally (c.f. Friedman & Polson, 1981). Two conditions would be needed for this double dissociation. First, there must be a decrement in performance on a primary imagery task when paired with a secondary imagery task but not when paired with a secondary storage task. Second, there must also be a decrement in performance on a primary storage task when paired with a secondary storage, but not with a secondary imagery task. These conditions would also need to be met within each visual and spatial modality. For example, a primary spatial imagery task could include something like the Road Map test while the participant had to simultaneously imagine walking around analogous to the Brooks Letter task. If imagery and storage were distinct, there should be a decrement when these two imagery processes are combined but not when the Road Map test is combined with some other spatial storage measure. Likewise there should be a decrement in performance if two spatial storage tasks had to be performed simultaneously. To date, there has been no research examining these types of imagery/storage dual task paradigms.

Investigating the everyday importance of the VSSP: multiple regressions and dyslexic analyses

Given that there has been little speculation and even less research concerning the importance of the VSSP in terms of everyday cognitive activities, a series of stepwise multiple regressions was conducted to determine if processing within the VSSP might play a role in reading. Baddeley and Logie (1999c) have suggested that the VSSP might be important for reading but, they have not discussed why or how this component might facilitate reading. One clue to the role of the VSSP in reading comes from individuals with dyslexia. Evidence suggests that some aspects of spatial processing, including visual localization (Graves et al., 1999) and spatial imagery (von Karolyi, 2001; Winner, 2001), are abnormal in certain dyslexic individuals. If this spatial processing abnormality plays some role in dyslexic's reading difficulties, then perhaps spatial processing skills, such as those controlled by the VSSP, are related to reading ability in general.

The original research hypothesis was that spatial processing would be more highly related to reading ability than visual processing. However, it was unknown whether imagery vs. storage would be relatively more related to reading ability. Since the imagery and storage measures loaded on the same factor, these components could not be investigated independently in this study. Instead, the relative importance of a general 'spatial' vs. 'visual' factor was investigated using composite scores based on the PCA results. The results of multiple regression analyses suggested that neither visual nor spatial processing contributed to reading performance in the normal sample. On the other hand, the spatial predictor did significantly predict reading fluency performance in the dyslexic sample. However, given the findings for collinearity and the possibility of sampling error, the spatial predictor may not be reliable. Thus, the conclusion from these findings with the current sample is that, in general, 'visuospatial' performance does predict reading fluency when the dyslexic participants are included.

The results from these analyses suggest that neither spatial nor visual processing, as reflected by the measures used in this study, predict phonic and structural analysis skills as measured by the Word Attack subtest. On the other hand, it appears that reading fluency *might* be predicted by visual processing (as reflected by the composite variable) in non-dyslexic individuals. However, this finding was not quite significant and the correlation was low (r = .178, p = .038, 1-tail). One reason for this finding could be the problems with the visual measures discussed earlier. With further refinement of these tasks, perhaps a stronger relation between visual storage/imagery and reading fluency would be detected.

Another possibility is that visual processing could be more strongly related to another aspect of reading ability not measured in the current study. For example, research has shown that visual and spatial imagery (Potylycki, 1997) and spatial storage (Goff, Pratt, & Ong, 2005) are related to reading *comprehension* or the ability to generate inferences, make predictions, and remember what is being read (Center, Freeman, Robertson, & Outhred, 1999). Also, visual imagery training has been found to improve comprehension (Center et al., 1999; Solomon, 1998). While more research on the relative contribution of visual vs. spatial imagery to reading comprehension is required, perhaps future research will reveal that these types of processes are more related to reading comprehension than reading fluency. Likewise, future research investigating the role of visual and spatial storage might reveal a stronger connection with reading comprehension than fluency.

Dyslexia and reading

While some form of visual processing might predict reading fluency or possibly reading comprehension in normals; the multiple regression results from this study indicate that some form of *spatial* processing, represented by the 'spatial' composite variable, predicts reading fluency in the dyslexic sample. However, since the predictor used in the multiple regression included measures of spatial imagery and storage, this finding does not reveal *which* aspects of spatial processing specifically contributed to reading fluency. Furthermore, the findings for collinearity discussed above indicate that it is difficult to separate the spatial and visual storage factors. Accordingly, a conservative interpretation of the regression results is that while the spatial predictor appeared to be superior to the visual storage predictor, because of collinearity, one can only safely conclude from these data that overall 'visuospatial' performance predicts reading fluency in this sample. A larger sample size is needed to further investigate the unique contributions of spatial vs. visual processing to reading fluency.

Although the dyslexic sample size was small, the multiple regression results are consistent with the hypothesis that spatial processing abnormalities in dyslexia play some role in reading difficulties. In fact, obtaining this result with such a small sample suggests that an even larger effect size (than $r = .41$) might be found with the increased power of a larger sample size since correlations increase with sample size. While the spatial hypothesis in dyslexia has stimulated much debate in the past, some researchers have concluded that visuospatial disturbances may account for reading problems in a small proportion of dyslexics (e.g. Just & Carpenter, 1987).

Several direct tests of the hypothesis that dyslexics have spatial processing abnormalities were conducted. This was done by first examining the individual differences between dyslexics and normals on the visual and spatial composite variables created from the PCA results. According to the individual test results and composite variable findings in Table 12, the current group of dyslexic individuals appeared to have abnormalities in *both* visual and spatial processing, making it difficult to detect the relative visual vs. spatial abnormalities. Furthermore, a complete examination of the relative visual vs. spatial processing deficit within each subtype of dyslexia could not be fully examined given the small numbers of each subtype (i.e. only 2 dyspheidetics, 3 dyseidetics, and 5 'unclassified' or normal according the ADT results). However, an overall spatial processing, but not visual processing, abnormality was detected when the group of dyslexics was compared to the normal sample as a whole using the Mann Whitney test. Moreover, this spatial processing abnormality represented a 'large' effect size ($d = 1.01$) according to Cohen's (1992) conventions.

The current findings for impaired spatial function in dyslexia are in line with other research on spatial abnormalties in this group. Other evidence for spatial dysfunction in dyslexia originates from findings that magnocellular cells of the lateral geniculate nucleus were smaller and more disorganized than normal in dyslexic brains (by about 27%) (Galaburda, 1993; Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985). These magnocelluar cells appear to mediate the perception of spatial properties such as global form and movement (Habib, 2000) and may specifically be involved in visuospatial localization (Graves et al., 1999). These cells also form part of the dorsal visual pathway extending from the retina to the inferior parietal cortex which has generally been found to be responsible for 'spatial vision' (Mishkin et al., 1983).

