Rehearsal in the Visuospatial Sketchpad: Spatial Sequence Memory and Central

Executive Processes

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Abstract

Within the framework of the working memory model (Baddeley and Hitch, 1974; Baddeley, 1986), numerous studies have explored the nature of verbal rehearsal and the phonological loop, but fewer have investigated rehearsal in the visuospatial sketchpad and this mechanism remains less well understood. Baddeley (1986) suggested that an implicit motor-based process might be implicated, and proposed a link between movement and visuospatial rehearsal. Evidence for this link was provided by Logie and Marchetti (1991) who found that spatial tapping disrupted memory for spatial sequences, while viewing irrelevant pictures disrupted recall for colour hues. These results confirmed a visual-spatial double dissociation in the visuospatial sketchpad, and subsequently Logie (1995) revised the model of the sketchpad to account for rehearsal by including a mechanism for storing visual information (visual cache) and an active spatially-based mechanism for rehearsal (inner scribe). This model has stimulated much research and although evidence supports the concept of a visual cache, the mechanism of the inner scribe is not well understood, largely due to its complexity.

Therefore, the aim of this thesis was to explore the role of movement in visuospatial memory using Logie's (1995) reformulation of the visual spatial sketchpad as a conceptual framework. Three experiments using first year university students as participants were conducted. The first was an attempted replication of Logie and Marchetti (1991), chosen to confirm the selective effect of movement on spatial memory. Unexpectedly, the replication was unsuccessful with no visual-spatial dissociation demonstrated, but rather a generalised effect of interference. When a sub-set of poorer performing participants was excluded from analysis, the results moved in the expected direction, although the differences were still non-significant. Two

further experiments were conducted specifically to examine spatial rehearsal

processes. Experiment 2 compared spatial memory performance with a simple

measure of memory span (digits forward) using an interference paradigm with three

secondary interference tasks. It was found that although higher span participants

performed significantly better than lower span participants, the expected interaction

between span and interference type did not occur.

Experiment 3 compared spatial memory with performance on the PASAT, a measure

of divided attention containing storage and processing components. Again, high

scoring PASAT participants performed significantly better than low scoring PASAT

participants. Although the interaction was non-significant, results showed a trend for

high PASAT participants to make fewer errors than low PASAT participants, with

post-hoc analyses revealing that the high PASAT group made significantly fewer

errors under the spatial interference condition. This finding suggests that individuals

with more efficient attentional processes are better able to cope with dual task

demands when rehearsing spatial information in working memory. The findings are

discussed with reference to individual differences in working memory, problems with

interpreting results within the conceptual framework of Logie's (1995) model, and

issues concerning subject selection in working memory research.

CHAPTER 1

Overview of the Thesis

The ability to hold and manipulate visual and spatial representations temporarily in mind is necessary for many disparate but useful activities from remembering a series of chess moves to envisaging the layout of one's house or recalling the image of an artwork. This capacity is thought to be the province of a mechanism known as the 'visuospatial sketchpad,' which is conceptualised to be a non-verbal component of the tripartite model of working memory originally proposed by Baddeley and Hitch (1974). The model, which is described in Chapter 2, was formulated to account for the variety of cognitive processes underlying short-term memory, and incorporates three separate mechanisms; a verbal component (phonological loop), a non-verbal component as described above, and an attentional control mechanism (central executive) thought to be responsible for the coordination of the other two systems. The experimental approach utilized by Baddeley and Hitch (1974; 1976) and which has been extensively used since then, is a dual-task methodology designed to manipulate demand on short-term memory. This approach predicts that if two tasks use the same cognitive components, they cannot be performed successfully simultaneously; and conversely, if these two tasks use different components it is logical to expect to be able to perform them as well together as separately. Chapter 2 reviews experimental studies using this methodology that provide evidence to support the existence of separable verbal and visuospatial components in working memory consistent with the Baddeley & Hitch model. However, it became apparent by the 1980's that because of its relatively complex nature and close relationship with the

central executive, which itself had also been largely neglected from a research perspective, the sketchpad was lagging far behind the phonological loop in terms of clear specifications of its function and structure.

In response to this theoretical uncertainty, and in particular to address the question of visuospatial rehearsal, which Baddeley (1983; 1986) had suggested might involve an underlying motor-based process, Logie (1995; 2003), proposed a re-formulation of the role of the sketchpad which is detailed in Chapter 2. This conceptualisation describes two sub-systems; a 'visual cache', which acts as a passive store for visual information such as the shape and colour of objects, and an 'inner scribe', which is envisaged as a rehearsal mechanism for spatially-based information such as mental pathways and movement sequences. Logie's assumption that the visuospatial sketchpad consists of separate visual and spatial components has been supported by evidence from a wide range of paradigms including cognitive, developmental, and neuropsychological studies. This research is reviewed in Chapter 3, along with evidence from brain imaging studies using PET and fMRI technology, with general agreement in the literature that the visuospatial sketchpad can be fractionated into at least two sub-components; visual and spatial.

However, one issue that remains unresolved is the process of visuospatial rehearsal. As noted above, Baddeley (1986) suggested an implicit motor-based process might be implicated in the ability to maintain information in non-verbal working memory, and this link has been extensively investigated in numerous studies that ask participants to move a part of their body while concurrently performing a memory task. One such study by Logie and Marchetti (1991) found that memory for spatial information (a set of sequences) was disrupted by a tapping task, while a visual task (memory for colour hues) was disrupted by viewing line drawings.

Moreover, there was no disruption of spatial by visual interference or vice versa and this double dissociation was interpreted as evidence of separate components for storing and rehearsing information in the sketchpad. However, as outlined in Chapter 3, some researchers have argued that rehearsal is not mediated by movement but linked to shifts of attention (e.g. Smyth & Scholey, 1994; Awh, Jonides & Reuter-Lorenz, 1998), or demands on central executive resources (e.g. Smyth & Pelky, 1992; Klauer & Stegmaier, 1997; Fisk & Sharp, 2003).

In order to try to clarify some of these issues, a series of three experiments were carried out with the overall aim of investigating rehearsal in the visuospatial sketchpad. The initial aim of the thesis was to investigate the role of movement in rehearsal of spatial information, and Chapter 4 describes a replication of Logie and Marchetti's (1991) study, which hitherto has not been so closely duplicated. Unexpected results from this replication led to two more experiments, described in Chapters 5 and 6, which attempt to explain the discrepant findings by investigating individual variations in attentional ability and the effect of these differences on performance of a spatial memory task.

In Chapter 7 the thesis concludes with a discussion of the overall findings. These are explained in the context of Baddeley and Logie's models of working memory, and the importance of acknowledging individual differences in working memory research is highlighted.