If magnocellular cells, which form part of the visual pathway important for spatial processing, are in fact abnormal in dyslexic individuals, then it follows that spatial processing abnormalties might exist in dyslexics. There is psychophysical evidence for visual deficits associated with the magnocellular functions in dyslexics (see Habib, 2000 for a review). Furthermore, Graves and colleagues (1999) found that dyslexic individuals were impaired on the ability localize the positions of small visual stimuli. To further support the spatial processing deficit in dyslexia, there is neuroimaging evidence (Eckhert & Leonard, 2003; Habib, 2000; Hier, LeMay, & Rosenberger, 1978; Leonard, Voeller, Lombardino, & Morris, 1993) for abnormal parieto-occipital asymmetries in dyslexic brains along with behavioural evidence for abnormal parietal functions such as the spatial distribution or orientation of visual attention (Facoetti & Molteni, 2001; Facoetti, Paganoni, & Lorusso, 2000; Facoetti & Turatto, 2000; Facoetti, Turatto, Lorusso, & Mascetti, 2001; Hari, Renvall, & Tanskanen, 2001) and abnormal spatial imagery (Winner, 2001) in dyslexia.

There are a number of ways these spatial deficits could contribute to reading difficulties in dyslexics. For example, a disruption of spatial attention and visual localization could lead to a disruption in the ability to shift attention spatially or orient to visual stimuli such as letters and words. This could disrupt fluent reading through a reduced ability to locate and refixate on the beginning of one line of text from the end of the previous line (Graves et al., 1999). This localization disruption could manifest itself on spatial imagery and storage measures that require similar localization processes (e.g. Brooks task: locate one corner of a letter and refixate on the next, VSMT location: locate one shape, then refix on another repeatedly during stimulus presentation). In turn, these spatial imagery and/or storage processes might be important for scanning and maintaining the spatial relations amongst letters, words, and lines of text as a means of facilitating fluent reading. If dyslexic individuals' spatial imagery and/or storage abilities are disrupted, the spatial relations within the text might be lost, leading to less fluent reading and ultimately, poor comprehension.

In addition to the preceding research with dyslexics, additional research supports the importance of the parietal lobe and spatial processing in reading. With respect to the parietal lobe, as Hari and colleagues (2001) point out, lesions of the posterior parietal lobe may cause 'acquired' dyslexia (c.f. Brunn & Farah, 1991). As for spatial processing and reading; Goff, Pratt, and Ong (2005) found that performance on the forward Corsi block task (similar to the Spatial Span storage measure) made a small, but significant contribution to reading comprehension (which is in turn related to reading fluency) in a group of normal school-aged children. While this finding does not suggest that spatial storage is the most important predictor of reading ability, it does suggest that it might play a small role. Whether or not spatial imagery plays a similar role remains to be seen, but future research might shed further light on this issue.

Conclusions

The purpose of this study was to examine a revised structure of the VSSP and investigate how it might play a role in one everyday cognitive activity, reading. The VSSP structure was examined by creating a battery of tests including several popular measures used to study visual and spatial processing in WM and a few new measures designed for the current study. These tests were used to measure the processes underlying the four proposed components of the model: visual storage and imagery and spatial storage and imagery. Two lines of reasoning supported the proposed, four component VSSP model.

One line of reasoning was that the model should be dissociated according to the type of information (i.e. visual vs., spatial) being processed. This distinction between visual vs. spatial processing originates from the well-established dissociation of perceptual object (i.e. 'visual') from spatial vision that was first established cortically with monkeys (Mishkin et al., 1983). This perceptual distinction extends to WM as evidenced from cognitive (e.g. Logie & Pearson, 1997; Pickering, 2001; Salaway & Logie, 1995), neuropsychological (Carlesimo et al., 2001; Farah & Hammond, 1988; Morton & Morris, 1995; Wilson et al., 1999), and neuroimaging (Courtney, Ungerleider, Keil, & Haxby, 1996; Goldberg et al., 1996; Haxby et al., 1994; Jonides, Smith, Koeppe, Awh, & Minoshima, 1993; Owen et al., 1996; Smith et al., 1995) research.

The second line of reasoning supporting the proposed four-component model was that separate imagery mechanisms might serve as rehearsal mechanisms for visual and spatial storage. The storage components were suggested to reflect the link between perception and memory (c.f. Craik & Jacoby, 1975; Craik & Lockhart, 1972; Graves, 1973). The imagery mechanisms were thought to provide a means of refreshing information in storage so that it would not decay and be lost. The spatial imagery component was proposed to support the mental manipulation or processing of spatial properties of internally generated or visually presented objects. The visual imagery component was proposed to support the internal visualization of an object's figurative properties. Evidence for a dissociation between visual and spatial imagery came from neuroimaging (Mazard et al., 2004) and neuropsychological (Farah & Hammond, 1988; Luzzatti et al., 1998) research.

The findings from the current study provide some support for a visual vs. spatial dissociation in WM. However, this visual vs. spatial dissociation was only detected in the dyslexic sample in the form of separate spatial and visual factors in the PCA. On the other hand, only one general factor emerged from the normal sample. The lack of dissociation in the normal sample could be due to the nature of the tests used (i.e. ceiling effects and low reliability in this sample), could reflect difficulties detecting the dissociation using shared variance techniques (c.f. Delis et al., 2003), or could be due to the presence of 'verbalizers' masking the dissociation (c.f. Kozhevnikov et al., 2005). As discussed later, there are several avenues of future research that could develop from these issues.

Although there was evidence for a visual vs. spatial dissociation in WM, there was no evidence for a storage vs. imagery dissociation. One reason for this could be that the storage measures used for this study relied imagery processes during retrieval. This line of research dissociating imagery from storage would be particularly interesting to pursue. For example, the single dissociation of visual and spatial imagery from storage from existing case studies might eventually prove to be a double dissociation if cases with impaired storage but preserved imagery are found and reported.

Also, while a behavioural dissociation between imagery and storage has been elusive in adults, perhaps a developmental dissociation could be found. That is, the abilities to store and manipulate visual and spatial information might develop at different rates in children and somewhere along the line, the strategies for each become difficult to separate. This type of developmental research has already been used to support the visual vs. spatial dissociation in WM. For example, Logie and Pearson (1997) found different developmental trajectories of visual and spatial processing abilities in children. According to these findings, the ability to retain and recognize a series of matrix patterns (visual task) developed more rapidly with age than the ability to retain a sequence of spatial movements (Corsi Blocks). Since these two abilities developed at differential rates, it was concluded that they depended on separate cognitive systems. Perhaps different developmental trajectories of storage and imagery could also be detected in children.

In addition to the current study, other authors have similarly suggested the need to further fractionate and understand the components of the VSSP. For example, in a recent review, Repovs and Baddeley (2006) provide an interesting functional account of WM including a discussion of the behavioural properties and capacities of the VSSP. Repovs and Baddeley suggest that visual perception is closely linked to visual WM and that visual information is retained in WM as integrated objects (not individual feature of objects). However, they feel that the mechanisms for maintaining this information is unclear but that further insight might come from research relating visual WM to visual imagery. While they do not elaborate on the imagery-visual WM connection, or specifically suggest separate visual storage and imagery mechanisms, Repovs and Baddeley's implied connection between visual WM and visual imagery is in-line with the current study's proposal. The present study further contributes to this line of reasoning by proposing that visual imagery could serve as a type of rehearsal mechanism by mentally viewing images in the mind's eye so they do not decay from the visual store.

In terms of spatial WM, Repovs and Baddeley (2006) present a mechanism much like the inner scribe proposed by Logie. Repovs and Baddeley (2006) suggest a close connection between spatial WM and spatial attention proposing that local shifts of attention to locations provides a rehearsal-like mechanism for visual information. They also cite evidence for a close connection between eye movements and these rehearsal-like functions. Unlike the current study, these authors do not suggest a link between spatial perception and spatial WM. Furthermore, they do not make a connection between spatial imagery and spatial WM. Thus, although there are some similarities between some of Repovs and Baddeley's (2006) suggestions and those presented here, they do not propose the same 4-component model.

As mentioned previously (pg.45) the results from the current study (i.e. visual and spatial factors revealed by the PCA) could be interpreted to support Repovs and Baddeley's (2006) suggestion for a 2-component model much like that proposed by Logie. However, as discussed, additional research might reveal a dissociation between visual storage/perception and visual imagery/rehearsal as well as between spatial storage/perception and spatial imagery/rehearsal.

Further support for the visual vs. spatial dissociation in WM comes from a dual-task study by Mohr and Linden (2005) who demonstrated a dissociation of visual from spatial manipulation in WM. This study was similar to the current study in that the authors examined the dissociation of visual from spatial manipulation mechanisms, but they did not specifically examine imagery or propose a mechanism that might serve to refresh information in a visual or spatial store. What they found was that there is a dissociation between visual and spatial manipulation processes that are closely linked to the central executive. They also found that these executive types of processes were not linked to visual or spatial maintenance in WM, thus providing evidence for a distinction between storage in the VSSP and manipulation via the central executive.

In addition to investigating the structure of the VSSP, another purpose of the current research was to explore the role that the VSSP plays in reading, an important everyday cognitive activity. The findings suggested that one line of research that could be pursued is the role of imagery and storage in reading in both normals and dyslexics. In normals, the results, while not significant, were in the direction of other findings that higher visual imagery skills are related to higher reading comprehension skills[5]. One suggestion for this relationship is that forming mental images while reading helps readers manage the information in a novel way, thus improving their understanding and ability to retain what they have read (Center et al., 1999). According to this view, it seems that visual imagery is not a *necessary* process for effective reading and may not necessarily improve reading *fluency*, however; it could be a useful strategy to help improve reading comprehension.

As with the normals, the current results support a relationship between components of the VSSP and reading in dyslexics. However, instead of a visual/reading relationship, a spatial/reading relationship was found. This relationship between spatial processing and reading in dyslexics mirrored their spatial processing deficits. One reason for this spatial processing deficit could be that brain regions critical for this spatial processing are abnormal in dyslexics. There is evidence for dyslexic abnormalities in two critical brain regions for spatial processing, both of which form part of the dorsal visual pathway for spatial vision. On one hand, magnocellular cells are smaller and more disorganized in dyslexic brains (Galaburda, 1993). In line with this, functions associated with these cells are also impaired (e.g. Graves et al., 1999; Habib, 2000). On the other hand, inferior parietals areas are abnormally lateralized in the dyslexic brain (Eckhert & Leonard, 2003; Habib, 2000; Hier et al., 1978; Leonard et al., 1993) and related spatial attention mechanisms are also abnormal (Facoetti & Molteni, 2001; Facoetti et al., 2000; Facoetti & Turatto, 2000; Facoetti et al., 2001; Hari et al., 2001).

One explanation for the relationship between spatial processing and reduced reading fluency in dyslexics is that impaired spatial attention and visual localization abilities reduces the fluency with which a dyslexic individual is able to shift attention amongst letters and/or words in

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[5] While the visual composite variable included visual storage measures, according to the study results; storage and imagery as measured by these types of tests might not be dissociable.

written text. These types of spatial attention shifts are also important for spatial imagery, which requires scanning the spatial relations of mental images. If a dyslexic individual is unable to effectively scan and shift their attention between various points in space, then their ability to maintain a spatial representation of letters, words, and lines of text could also be affected. As a result, reading fluency and comprehension could be compromised. Along these lines, there is some evidence for a relationship between spatial storage (i.e. spatial span) and reading comprehension (Goff et al., 2005).

Perhaps one way spatial scanning (in the form of imagery and storage) facilitates reading fluency and comprehension is by providing a strategy for 'chunking' text so that it can be maintained more efficiently. Previous research suggests that verbal chunking strategies are not that efficient in dyslexic readers, as a result, verbal WM capacity limits comprehension (Daneman & Carpenter, 1980). Perhaps this is also true with spatial WM where the ability to scan and maintain the spatial relations amongst letters, words, and lines of text increases the capacity to temporarily store a spatial framework of text. After searching the literature, there appears to be no research on the role of spatial WM and spatial chunking strategies in dyslexic readers. This type of research could reveal some important findings regarding the role of the VSSP in reading.

In general, the current study has provided evidence that the VSSP should be dissociated according to the type of information (i.e. visual or spatial) processed and that its components are indeed related to the ability to read. There are many lines of future research than can be pursued based on the results of this research. For example, many suggestions for how to improve current behavioural measures of visual and spatial storage and imagery have been provided. This line of research is crucial for the improved understanding of the variety of tasks used across the fields of cognitive psychology, neuropsychology, and cognitive neuroscience.

Another line of research that could be pursued is the dissociation between visual and spatial storage and imagery processes. Perhaps additional case studies will be found that demonstrate a full double dissociation between these processes or perhaps differential developmental trajectories will be discovered. With respect to spatial storage in particular, the differences between the current measures suggests a need to investigate the different types of coding processes that might be involved in retaining spatial information. For example, perhaps the differences in these tests reflect separate mechanisms for retaining topographical vs. spatial 'order' information within the spatial store. This could be analogous to Baddeley's recent suggestion for separate item and order mechanisms within the phonological loop (Baddeley, 2003a).

The masked visual vs. spatial dissociation in the normal sample suggests that another interesting area for future research would be to investigate whether cognitive style (i.e. verbalizers vs. object/spatial visualizers) is related to VSSP processing and whether the presence of verbalizers does in fact mask the visual vs. spatial dissociation. Also, the masked visual/spatial dissociation speaks to a need to use shared variance techniques with specific clinical samples in future VSSP research. The use of clinical groups with damage to brain areas vital for either visual or spatial processing, such as the dyslexic group used in the current study, should be used to help dissociate functioning within the VSSP.

With respect to research concerning spatial processing and dyslexia, the results from the current study add to the evidence that there is a spatial processing deficit in dyslexic individuals. The results also provide more support for a connection between spatial storage and/or imagery and reading fluency. Research on this connection between spatial processing and reading, as well as the connection between visual imagery and reading as seen in the normal sample, could provide information on some of the strategies used by fluent readers. In turn, information on these strategies could be used to help improve reading skills in both normal and dyslexic readers.