CHAPTER 2

Working Memory

Working memory describes a process essential to human cognition, involving the temporary storage and manipulation of information in short term memory. This ability to simultaneously store and process incoming verbal and visual information is regarded as a necessary component for such complex cognitive activities as comprehension of language, learning and reasoning (Baddeley, 1992; 2003), and indeed the very term 'working' memory implies an active and dynamic process. The most generally accepted current model of working memory was proposed by Baddeley and Hitch, (1974) who developed a three-part model to account for short term processing of both verbal and visual spatial material in immediate memory. Their model arose in order to address perceived shortcomings of the then dominant multi-store models of short-term memory, and has evolved over time from the earliest conceptualisation to be a relatively sophisticated and multicomponent model of immediate memory function. The fundamental difference between the working memory model and multi-store models is that Baddeley and Hitch envisaged short-term memory as consisting of several subsystems, whereas multi-store models described short-term memory as a unitary structure. Before discussing the current working memory model in more depth, some historical background is outlined to give a sense of why and how the contemporary model evolved.

2.1 Historical antecedents of the working memory model

Prior to the conceptualisation of short term memory as a multi-dynamic process in its own right, evidence had been mounting from experiments conducted in the 1950's

and 1960's to support a dual short term/long term memory system as opposed to one single system that encompassed both.

Two early key studies by Brown (1958), and Peterson, and Peterson (1959) who separately set out to investigate the duration of short-term memory, found that individuals would forget even small amounts of material unless given the opportunity to actively rehearse them. The Petersons presented their participants with sets of nonsense syllables in trigrams (e.g. BCM) which they were then required to recall after a period of delay of between three and 18 seconds. In the delay period, an interference task was used to prevent rehearsal and it was found that as the time delay increased, the level of recall diminished dramatically from 80% recall after three seconds down to less than 10% recall after 18 seconds (Peterson & Peterson, 1959). Brown (1958) used a similar technique (later known as the Brown-Peterson task) with the same outcome, and both studies concluded that even if material to be recalled is well within memory span, storage memory traces will fade away spontaneously as a result of inhibition of rehearsal. This finding implied the existence of a time-limited short-term memory store as discrete from a long-term store of unlimited capacity and duration.

The weight of evidence from studies such as these and other experimental activity during the period led to increased interest in developing a dual model of memory. The most influential model to arise from this research was proposed by Atkinson and Shiffrin (1968; 1971) and came to be known as the multi-store or modal model. Their model emphasised the structural concept of memory as a short-term store that receives incoming stimuli from the environment through the senses before passing the information on to long-term memory, and was representative of the changing view of memory from purely unitary to that of two separate memory

systems: long term and short term. The Atkinson and Shiffrin model placed great

emphasis on the process of rehearsal as a means of retaining information (see Figure

1).

rehearsal

Information → **Sensory Memory** → **Short term Memory (STM)** → **Long term Memory (LTM)** → Recall
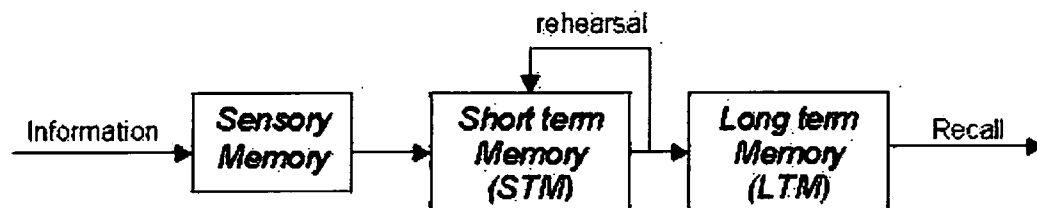
Figure 2.1. Atkinson & Shiffrin's multi-store model of memory.

Perhaps the strongest evidence in support of the modal model was derived

from neuropsychological case studies such as those of the patients KF and HM. KF,

who sustained a brain injury after a motorbike accident, was found to have poor

short-term memory for verbal information but intact long-term memory as

demonstrated by an unimpaired primacy effect but poor recency effect (Shallice &

Warrington, 1970).   In contrast, HM whose circumstances are described in detail in a

paper by Scoville and Milner (1957), was a young man who, following brain surgery

for epilepsy, suffered very specific memory deficits. Though able to hold information

for short periods (intact working memory) HM was unable to consolidate new

information into long-term memory despite multiple repetitions. Evidence such as

this provided additional support for the existence of two separate memory stores.

However, despite all the evidence, unresolved problems remained that could not be

satisfactorily explained by the modal model of memory.

For instance, Craik & Lockhart (1972) who used an incidental-learning paradigm to demonstrate that efficient learning was dependent on the depth of processing that took place, challenged the modal model's assumption that rehearsal is essential for the transfer of information into long-term memory. In this experiment, participants were not required to specifically remember words, but were instead asked to note the physical characteristics of a word (upper or lower case), or the acoustic characteristics, (does the word rhyme with a target word?) or to place the word in context and apply meaning to it in some way. Results showed that recall was weakest for the first condition, slightly better for the acoustic condition and far superior for the semantic condition (Craik & Lockhart, 1972). They proposed that information would be more memorable depending on how it was encoded, and according to this interpretation, storage of information is dependent upon the level of processing and not merely a product of a 'holding' function in short-term memory.

Although useful for emphasizing the distinction between short term and long-term memory, by the 1970's it had become apparent that the modal model was over-simplified by assuming that both stores operated in a regimented unitary fashion, and a more multi-faceted approach to understanding memory was needed in order to better explain the complexities of short-term memory.

2.2 The Baddeley and Hitch Model of Working Memory

Although on the face of it neuropsychological case studies seemed to provide robust support for the modal model, the evidence was also paradoxical. Patients with impaired short-term memory did not necessarily suffer from deficits in their ability to deal with day-to-day problems, or with a range of complex comprehension and reasoning tasks assumed to be reliant on the short-term memory system (see Baddeley 1996a). In order to address this apparent anomaly, Baddeley and Hitch (1974; 1976)

conducted a series of experiments designed to clarify the nature of short-term

memory as other than a simple storage utility. Based on the reasoning that short-term

memory must be involved in a range of tasks, Baddeley and Hitch (1974; 1976)

utilised a dual-task methodology to manipulate demand on short-term memory.

Participants were required to rehearse digit sequences while performing additional

tasks involving reasoning and comprehension assumed to depend on short-term

memory. The results were illuminating, in that although a decrement in performance

did occur with increasing sequence length, accuracy remained high and speed of

performance did not dramatically suffer. Subsequently, Baddeley and Hitch reasoned

that if performance on a digit span and verbal reasoning task did not differentially

affect each other, the two tasks must use different components. This led them to

propose an alternative model that could account for both storage and processing in

short-term memory, as opposed to a single unitary storage mechanism. Their model

makes two fundamental predictions; firstly, if two tasks use the same component then

they cannot be performed successfully at the same time; and secondly, if these two

tasks use different components, logically it should be possible to perform them as

well together as separately. The dual task paradigm they employed continues to be

extensively used in working memory research to demonstrate that if the working

memory system has a limited capacity, then performance in any given modality

should decline if two tasks are competing for the same storage space.

The alternative model of short-term, now termed 'working memory'

introduced by Baddeley and Hitch was proposed to consist of three main components;

the articulatory loop and visual-spatial sketchpad which were presumed to deal with

the short term storage and maintenance of auditory and visual-spatial information

respectively, plus a third component, the central executive (Figure 2). This

mechanism was conceived to be a kind of attentional controller or decision maker for the two other 'slave systems' which were felt to play rather more subsidiary roles (Baddeley 2001).