In conclusion, the findings from this study not only elucidated the structure of the VSSP and its role in reading, but they also opened many doors for learning about how humans process and store visual and spatial information in WM. Future research is bound to reveal many exciting discoveries concerning this complex cognitive function.

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Table 1. Areas activated during spatial processing tasks

Study	**Broadmann's areas activated during spatial processing tasks**
(Courtney et al., 1996)	19 and 7
(Goldberg et al., 1996)	18, 19, 7
(Haxby et al., 1994)	19, 7
(Jonides et al., 1993)	40
(Owen et al., 1996)	17, 18, 19, 40
(Smith et al., 1995)	19, 40

Table 2. Areas activated during visual processing tasks

Study	**Broadmann's areas activated during visual processing tasks**
(Courtney et al., 1996)	18, 37, and 20
(Haxby et al., 1994)	19 and 37
(Owen et al., 1996)	17, 18, 20, and 37
(Smith et al., 1995)	37

Table 3. Demographic measures for normal and dyslexic participants

	Normal (N = 101)	**Random subset of 101 normals (N=20)**	**Dyslexic (N = 10)**	**20 Normal/10 Dyslexic (N = 30)**
Age; *M* (*SD*)	19.30 (2.45)	18.90 (1.55)	30.50 (18.53)	22.77 (11.79)
Number of Males (Number of Females)	49 (52)	10 (10)	3 (7)	13 (17)

Table 4. Z scores and discrepancies on IQ and reading measures for 10 participants reporting reading difficulties

Participant	WAIS Vocabulary (IQ)	WJ Word Attack	WJ Reading Fluency	IQ – Word Attack discrepancy	IQ – Reading Fluency discrepancy	Meets 1 SD deviation criteria for dyslexia	ADT classification
JS	-0.55	-1.50	-2.24	0.95	1.69*	Yes	Dysphoneidesia
AB	1.74	-0.04	0.72	1.78*	1.02*	Yes	Dyseidesia
CH	0.98	-1.86	-2.24	2.84*	3.22*	Yes	Normal
LM	-1.16	-2.60	-0.29	1.43*	-0.87	Yes	Dyseidesia
RD**	0.67	-1.13	-0.63	1.81*	1.30*	Yes	Dysphoneidesia
SD**	0.83	-1.50	-1.14	2.33*	1.97*	Yes	Above Normal
OS	-1.32	-1.13	-2.66	-0.18	1.34*	Yes	Dyseidesia
EM	1.44	0.33	-0.21	1.11*	1.65*	Yes	Normal
NG	-0.40	0.33	-3.17	-0.73	2.77*	Yes	Normal
EW	2.36	1.06	0.81	1.29*	1.55*	Yes	Normal

* Discrepancy of 1 standard deviation or greater between IQ and reading score

** Identical twins

Table 5. Descriptive statistics for all study variables

	Test	Normal (N = 101)		Normal/Dyslexic (N = 30)		Dyslexic (N = 10)		Normal (*N*=20)	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Visual Imagery	**Animal Tails**	18.19	1.347	18.27	.980	18.50	.972	18.15	.988
	Emergent Forms	15.43	3.087	14.50	3.340	13.40	2.011	15.05	3.762
Visual Storage	**VSMT Shape**	35.21	3.232	33.80	4.262	32.90	5.685	34.25	3.432
	BVRT Visual (# incorrect)	.70	.831	1.07	1.999	2.00	3.162	.60	.821
Spatial Imagery	**Brooks**	16.78	3.778	14.47	4.562	14.10	4.358	14.65	4.760
	MRT	10.06	4.381	9.30	4.496	8.60	4.274	9.65	4.671
	Road Map (efficiency score)	1.3136	.49965	1.2681	.50306	.9569	.35280	1.4237	.50088
Spatial Storage	**VSMT Location**	40.87	3.638	39.37	4.575	38.50	4.478	39.80	4.675
	Spatial Span	9.79	1.687	9.03	1.771	8.30	2.312	9.40	1.353
	BVRT Spatial (# incorrect)	1.57	1.381	1.57	1.073	1.20	.632	1.75	1.209
IQ	**Vocabulary subtest**	48.40	6.388	49.17	7.634	51.60	8.208	47.95	7.236
Reading	**WJ Word Attack**	28.32	2.619	27.63	2.553	25.90	3.178	28.50	1.670
	WJ Reading Fluency	89.85	10.457	84.50	14.355	75.40	16.688	89.05	10.826

Table 6. Test reliabilities with and without outliers

	Test	Reliability (N=101)	Reliability with outliers removed
Visual Imagery	**Animal Tails**	Crobach's α=.265	Cronbach's α=.204 (N=90)
	Emergent Forms	Cronbach's α=.402 Inter-rater reliability = .956	NA
Visual Storage	**VSMT Shape**	Cronbach's α=.214.	NA
	BVRT Visual (# incorrect)	Cronbach's α=.077 Inter-rater reliability = .621	Cronbach's α=-.093 (N=99)
Spatial Imagery	**Brooks**	Cronbach's α=.732	Cronbach's α=.658 (N=99)
	MRT	Cronbach's α=.911 (Peters, 2007: personal communication)	-
	Road Map (efficiency score)	Not available (only 1 trial)	-
Spatial Storage	**VSMT Location**	Cronbach's α=.565	Cronbach's α=.511 (N=101)
	Spatial Span	Cronbach's α = .79 (Wechsler, 1997)	-
	BVRT Spatial (# incorrect)	Cronbach's α=.311 Inter-rater reliability = .645	Cronbach's α= -.259 (N=91)
IQ	**Vocabulary subtest**	Cronbach's α=.93 (Wechsler, 1997)	-
Reading	**WJ Word Attack**	Test-retest reliability=.83 (Woodcock et al., 2001)	-
	WJ Reading Fluency	Test-retest reliability=.88 (Woodcock et al., 2001)	-

NA: no outliers detected in sample

Table 7. Observed correlations, reliability values, and corrected correlations among all measures (N = 101)

		Visual Imagery		Visual Storage		Spatial Imagery			Spatial Storage			IQ	Reading	
		Animal Tails	Emergent Forms	VSMT Shape	BVRT Visual	Brooks	MRT	Road Map	BVRT Spatial	VSMT Location	Spatial Span	Vocab	WJ Reading Fluency	WJ Word Attack
Visual Imagery	Animal Tails	(.265)	-0.07	0.14	-0.09	-0.15	-0.07	.207(*)	-0.03	-0.14	-0.03	-0.14	-0.01	-0.01
	Emergent Forms	**-0.21**	(.402)	-0.03	-0.08	.380(**)	.440(**)	.283(**)	-.253(*)	0.11	0.18	.203(*)	0.09	.260(**)
Visual Storage	VSMT Shape	**0.58**	**-0.11**	(.214)	0.01	.214(*)	0.18	0.14	-0.06	0.11	0.06	-0.01	0.02	0.19
	BVRT Visual	**-0.65**	**-0.45**	**0.09**	(.077)	-0.06	-0.13	-0.08	.199(*)	-0.09	-0.13	0.04	-0.17	-0.02
Spatial Imagery	Brooks	**-0.34**	**0.70**	**0.54**	**-0.25**	(.732)	.372(**)	.402(**)	-.235(*)	0.07	.275(**)	0.08	-0.01	0.15
	MRT	**-0.14**	**0.73**	**0.41**	**-0.50**	**0.46**	(.911)	.491(**)	-.431(**)	0.10	.258(**)	0.03	0.11	0.15
	Road Map	NA	NA	NA	NA	NA	NA	(NA)	-.202(*)	0.14	.345(**)	0.09	0.04	0.03
Spatial Storage	BVRT Spatial	**-0.10**	**-0.72**	**-0.24**	**1.29**	**-0.49**	**-0.81**	NA	(.311)	-0.07	-0.03	0.08	-0.09	-0.10
	VSMT Location	**-0.35**	**0.24**	**0.31**	**-0.43**	**0.10**	**0.14**	NA	**-0.16**	(.565)	0.02	0.08	.218(*)	-0.12
	Spatial Span	**-0.07**	**0.31**	**0.15**	**-0.51**	**0.36**	**0.30**	NA	**-0.05**	**0.03**	(.790)	-0.01	-0.11	-0.07
IQ	IQ (Vocab)	**-0.28**	**0.33**	**-0.03**	**0.15**	**0.10**	**0.03**	NA	**0.15**	**0.12**	**-0.01**	(.930)	.326(**)	.302(**)
Reading	WJ Reading Fluency												(.880)	.383(**)
	WJ Word Attack													(.830)

Note: alpha coefficients presented on the (diagonal), observed correlations above the diagonal, **correlations corrected for attenuation below the diagonal**

p*<.05,*p*<.05

Table 8. Factor loadings for 101 normal participants

Factor 1 (Eigenvalue = 2.73; 27.3%)		**Factor 2 (Eigenvalue = 1.24; 12.4%)**		**Factor 3 (Eigenvalue = 1.11; 11.1%)**		**Factor 4 (Eigenvalue = 1.05; 10.5%)**	
MRT	**.79**	**Animal Tails**	**-.78**	**VSMT Shape**	**.78**	**VSMT Location**	**.80**
Road Map	**.73**	**BVRT Visual**	**.48**	**BVRT Visual**	**.46**	**Spatial Span**	**-.48**
Brooks	**.69**	BVRT Spatial	.43	BVRT Spatial	.30	VSMT Shape	.32
Emergent Forms	**.63**	VSMT Shape	-.31	Emergent Forms	-.26	Animal Tails	-.18
BVRT Spatial*	**-.52**	Road Map	.23	Animal Tails	.21	BVRT Spatial	-.15
Spatial Span	**.48**	VSMT Location	.16	Brooks	.19	Brooks	-.096
VSMT Shape	.25	MRT	-.13	Spatial Span	.15	Emergent Forms	-.086
VSMT Location	.24	Spatial Span	.12	Road Map	.14	Road Map	-.054
BVRT Visual	-.24	Brooks	.119	VSMT Location	-.80	BVRT Visual	-.048
Animal Tails	-.19	Emergent Forms	.038	MRT	-.013	MRT	-.011

*Negative loadings for BVRT are expected (measures number of *incorrect* responses)

Table 9. Factor loadings for 10 dyslexic and 20 normal participants

Factor 1 (Eigenvalue = 3.39; 33.9%)		**Factor 2 (Eigenvalue = 1.64; 16.4%)**		**Factor 3 (Eigenvalue = 1.08; 10.8%)**	
Emergent Forms	.80	**VSMT Shape**	**.69**	**BVRT Spatial**	**.94**
Road Map	**.70**	**BVRT Visual**	**-.65**	VSMT Shape	-.21
Spatial Span	**.66**	Animal Tails	.44	MRT	-.19
Brooks	**.61**	VSMT Location	.35	Road Map	.18
VSMT Location	**.61**	Road Map	-.35	VSMT Location	-.16
MRT	**.60**	MRT	-.31	BVRT Visual	-.14
BVRT Visual	**-.59**	Emergent Forms	-.29	Spatial Span	.14
Animal tails	-.46	Brooks	-.25	Emergent Forms	.073
VSMT Shape	.38	Spatial Span	.24	Brooks	.018
BVRT Spatial	-.10	BVRT Spatial	.12	Animal Tails	-.018

*Negative loadings for BVRT are expected (measures number of *incorrect* responses

Table 10. Zero-order correlations from stepwise regressions with 101 normals

Correlations between predictor and criterion variables		
	Spatial	**Visual**
Spatial		
Visual	**.233***	
Word Attack	**.105**	**.137**
Reading Fluency	**.101**	**.178**

*$p < .05$

Table 11. Zero-order correlations from stepwise regressions with normals and dyslexics

Correlations between predictor and criterion variables		
	Spatial	**Visual**
Spatial		
Visual	**.445****	
Word Attack	**.111**	**.145**
Reading Fluency	**.414***	**.335**

*$p < .05$

Table 12. Visual and spatial imagery and storage means and SD's for normals and dyslexic participant's corresponding scores

		Controls		Dyslexic Participants									
	Test	M	SD	JS	AB	CH	LM	RD	SD	OS	EM	NG	EW
Visual Imagery	Animal Tails	18.20	1.34	18	17	18	20	19	18	18	20	18	19
	Emergent Forms	15.43	3.09	9*	14	15	15	15	13	13	15	11	14
Visual Storage	VSMT Shape	35.25	3.25	25**	32	39	32	34	37	42*	34	24**	$30^{\dagger}$
	BVRT Visual (# incorrect)	0.70	0.83	10**	0	2	1	0	0	0	0	4**	3**
Spatial Imagery	Brooks	16.81	3.77	10*	9*	16	12	19	20	14	11	10*	20
	MRT	10.04	4.36	7	8	17	5	14	7	10	4	4	10
	Road Map (efficiency score)	1.31	0.50	0.78	0.82	1.1	0.59	1.22	1.41	0.77	1.52	0.95	0.41*
Spatial Storage	VSMT Location	40.89	3.63	30**	41	41	44	40	38	43	38	32**	38
	Spatial Span	9.81	1.69	5**	9	10	12	8	9	11	$7^{\dagger}$	6*	6*
	BVRT Spatial (# incorrect)	1.58	1.38	1	2	1	1	1	0	2	1	2	1
Composite Variables	Spatial (z-score)	-.0165	3.72	-11.48**	-4.43	0.96	-1.87	-0.15	-1.72	-1.34	-5.12	-10.05**	-4.48
	Visual (z-score)	-.023	1.39	-14.35**	-0.16	-0.42	-1.36	0.46	1.38	2.92*	0.46	-7.44**	-4.39**