Over the past 30 or so years since the initial formulation, the working memory model has stimulated an enormous body of research. This has given rise to a more sophisticated understanding of short-term memory, whereupon all elements of the original model have been scrutinised and expanded upon, with the recent inclusion of a fourth component, an episodic buffer (Baddeley, 2000) shown in Figure 3. Each component of working memory, as currently understood, will now be described in more detail.
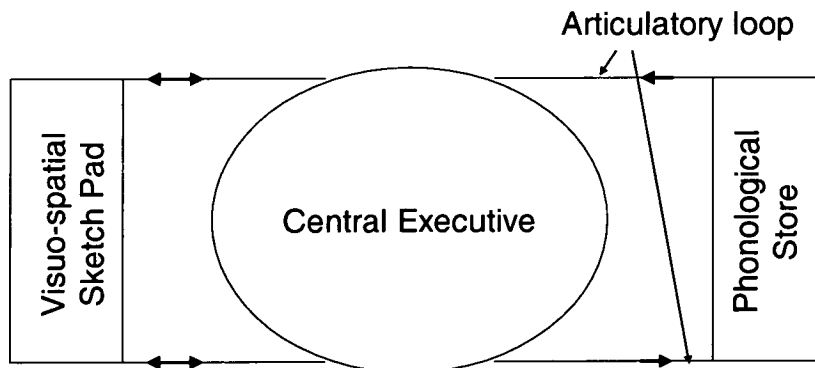
Figure 2.2. The original Baddeley & Hitch (1974) model of working memory.
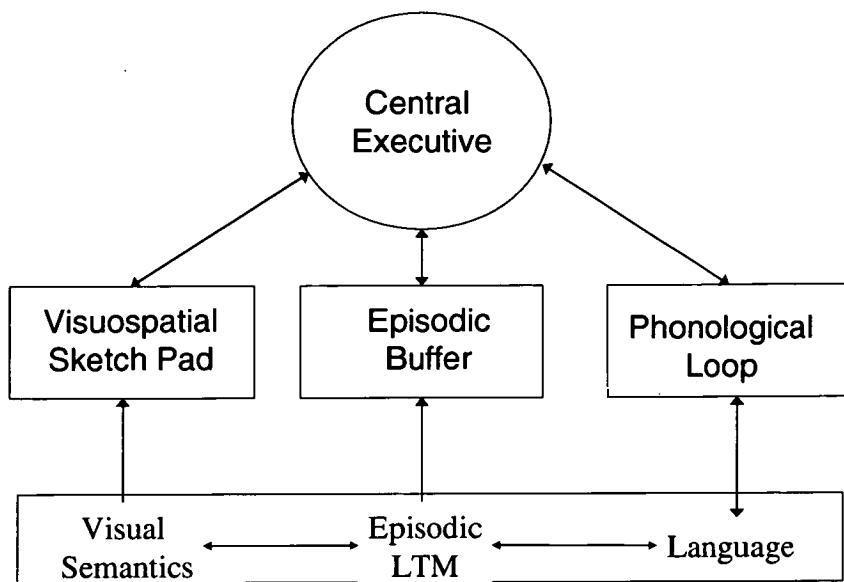
Figure 2.3. The expanded working memory model including episodic buffer (Baddeley, 2000).

2.3 The Phonological Loop

The phonological loop (formerly articulatory loop in the original model) is assumed

to reflect a temporary storage facility (phonological store) that holds verbal

information for several seconds before the traces fade (Figure 2). The phonological

loop is supported by an *articulatory rehearsal* component, which retrieves and

refreshes information as required (Baddeley & Hitch, 1974; Salame & Baddeley,

1982, Vallar & Baddeley, 1982) and is thought to be analogous to sub-vocal speech

(Baddeley, 2003). This same sub-vocalisation process is also used to verbally code a

visual stimulus for registration in the phonological store (Baddeley & Hitch, 1994).

Considerable research has been undertaken to explore this aspect of the model and

has resulted in a variety of well-used techniques for explaining a range of phenomena

attributed to the phonological loop such as the effects of *phonological similarity*,

word length, irrelevant speech and *articulatory suppression*. The first of these, the

phonological similarity effect, has been shown to occur when items similar in sound

e.g. D, V, G, B, or fit, lit, mitt, wit, are recalled less efficiently than items with

dissimilar sound, e.g. K, M, F, Y, or got, ran, lid, moat. The observation that this

does not occur when there is *semantic* similarity, supports the underlying assumption

of the model, that verbal material is encoded largely by sound (Conrad & Hull, 1964;

Baddeley, 1966a, 1996b). The phonological similarity effect also occurs with

visually presented items, and is assumed to reflect the storage component of the loop

whereby material with similar phonological structure is more likely to decay due to

difficulty in discrimination (Salame & Baddeley, 1982).

The articulatory rehearsal component of the phonological loop was proposed to

account for the word length effect, that is, a list of short words e.g. rat, crib, lot, pen

is remembered better than a list of long words e.g. university, recreation, apartment,

fortunate. This is explained by the fact that short words can be articulated more

swiftly thus allowing more words to be silently articulated before they decay

(Baddeley Thompson & Buchanan, 1975). The model is further supported by the

observation that when rehearsal is prevented by concurrent irrelevant speech e.g.

repeating a word such as 'the' 'and' or 'three', the word length effect is extinguished

(Baddeley et al., 1975) a process known as articulatory suppression.

In summary, the phonological loop is a two-part sub-component of the working

memory model and is comprised of a phonological store that registers auditory

memory traces that are vulnerable to decay unless retrieved by the articulatory

rehearsal component via a process of sub-vocal (silent) articulation. This system is

thought to be involved in language perception and production processes, both

important for learning to read (Baddeley 2003) and necessary for acquisition of

language (e.g. Gathercole and Baddeley, 1989). However, further review of this

aspect of working memory is beyond the scope of this thesis and as such, will not be discussed further.

2.4 Visual Spatial Sketchpad

Support for the existence of a separate mechanism for dealing with non-verbal information first arose from studies that showed clear dissociations between performances on tasks that require either verbal or visuospatial processing. Early evidence for such a separation emerged from studies by Brooks (1967; 1968) who developed an imagery task that has since been widely used to investigate the function of the sketchpad. Brooks (1967) employed a task in which subjects were told to imagine a 4x4 grid, and encouraged to use spatial imagery to recall a sequence of sentences, which were presented using spatial or nonsense adjectives for example: 'in the next square to the right put a two' (spatial) or 'to the next square to the quick put a two' (non-spatial). Brooks observed that when subjects were unable to use imagery to remember the sentences and had to rely on rote learning, performance suffered. He made the assumption that mental images are stored visually, not verbally, which suggests that different modes of storage operate in working memory.

In a subsequent study, Brooks (1968) reported selective interference effects between visual and auditory storage in working memory. This time, he asked subjects to visualise a letter, "F" and while holding this image in mind, half the participants were instructed to describe the characteristics verbally, and half to respond spatially (by pointing to a series of written responses). Results clearly showed that subjects found pointing more difficult than verbal responses, and thus Brooks concluded that maintenance of a visual image in mind involves spatial coding which is interfered with by simultaneous visual processing. This finding was reinforced by a further experiment that showed sentence memory to be impaired by verbal but not spatial

responses, thus consolidating the evidence for separable modes of storage in working memory, and suggesting that non-verbal processes in short-term memory may be primarily spatial in nature (Brooks, 1968).

In a later study that explored the distinction between memory for spatial location and memory for visual information using the Brooks matrix task, Baddeley and Lieberman, (1980) demonstrated that memory for spatial locations was disrupted by a spatial tracking task, but not significantly disrupted by brightness judgements. This finding led them to speculate on the existence of separate visual and spatial processing systems in working memory, and to conclude that the visuospatial sketchpad was primarily spatial. However, this view was contradicted by Beech (1984) whose partial replication of the study by Baddeley and Lieberman (1980) found that spatial memory was in fact disrupted by a brightness judgement task as well as a secondary spatial tracking task. In contrast, there was no effect of visual or spatial interference on verbal memory processing. These findings provided evidence not only for a distinction between verbal and visuospatial processing in working memory, but also suggested that both visual and spatial processes are involved in processing in the sketchpad thus ruling out a purely spatial system. Farmer, Berman and Fletcher (1986) further clarified the independent nature of the sketchpad from the phonological loop when they showed that articulatory suppression had no effect on a visuospatial reasoning task, while continuous sequential tapping did disrupt performance.

Thus by the middle of the 1980's, research had progressed to the point whereby it had been shown that auditory and visuospatial working memory could be clearly distinguished experimentally, and that further visual-spatial distinctions were likely to exist within the sketchpad itself.

Generally, though, progress into formulating a clearly definitive model of the functions of this sub-component of working memory has lagged behind that of its counterpart, the phonological loop, largely due to difficulties with finding suitable tasks to provide purely visual or purely spatial measures. It has been observed that because these early studies assumed that visual memory and visual imagery were synonymous, there has been a tendency to use both imagery and short-term memory tasks as measures in visuospatial working memory research (Andrade, 2001). Some researchers have argued that this approach has led to confusion in the literature and a lack of a clear distinction between imagery and visuospatial memory (Pearson, 2001). Moreover, it has been acknowledged that compared with the phonological loop, the visuospatial sketchpad is a more complex system due in part to its relationship with the central executive (Baddeley, 2001). This means that this aspect of working memory is more difficult to investigate experimentally because of problems finding tasks that tap into purely spatial or purely visual characteristics and that do not involve additional cognitive input from the executive system.

2.5 Logie's model of the visuospatial sketchpad

In response to the conceptual elusiveness of this non-verbal component of working memory, Logie (1995; 2003) proposed a reformulation of the working memory model with particular emphasis on the role of the sketchpad. This revised version closely parallels Baddeley's tripartite model in terms of the phonological and executive components, but stipulates a role for the sketchpad as consisting of two specific components, a 'visual cache' and 'inner scribe' that are clearly separable but which work in close partnership (Figure 4). According to this model, the visual cache has close links with the visual perception system, with capacity to quickly process and store visual information such as the shape and colour of objects. This component

is seen as fundamentally passive in nature and subject to both decay and to interference from incoming information, while the inner scribe acts as a rehearsal mechanism, somewhat analogous to the role of the phonological loop in verbal working memory (Logie, 1995).

2.5.1 The Visual Cache

The concept of a passive visual store, complemented by a spatially based active rehearsal mechanism has been investigated in research that has used interference paradigms to show differential disruption to occur between the two systems. Logie's (1995) proposal that a passive visual store will be vulnerable to unattended visual material, much as the phonological loop is susceptible to the equivalent verbal input, has been explored in several studies that use drawings or pictures to demonstrate how this could occur. A series of experiments (Logie, 1986) addressed the issue of obligatory access to the visual store from visually based interference material, an effect assumed to parallel the irrelevant speech effect in the phonological loop. Results from the fourth experiment demonstrated that performance on a visual imagery task declined when participants looked passively at line drawings of common objects and animals (Logie, 1986). A later study confirmed this effect using a purely visual task (memory for colour hues) whereupon recall was disrupted by the interpolation of line drawings during a short retention interval (Logie & Marchetti, 1991). Della Sala, Gray, Baddeley, Allamano, and Wilson (1999), who used pictures featuring abstract paintings to selectively disrupt performance on memory for matrix patterns, repeated this finding. However, not all studies have succeeded in obtaining the same results using pictures and drawings to cause visual interference effects. Quinn and McConnell (1996a) developed an alternative technique known as 'dynamic visual noise' that involves the passive observation of a flickering display,

after they discovered that the irrelevant picture effect proved problematic to replicate. In their first experiment, Quinn and McConnell found that dynamic visual noise caused disruption to the concurrent memorisation of word lists under mnemonic but not rote verbal instructions, while line drawings caused disruption under both conditions. They interpreted these results to mean that while both interference tasks are certainly visual in nature, thus implying automatic access to the visual store in line with Logie's (1995) assumption, using line drawings may attract central executive input because of the constantly changing nature of the task (Quinn & McConnell, 1996a). However, although subsequent studies have shown that visual noise does demonstrate selective interference in the passive visual store (Quinn & McConnell, 1999; McConnell & Quinn; 2000; 2004), others have challenged the veracity of this. For example, Andrade, Kemps, Werniers, May & Szmalec (2002) used dynamic visual noise as a secondary interference task but found that although there was a disruptive effect on visual imagery using the pegword task, there was no such effect on recall of visual memory using static patterns or Chinese characters. Andrade and colleagues concluded firstly, that visual working memory, unlike visual imagery, is insensitive to visual noise and therefore is not necessarily analogous to verbal working memory in that there is no obligatory access for irrelevant visual material to the visual store. Secondly, they suggested that visual imagery and visual memory processes are linked to different cognitive processes in working memory (Andrade et al., 2002). One of the implications of these findings is that visual noise may be a more useful task for disrupting imagery-based information than for selectively interfering with visual working memory. These mixed findings highlight the problematic issue of task selection across the area of visuospatial memory research generally, in that some chosen tasks may not necessarily tap into purely

visual processes, and this issue is further complicated because of lack of clarity concerning the role of imagery within the working memory model itself.

2.5.2 The Inner Scribe

The proposed function of the inner scribe on the other hand, is to rehearse the contents of the visual cache, manage a range of information about movement sequences, and play a role in the planning and execution of movement (Logie, 1995; Logie & Pearson, 1997). Indeed, Logie's re-formulation of the role of the sketchpad arose in part to address the issue of visuospatial rehearsal in working memory, which Baddeley (1986) had proposed might involve implicit motor-based processes perhaps analogous to sub-vocal articulation in the phonological loop. This proposal has stimulated a large body of research examining the link between movement and rehearsal in the sketchpad. Evidence to support this connection has been derived from studies such as those conducted by Smyth and colleagues (Smyth, Pearson & Pendleton 1988; Smyth & Pendleton, 1989) which contrasted memory for body movements and memory for location sequences. They found that memory for body movements were distinguishable from memory for specific targets in space, in that a spatial tapping task impaired spatial memory span, but did not affect memory for body movements. Subsequently they suggested that different mechanisms of rehearsal must underlie memory for spatial location in visuospatial memory. Unfortunately, because both the primary and secondary tasks were presented concurrently in these studies, it is not possible to be certain that interference occurred because of spatial intrusion or because of central executive involvement during the encoding stage.