* Significant difference from controls $p < .05$, one-tailed

** Significant difference from controls $p < .01$, one-tailed

† Difference from controls, $p = .05$

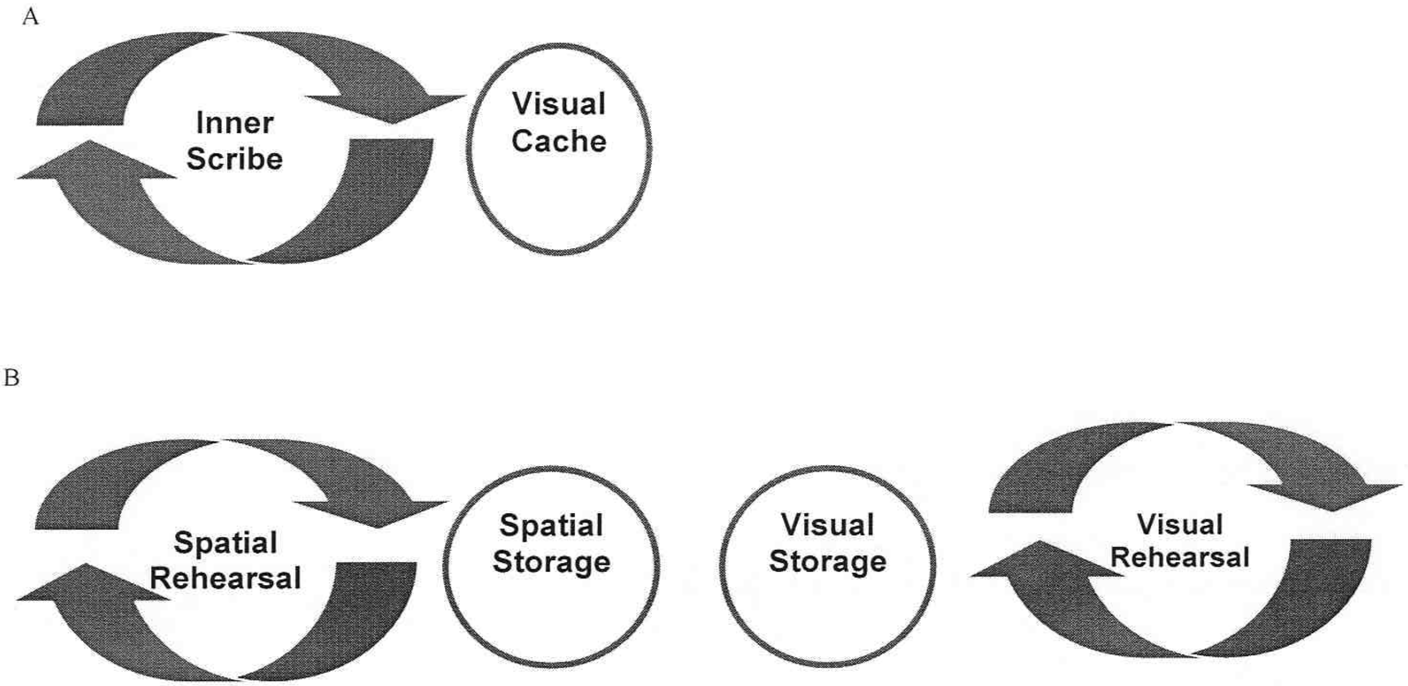


Figure 1. Logie's (A) and the proposed (B) dissociation of the VSSP

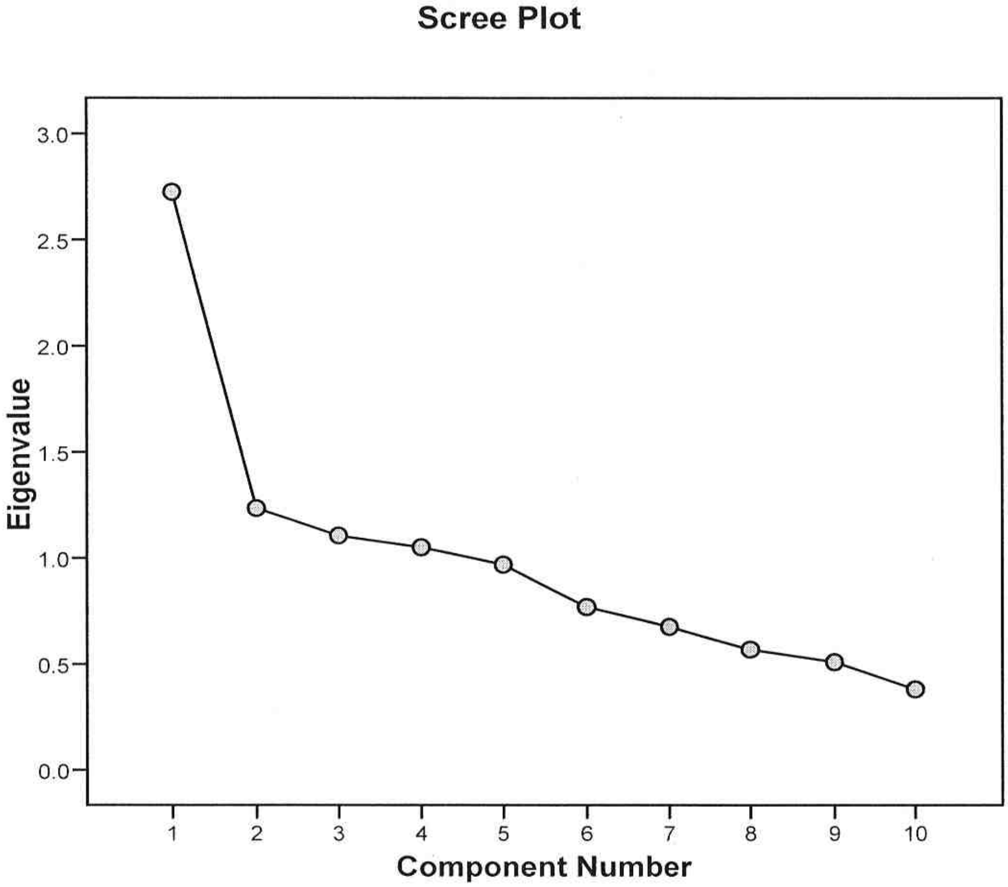


Figure 2. Scree plot from PCA for 101 normal participants

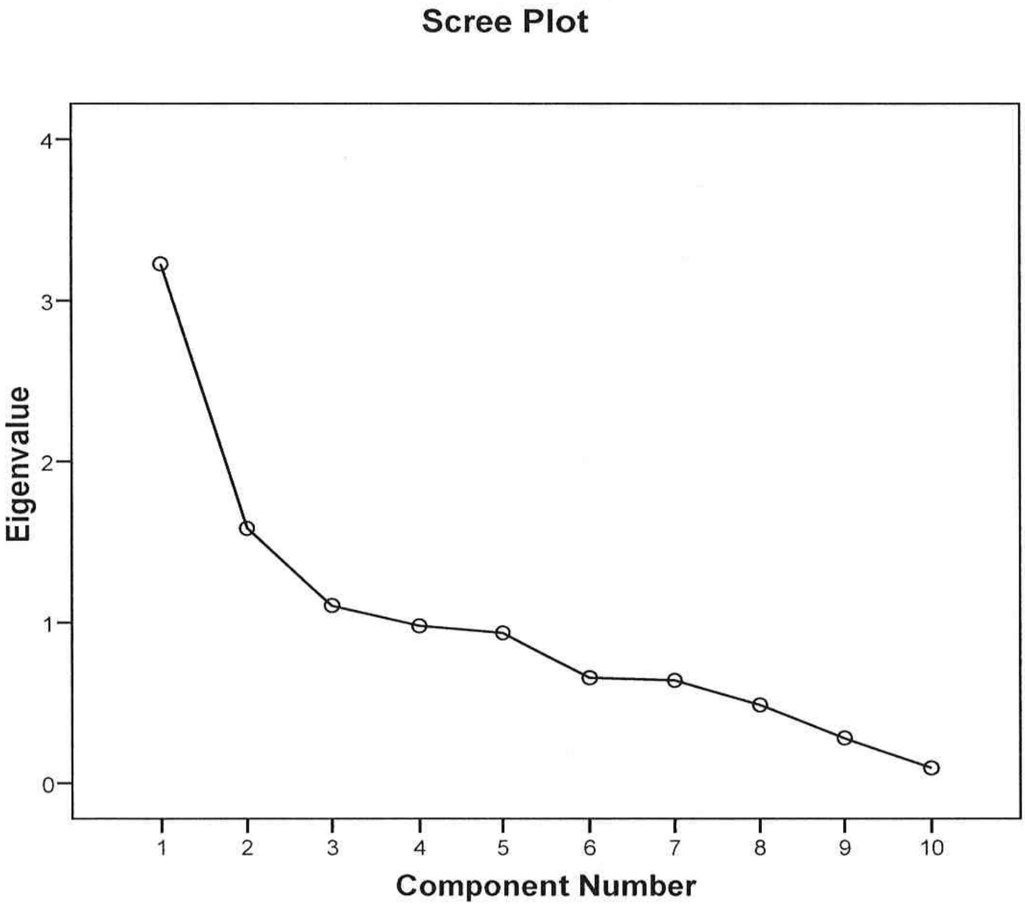


Figure 3. Scree plot from PCA for 10 dyslexic and 20 normal participants

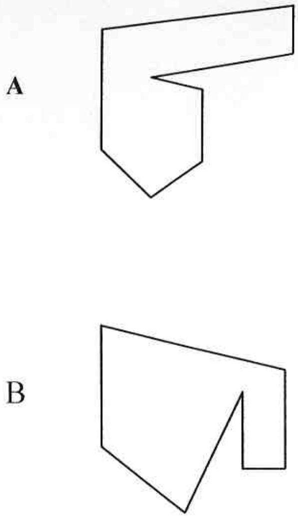


Figure 4. Sample stimuli from the VSMT

Appendix A

Confidential background questions

1. **Age:**
2. **DOB:**
3. **Handedness L R**
4. **Is English your first language? Y N**
5. **Did you learn any other languages at the same time as you learned English? Y N**
6. **Years Education (circle number that has been completed in full):**

High school	0 1 2 3 4 5 6 7 8 9 10 11 12