In a study that focussed on the retention of visual and spatial information in the sketchpad, Logie and Marchetti (1991) used an interference paradigm and found that movement (tapping around an array) during a retention interval disrupted

memory for spatial sequences but not memory for colour hues. They argued that this finding supports the notion of an active rehearsal mechanism responsible for the maintenance of a series of movements that is separate from both the passive visual store, and from central executive processing. This study has been influential in informing subsequent research, and is widely cited in visuospatial working memory literature, however although there have been a few studies that have reported a repetition of these findings (e.g. Tresch, Sinnamon & Seamon, 1993; Klauer & Zhao, 2004) none have used the same primary or secondary tasks. Therefore it has only been assumed that the results reported by Logie and Marchetti (1991) are due to a separation of visual and spatial resources and are not attributable to other characteristics of the tasks, sample population or methodology they used.

Additional evidence to support the separation of spatial from visual processes in the sketchpad according to Logie's revised model was provided by Quinn and McConnell (1996b) who designed an experiment to deliberately load onto both the visual store and the inner scribe. Two primary imagery tasks, the pegword mnemonic and the method of loci were employed, with dynamic visual noise and tracking a moving dot to pre-ordained locations used as visual and spatial interference tasks respectively. It was found that while the method of loci task was disrupted by visual but not spatial interference, both types of interference disrupted performance on the pegword task. The authors interpreted this selective disruption as reflecting the need for the cognitive processes required for the pegword task to allow access to both the visual store and the spatial rehearsal mechanism, while the method of loci needed only to load onto the visual store (Quinn & McConnell, 1996b).

As mentioned in section 2.4, two main types of tasks have been used in visuospatial research, those that use imagery-based measures such as the Brooks task, and tasks

that employ measures of memory span such as spatial sequencing or pattern span tasks. The studies reviewed in this section reflect this tendency in that a wide variety of tasks has been used to explore visual/spatial distinctions in the sketchpad. This is potentially troublesome in that the varying task requirements may be measuring different cognitive characteristics of visuospatial working memory, with some tasks demanding more cognitive resources than other tasks. Clearly, this is an area that warrants further clarification.

A further distinctive element of Logie's model is the emphasis placed on the role of long-term memory as the first port of call for information entering from the senses. Logie (2003) argues that information received via the senses does not pass directly into working memory but "incorporates some form of interpretation based on prior knowledge" (p. 42). He suggests that sensory information about for example, contours, textures, or shades perceived directly from the environment are then identified as meaningful shapes or objects based on information retrieved from long-term memory. In this conceptualisation, working memory is conceived as a mental workspace or `inner eye' whose function is to deal with incoming visual stimuli such as the shape and appearance of objects, and spatial information such as keeping track of where we are in relation to the environment around us (Logie, 1995, 2003). Additionally, the sketchpad can retrieve images from long-term memory for display when required, for example picturing in mind the layout of ones' house or garden, or forming a visual image of a known person who is not physically present. Clearly, there is need for a mechanism to update this information in response to constantly changing situational demands as we navigate our bodies through space, and the visuospatial sketchpad is thought to fulfil this role (Logie, 1995).

With regard to the relationship between visuospatial working memory and imagery, although Baddeley (1986) hypothesised that the sketchpad manages both short-term memory and the generation and manipulation of mental images, others have suggested that these two are not synonymous (Logie, 1995; Pearson (2001). As the present thesis is concerned primarily with the mechanism responsible for maintenance of spatial information in the visuospatial sketchpad, a comprehensive review of the imagery literature that in recent years has become extensive, will not be undertaken. However, given close linkages with the working memory model in terms of theory development, task use and interpretation of results the following points are relevant to the current review.

The Logie model envisages the visual cache and inner scribe as material-specific storage mechanisms quite separate from the system responsible for conscious imagery, and Logie's reformulation of the working memory model distinguishes the visual cache from a 'visual buffer' which is responsible for the representation of images (Logie, 1995; 2003; Pearson, 2001). More recently, it is has been suggested that mental synthesis, the ability to generate and manipulate novel information, draws on all parts of the working memory system, and may primarily be operated by the central executive (Pearson, Logie & Green, 1996; Pearson, Logie, & Gilhooly, 1999). Pearson (2001) has suggested that the revised model of visuospatial working memory as proposed by Logie is well placed to accommodate the role of visual imagery within the cognitive architecture of working memory. This is because the model conceptualises separate mechanisms, a visual buffer to represent conscious visual imagery, with a visual cache and inner scribe that deal with the respective storage of visual and spatial information. However, there is no clear consensus in the

literature as to whether or not mental imagery is best conceived as part of the working

memory model or as a separate system and research into this area is ongoing.
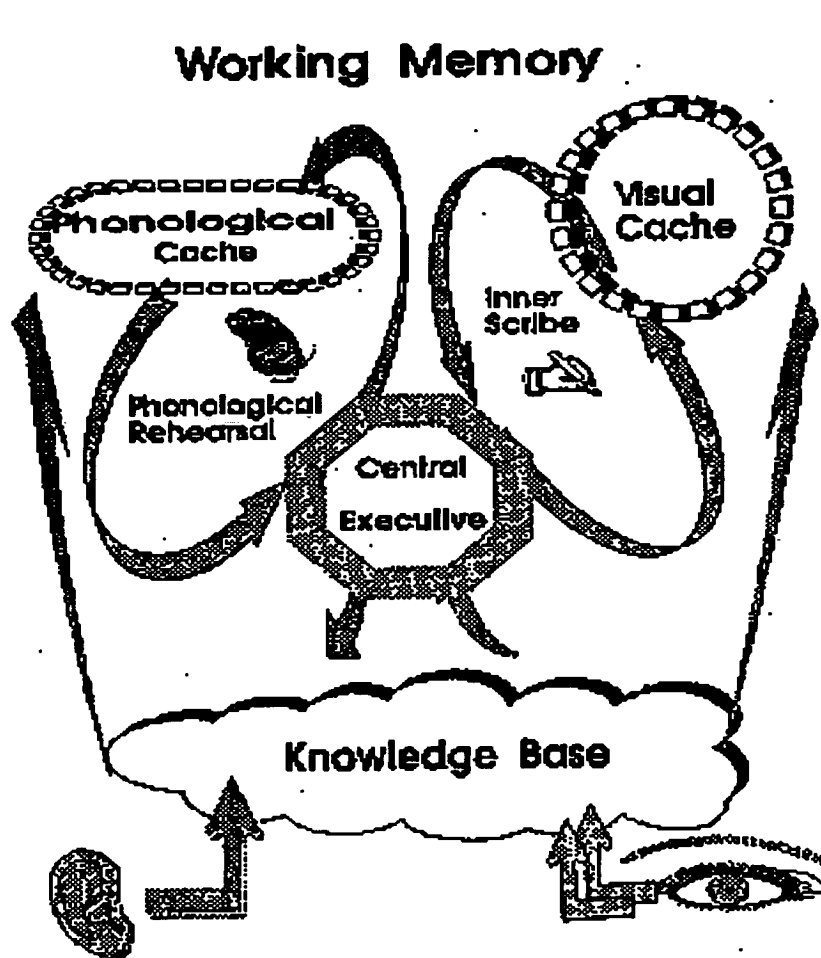
Figure 2.4 Logie's (1995) reformulated model of the visuospatial sketchpad showing links with long term memory (LTM).

2.6 Central Executive

It is interesting to note that although the central executive has always been

considered the most important component of the working memory model, this feature

has also been the least well defined (Baddeley, 2003). As observed earlier, the central

executive was initially conceptualised as an attentional mechanism, albeit described

in somewhat vague terms as 'ragbag' or 'homunculus,' and considered to fulfil an

essential but limited capacity processing role as coordinator and overseer for the two

slave storage systems (Baddeley, 1996a; 2001). In an endeavour to describe and

formulate the role of the central executive, Baddeley (1986) suggested that a

framework could be modelled on the *supervisory activating (attentional) system*

(SAS) proposed by Norman and Shallice (1986). The SAS model distinguished

between two types of control of action. For example, the routine activation of well-

learned skills or schemata that govern everyday activities such as driving to a familiar

location, or getting dressed in the morning, and a higher level of action that requires

conscious control such as the activation of new behaviours in an unexpected situation

(Gathercole, 1994; Baddeley, 2001). Attentional slips of action occur when one

absentmindedly drives to the office instead of the shops, or arrives at work in slippers

instead of work shoes, and such lapses are thought to be failure of the SAS to

override the behavioural schemata or habit underlying the action (Baddeley, 2001).

The impetus for emphasising the importance of an attentional role in coordinating

human behaviour was highlighted in several studies that found that patients with

frontal lobe deficits showed disturbances in the conscious control of behaviour such

as marked distractibility and perseveration (Shallice, 1982; 1988). This link with the

role of the central executive as an attentional mechanism has been extended further

by Baddeley, Logie, Bressi, Della Sala, and Spinnler (1986) who found that elderly

persons with Alzheimer's Disease (AD) showed clear limitations in dual task performance compared with another two groups consisting of normally ageing and younger persons. When conducting their study, Baddeley et al., (1986), assuming that the central executive has the ability to coordinate information from both slave systems, titrated the level of difficulty of a selection of tasks that reflected the roles of each system and required their subjects to combine performance on two of these. Results showed that although articulatory suppression did not significantly decrease performance on a visuospatial tracking task in any of the three groups, subjects with AD showed significantly poorer performance when combining the tracking task with reaction time to a tone, or digit span. A later follow up study (Baddeley, Bressi, Della Sala, Logie & Spinnler, 1991) found that performing tasks concurrently differentiated AD patients from control groups but task difficulty did not, again supporting the view that dividing attention requires central executive input.

Baddeley and colleagues concluded that these findings were consistent with the view that the ability to combine tasks, (an essential central executive and thus attentional function), is particularly affected in individuals with Alzheimer's Disease. Furthermore, Baddeley (1996b) has argued strongly that these results could not be explained by either an overall deficit in general intelligence, or the effects of normal ageing but are a direct consequence of damaged frontal lobe function. However, he also acknowledged that although the central executive is emphasised as an attentional mechanism this may not be an exclusive role, and therefore it would be premature to assume that the central executive resides in an absolute anatomical location in the brain (Baddeley (1996b). This view implies that the central executive is not a unitary system, but potentially consists of various sub-processes within the attentional sphere.

Robbins et al., (1996) addressed this issue by investigating the central executive's capacity to focus attention by examining the effects of various disruptive tasks on chess performance. They found that articulatory suppression had no effect on performance, thus ruling out a role for the phonological loop, but conversely, both a concurrent visuospatial task and a random generation task did disrupt performance to a significant degree. As chess is a game that presumably would require a great deal of central executive input, it was no surprise that random generation, also assumed to draw on executive resources, would cause significant disruption. However, the observation that a concurrent visuospatial task also caused disruption to chess performance adds weight to the argument that central executive resources and processes within the visuospatial sketchpad are indeed closely linked.

In summary, this least well understood and possibly most complex component of the working memory model is concerned with the attentional control of information and probably consists of many sub-processes that have yet to be identified. It is likely that the central executive is not, as first envisaged, a unitary component of working memory but in fact has strong links to the visuospatial sketchpad, an aspect that will be discussed further in the thesis.

2.7 The Episodic Buffer

This most recent addition to the working memory model (Figure 3) was proposed to address research data that could not be explained by the original three-part model Baddeley (2000). This included problems explaining the lack of effect of articulatory suppression on visual presentation of numbers (Baddeley, Lewis & Vallar 1984), and the finding that individuals with impaired short-term phonological memory showed better recall for visually presented digits than digits presented verbally (Shallice & Warrington, 1970). Evidence from a study by Logie, Della Sala, Wynn and Baddeley

(2000) which investigated the effect of visual similarity on verbal serial recall, found that recall performance of visually similar and dissimilar words and letters was sensitive to the effect of visual similarity despite the presence or absence of articulatory suppression. The above data suggested that individuals utilise a visual code as well as a verbal code when recalling serial information, thus implying that the phonological and visual systems interact in a manner not satisfactorily explained by the earlier version of the working memory model (Baddeley, 2000).

In addition, the 'chunking effect,' whereby recall is increased when words are related as in a piece of prose, (Baddeley et. al 1987) was not adequately explained by the model, nor was binding; the coherent combining of the features of an object in one's mind in order to make sense of the associations. This occurs for example, when an object is perceived, and features such as colour, shape, smell or movement are channelled through the senses and combined with the pre-existing knowledge of the object as familiar or unfamiliar (Baddeley, 2000).

In order to address the difficulties outlined above, Baddeley (2000) proposed a "limited-capacity temporary storage system" (p. 421) or 'episodic buffer' to provide the necessary interface between the slave systems and long term memory. The buffer is assumed to be controlled by the central executive through conscious awareness by utilising a multidimensional code that enables it to temporarily and episodically store information from a variety of sources, while also retrieving information from and channelling information into long-term memory. However, research into this new theoretical component is still under-developed and it remains to be seen how well it can be integrated, via experimental and neuroimaging research, into the original model.