Trade/college	13 14
University	13 14 15 16
Master's level or x-tra Undergrad	17 18
Ph.D. level	19 20 21

7. **Have you ever been diagnosed with attention deficit disorder with or without hyperactivity? Y N If yes, When?**

8. **Have you ever been diagnosed with a learning disability (other than dyslexia/reading disability), neurological disorder (e.g. epilepsy), or psychiatric disorder (e.g. depression or bipolar disorder)?**

9. **Have you ever been diagnosed with dyslexia or a reading disability by a Psychologist or physician? Y N**

If no,

10. **Do you have a history of reading difficulty that has interfered with your academic progress? Y N**

11. **Have you ever had a head injury that resulted in loss of consciousness or a period of disorientation? Y N**

If yes:

When?

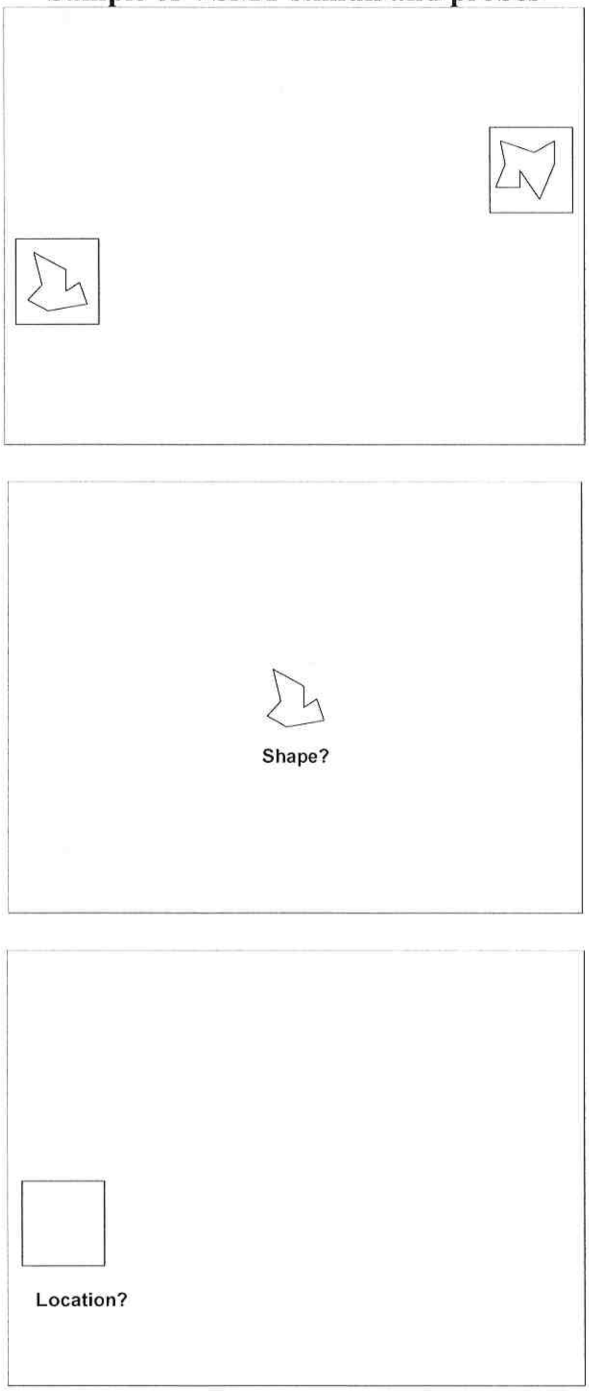
Length of loss of consciousness/period of disorientation?

Any lingering symptoms?