2.8 Alternative perspectives of working memory: Unitary or multi-resources?

While both Baddeley and Logie consider working memory to consist of multiple components and therefore "inherently non-unitary" (Baddeley & Logie, 1999, p 30), other perspectives differ in interpretation and emphasis. For example, Cowan (1988; 1999) proposes that working memory is primarily (though not exclusively) a unitary construct which is dependent on the activation of attention in order to carry out complex tasks. According to this view, attention is activated to focus on whatever mental aspect of cognition is currently required irrespective of whether the domain-type is verbal or non-verbal. Instead, each component of memory which includes activation of the relevant stimuli, focus of attention on the relevant stimuli and long-term memory are all 'embedded' within each other to allow *on demand* cognitive processing to occur (Cowan, 1999). Although Cowan acknowledges the existence of differential codes in working memory (e.g. phonological or visual) the underlying principle of the embedded processes model is that these are processed in the same way, i.e. by the utilisation of focused attention.

In common with Logie (1995), Cowan's model emphasises the link to long-term memory, but Cowan is more precise in including this component within working memory itself as part of the activation of attention (Cowan, 1999).

Engle and colleagues (Turner & Engle, 1989; Conway & Engle, 1994; Engle, Kane & Tuholski, 1999) who also emphasise the role of domain-free attentional processes in working memory, have put forward a theoretical standpoint closely akin to Cowan's perspective. Central to this conceptualisation of working memory is the notion of 'controlled attention' that is capacity-limited and required for "maintaining temporary goals in the face of distraction and interference" (Engle, Kane & Tuholski, 1999, p.

102). They propose that controlled attention is the underlying construct mediating task performance in working memory and because it is domain-free, any differences in individual capability will show up across a wide range of tasks. In order to demonstrate this claim, Engle and colleagues have employed operation span tasks (OPSAN) that involve both storage and processing demands on memory. Originally designed by Daneman and Carpenter (1980), OPSAN tasks require the participant to either read a series of sentences or solve a mathematical problem while concurrently trying to remember a list of unrelated words. Using extreme span groups (individuals who perform very poorly or very well on OPSAN tasks), Kane & Engle (2003) found that tasks that require attention but not memory are performed better by high span individuals. Moreover, high span groups perform consistently better than low span groups on a wide range of working memory tasks irrespective of domain type (Engle, Kane & Tuholski, 1999). Engle and colleagues interpret these findings as a resource trade-off between what information needs to be retained versus that which is irrelevant. Their interpretation implies to some extent an underlying unitary mechanism in that the deployment of attention needed to carry out such a complex task is essentially, as with Cowan, the central feature of working memory. It is used to activate memory traces from long-term memory, and maintain or inhibit activation. This in turn implies that attentional resources are not finite but shared in order to retain the relevant goals in a conscious state, meaning that either excitatory or inhibitory mechanisms come into play depending on the complexity of processing required. Similarly, Hasher and Zacks (1979, 1984) have proposed that memory processes can be understood as either 'automatic' or 'effortful' depending on the amount of attentional capacity needed. For example, remembering how to sign one's name would be considered automatic and thus require little attentional capacity, while

rehearsing a list of words or patterns in one's mind would require substantially more attention.

However, although the perspectives outlined above differ from the multi-component model in that they tend to regard attentional control as central to working memory processes, they are not dissimilar to Baddeley's conceptualisation of the central executive as an attentional controller as outlined in Section 2.6. The model described by Engle and colleagues closely parallels central executive control, and with regard to Baddeley and Hitch's (1974) and Logie's (1995) tripartite models, controlled attention is equivalent to the capacity of either the phonological loop or the visuospatial sketchpad plus the efficiency of the central executive (Miyake, 2001). More recently Kane and Engle (2002) have suggested that because executive attention and the "constructs of WM capacity" (p. 647) overlap this means that similar or identical brain structures must be involved, a perspective congruent with interpretations of frontal activation from neuroimaging research as described in the next section of the review.

2.9 Neuroanatomical advances: Linking the working memory model with brain function

Neuroimaging studies, which utilise positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) techniques to observe brain activation during the performance of various tasks, have added a new dimension to the study of working memory. The increased use of this technology has allowed for a greater understanding of the links between specific anatomical locations in the brain and neural networks involved in working memory processes. Using PET, Smith, Jonides and Koeppe (1996) identified a dissociation between verbal and spatial working

memory when they found that memory for spatial locations produced activation in the

posterior parietal and dorsolateral pre-frontal cortex of the right hemisphere, while a

verbal identity task produced activation in the left hemisphere. Evidence to support a

subdivision of the visuospatial sketchpad into functionally and anatomically distinct

areas for visual processing of object location (left hemisphere) or spatial information

(right hemisphere) has also been found using PET (Smith, Jonides, Koeppe, Awh,

Schumacher & Minoshima,1995) and fMRI (McCarthy, Puce, Constable, Krystal,

Gore, & Goldman-Rakic, 1996).

A series of PET studies by Awh and colleagues have been fruitful with regard

to separating storage and maintenance functions in working memory. Awh,

Jonides, Smith, Schumacher, Koeppe & Katz (1996) used a verbal memory task

(the 2-back task) whereby participants saw a series of letters on a computer screen

and were required to indicate whether or not the letter presented had occurred two

letters earlier in the sequence. A rehearsal condition was added, in which the

participant was instructed to silently repeat each letter until the next one appeared.

When this condition was subtracted from the 2-back task, it was found that

activation in Broca's area and the left pre-motor cortex ceased, both of which areas

are hypothesised to be involved in phonological rehearsal. Furthermore, activation

in the posterior parietal cortex remained, which implicates this area of the brain in

phonological storage.

Several neuroimaging studies have attempted to identify the anatomical

location of the central executive and some researchers have argued that this is

located in the frontal cortex. Using fMRI to identify brain regions involved in dual

task performance, D'Esposito, Detre, Alsop, Shin, Atlas & Grossman (1995)

showed that dorsolateral areas within the frontal cortex were activated under a dual

task, but not under a single task condition, and concluded that this reflected the role of the central executive in allocating attentional resources. Activation of the anterior cingulate cortex has been observed in PET studies when participants perform the Stroop task, which requires the executive resources of attention and inhibition (see Smith & Jonides, 1999 for a review). However, many other studies suggest that dual-task performance is not necessarily dependent on the pre-frontal cortex, but is likely to involve different brain regions, which activate on a task-specific basis (Andres & Van der Linden, 2002; Collette & Van der Linden, 2002). This last view makes more sense given the likelihood that the central executive consists of more than one component (Miyake et al. 2000) and is also consistent with Baddeley's (2001) view that neither the central executive or the episodic buffer are likely to reside in any specific anatomical locations.

2.10 Individual differences and working memory

Although the concept of 'working memory' is widely accepted in the literature, there is ongoing debate as how best to explain how it actually 'works' with some researchers highlighting the importance of the role of individual differences in the ability to store and process information efficiently (Miyake 2001).

As outlined in Section 2.8, one influential line of research argues that underlying differences in working memory depend on the individual's ability to control attention. Engle and colleagues (Engle, Kane & Tuholski, 1999; Kane, Bleckley, Conway & Engle, 2001) have proposed that performance on working memory span tasks is determined by a combination of memory capacity and controlled attentional ability. The single resource approach to working memory has stimulated an ongoing line of research focussed on individual differences in working memory, in particular the

relationships between cognitive abilities and performance on memory span tasks (e.g.Oberauer, Lange & Engle, 2004; Colom, Rebollo, Abad & Shih, 2006). There is also evidence from correlational data and studies using factor analysis that the ability to control attention, as measured by performance on working memory tasks is closely related to general intelligence or *gf* (Kane & Engle, 2002).