12. Do you have any known problems with your colour vision? Y N

Appendix B

Sample of VSMT stimuli and probes



Appendix C

BVRT scoring details

The original BVRT scoring procedure divided specific types of errors into six categories: Omissions, Distortions, Perseverations, Rotations, Misplacements, and Size Errors (Benton, 1991). For the current study, 'Rotations' and 'Misplacements' were considered to be spatial errors while the other four categories included visual errors. An example of a rotation error would be a plane rotation of a certain number of degrees (i.e. 25 to 180) of either a major or peripheral figure. For the purpose of this study, rotations of internal details (e.g. 90 degree rotation of vertical line to the horizontal) were also counted as spatial errors. An example of a misplacement error would be a left-right reversal of the relative positions of the two major figures or a displacement of a peripheral figure. An additional error added to this category was the displacement of internal details (e.g. left-right reversal of an internal detail such as vertical line inside a right major figure incorrectly drawn in the left major figure). Another change was to make the peripheral figure placement criteria more stringent. The original BVRT criteria for peripheral figures placed at the bottom of the image was that at least part of the figure must lie in the area defined by the midline and the lower limit of the major figures. This was changed so that the entire figure must lie in the previously defined area. For peripheral figures placed at the midline, the original criterion was that at least part of the figure must lie in the area defined by the upper and lower limits of the major figures. The revised criterion is that at least part of the figure must lie in the area defined by the top and bottom quarters of the major figures.

Appendix D

Participant Consent Form

This study, called "Visuospatial Memory", is being conducted by a graduate student in Psychology, Jodie Royan, as part of a degree in Psychology under the supervision of Dr. Roger Graves. You are being asked to participate in this study because you signed up for Psychology 100 course credit through the experimentrix system and: your first language is English, you have not been previously diagnosed with a reading disability (i.e. dyslexia) by a medical doctor or Psychologist, you have not been previously diagnosed with attention deficit disorder/a neurological or psychiatric disorder/impaired colour vision, and you have not had a serious head injury,.

The purpose of this research project is to find out if various types of visual information are remembered differently and to see if this is related to reading ability. Research of this type is important because it will help reduce some of the confusion concerning how people remember visual information and whether it relates to the ability to read.

If you agree to voluntarily participate in this research, you will be asked a few personal questions including your age and gender, and whether you match the above conditions. You will also be asked to complete a number of standardized neuropsychological and common research tasks to measure memory, reading, vocabulary, and perceptual ability. For the reading tasks you will be asked to read some individual words out loud and to read sentences to yourself as quickly as you can. For the visual tasks, you will be asked to do a number of things: remember a series of irregular shapes, imagine and describe some visual patterns and other objects, copy a series of movements performed by the experimenter, mentally rotate some shapes and letters, follow a route traced on a map in your head, and fill out a questionnaire. You will also be asked some vocabulary questions. The session will last approximately one and a half to two hours and will take place entirely in this room (Cornett A085, A139e, Lhut-40).

There are no known or anticipated risks to you by participating in this research. As a benefit of participating in this study, you will learn something about the nature of psychological experimentation and testing procedures, and you will receive credit towards Psychology 100.

Your participation in this research must be completely voluntary and any information concerning your decision to participate, not to participate, or to withdraw from this study will be kept confidential. If you decide not to participate after reading this consent form, there will be no penalty in terms of your grades, standing in your classes, or any other adverse affects. If you do decide to participate and sign the consent form, you can still withdraw from the study at any time, for any reason without consequence, and you will receive credit for the time you did participate. If you decide to withdraw from the study, none of your data will be used and will be destroyed immediately. Since the study can take up to two hours to complete, you will be reminded of your right to withdraw a number of times throughout the session, particularly if you appear to be getting tired.

To protect your anonymity all your data will be handled and reported anonymously. Your data will be coded (score sheets, data files etc.) with a number that is in no way connected with your name. The only exception is that your name and information about your participation (i.e. number of hours/credit earned) will be provided to Psychology 100 staff so that you can receive research participation credit, but no results will be provided. Some of the tasks in this session will be recorded on audio tape. To maintain your anonymity, the cassettes will be coded with a number that is not connected to your name and these recordings will be erased upon the completion of the study (in approximately 12 months). If you do not wish to have audio-recordings made you may decline to participate in the study at any time without consequence. No video recordings of this session will be made and no form of deception will be used.

Ms. Royan will use data from this study for a research paper for course credit and potentially for publication in a psychology journal and a conference report in order to share the results with others. Also, either Ms. Royan or Dr. Graves (research supervisor) could use the data for future research or teaching. Any such use of the data will be completely anonymous, with no information about the individuals who provided the data

Any information with your name attached will be destroyed upon completion of the study (i.e. shredding paper or deleting computer files). Data coded with your anonymous participant number (e.g. computer files, raw data forms) may be retained by Ms. Royan or Dr. Graves.

If you have any questions or concerns about this study, please feel free to contact either the researcher, Jodie Royan at royanj@uvic.ca, or her supervisor, Dr. Graves at rgraves@uvic.ca. If you have any questions or concerns about the ethical approval of this study, you may contact the Associate Vice President of Research at the University of Victoria at 250-472-4362. You may also address any questions or concerns to the chair of the Psychology Department, Dr. Elizabeth Brimacombe at (250) 721-7547 and spam@uvic.ca.

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

______________________	______________________	____________
Name (print)	*Signature*	*Date*

A copy of this consent form will be left with you, and a copy will be taken by the researcher.

Appendix E

Debriefing

The purpose of this study is to investigate memory for different types of visual information and to see how it relates to reading. Currently, researchers are not sure how people remember different types of visual information (i.e. are there different processes for remembering different types of information?) and how this type of memory is important for everyday life. We think that the processes involved in remembering some types of visual information for very short periods of time might somehow be important for reading, an important daily activity. Furthermore, we think that people who have difficulties reading might also have difficulties remembering particular types of visual information. In order to test out these predictions, we are testing memory for visual information and reading ability for two groups of people. One group includes those who have a history of reading difficulties or dyslexia, the other group includes those who have no such a history. We will be comparing these two groups on their visual memory and reading and looking at the how they relate to each other. In general, we expect that the ability to remember certain types of visual information will be related to reading ability. We also expect that people who have difficulties with reading will also have difficullties remembering certain types of visual information. This type of research and the findings from this study are important because they will help researchers understand how human visual memory works, how it might be important for reading, and how problems with visual memory might contribute to reading problems.

If you have any questions or concerns about this study, please feel free to contact either the researcher, Jodie Royan at royanj@uvic.ca, or her supervisor, Dr. Graves at 250-721-7539 and rgraves@uvic.ca. If you have any questions or concerns about the ethical approval of this study, you may contact the Associate Vice President of Research at the University of Victoria at 250-472-4362. You may also address any questions or concerns to the chair of the Psychology Department, Dr. Elizabeth Brimacombe at (250) 721-7547 and spam@uvic.ca.