A second and related line of research has emphasised a resource-sharing hypothesis, whereby individuals perform best on a working memory task if they can selectively allocate cognitive resources according to their respective skill levels (Daneman & Carpenter, 1980). According to this model, performance on working memory span tasks will depend on whatever cognitive resources are available after processing requirements are dealt with (Miyake, 2001). According to this approach, working memory abilities are, or can be, separable based on specific components, for example visuospatial from verbal (Shah & Miyake, 1996).

The question of whether individual differences in working memory ability are best described as domain specific (e.g. resource sharing) or domain general (e.g. attentional control) is still unresolved. Intensive scrutiny of this area of working memory research is beyond the scope of this thesis however, the general consensus appears to be that both domain-general and domain-specific components contribute to performance on working memory tasks. For example, as already noted, domain-specific effects have been widely reported in dual task studies where articulatory suppression and planned tapping differentially affect verbal and spatial span memory in line with the multi component models of Baddeley (1986) and Logie (1995).

In a comprehensive review that included comparisons of several differing contemporary theories of working memory, Miyake and Shah (1999) suggest that given the weight of evidence against a purely unitary model of working memory, it

may be more fruitful if researchers attempt to account for evidence to support

domain-specific sub-systems of working memory rather than focus on a unitary

versus non-unitary dichotomy. Logie's (1995; 2003) revision of the role of the

visuospatial sketchpad, and Baddeley's ongoing contribution to clarifying the role of

the central executive are good examples of this line of research, and provide a

framework for studies that aim to investigate the role of working memory in human

cognition.

It has been observed that often in working memory research, insufficient

attention is given to individual differences that arise as a function of characteristics of

the sample population. Miyake (2001) suggests that factors such as varying levels of

motivation or failure to understand task requirements reduces the likelihood of an

individuals' ability to differentiate working memory resources and thus results could

be interpreted as domain-general rather than domain specific.

Conversely, using a restricted range of cognitively advantaged participants such as

university students is more likely to bias the results in the direction of domain

specificity (Miyake, 2001). This observation is relevant to working memory studies

whose focus is not necessarily individual differences per se, but which use restricted

sample populations and neglect to consider this when interpreting the results. There

is an obvious need for more studies to address the issue of subject variability and how

this factor might influence performance on working memory tasks.

In summary, as a practicable theoretical construct to explain human ability to

temporarily store and manipulate information, the tripartite working memory model

has proved to be both robust and useful in explaining a wide range of data from both

developmental and experimental paradigms. The model allows for a more

comprehensive view of cognition than the more traditional short-term memory model,

and a growing body of literature has emerged that supports the fractionation of all three sub-systems.

The next chapter will focus on one of these components, the visuospatial sketchpad, and review research that offers evidence to show that this subsystem can be best understood as a non-unitary component of working memory.

CHAPTER 3

Fractionation in the Visuospatial Sketchpad

Since the initial formulation of the working memory model, research into the visual-spatial sketchpad has lagged behind its verbal counterpart in terms of sophistication and clarity of the system. In contrast to the phonological loop, which attracted lively research interest due to its link with the acquisition of vocabulary and language (Baddeley, Gathercole & Papagno, 1998; Vallar & Papagno, 2002), the sketchpad has proved much more difficult to explore. Indeed, until relatively recently this component of the working memory model was viewed as a unitary construct, however based on growing evidence from cognitive, developmental and neuropsychology, there is now a consensus among researchers that the sketchpad probably consists of at least two separate sub-components (Baddeley, 1996a). However, the exact nature of these is subject to ongoing discussion in the literature with some researchers interpreting the differences as evidence of a visual versus spatial distinction, while others believe that the disparity arises from the type of material presented, the type of tasks used, or varying demands on resources required to carry out the tasks.

The evolution of a visual-spatial distinction in working memory is underpinned by research into both the primate and human visual systems, out of which emerged evidence for two separate neural pathways, *parvocellular* and *magnocellular,* or as often referred to in the literature, the *what* and *where* distinction (Klauer & Zhao, 2004; Luzzatti, Vecchi, Agazzi, Cesa-Bianchi & Vergani, 1998). The parvocellular (what) pathway processes information regarding form and colour,

while the magnocellular (where) pathway is responsible for processing information about spatial characteristics and movement (Breitmeyer, 1992).

From a functional viewpoint, it is therefore likely that the visuospatial sketchpad involves separable sub-systems that deal in turn with spatial information such as the location of items in space, and visual information such as the form and appearance of those items (Logie, 1995; Pickering, Gathercole, Hall and Lloyd, 2001).

The following sections will outline the main streams of research that have emerged to provide evidence to support a visual-spatial segregation in working memory.

3.1 Evidence from cognitive studies

The cognitive approach to investigating fractionation of the visuospatial sketchpad has been to design and utilise experimental tasks that can selectively disrupt either the visual or the spatial component of memory in order to show a separation. The paradigm most commonly used is dual task methodology described in section 2.2, whereby primary memory tasks are combined with secondary interference tasks to demonstrate selective interference on visual or spatial processing.

Logie and Marchetti (1991) used this approach to explore the premise that two separate subsystems are responsible for retention of visual and spatial information. They used two primary memory tasks and showed that retention of visual information (colour hues) was disrupted by viewing irrelevant pictures, while retention of spatial information (spatial sequences) was disrupted by tapping in a predetermined pattern. This effect was selective with neither primary task disrupted by a secondary task of dissimilar type, an effect known as a *double dissociation*. Tresch, Sinnamon and Seamon (1993) repeated this finding; however, they used a very different selection of tasks to demonstrate the dissociation. For the primary spatial task, subjects were instructed to remember the location of a single dot and for the primary visual task, the

form of a simple geometric shape. Due to the simplicity of these tasks, stimulus

duration was adjusted so as to achieve 80-90% accuracy. It was found that a

secondary movement detection task selectively disrupted memory for dot location,

while a colour discrimination task interfered with recall of the geometric shape

(Tresch, Sinnamon & Seamon, 1993).

In a series of experiments that included a partial replication and extension of the study

by Tresch and colleagues, Klauer and Zhao (2004) used an interference paradigm

with a variety of primary and secondary tasks and found robust evidence to support

the segregation of visual and spatial processes. They were careful to rule out

alternative explanations for the dissociations, for example they used Chinese

characters as a visual memory task to guard against long-term memory involvement,

and with their 4th experiment showed that neither maintenance of spatial information

(dot location) or maintenance of visual material (Chinese characters) were influenced

by eye movements.

Further experimental evidence for a dissociation between visual and spatial

memory was reported by Hecker and Mapperson (1997) who utilised visual and

spatial memory tasks presented under three conditions; no interference, colour flicker

or achromatic flicker. The predicted double dissociation that colour flicker would

interfere with the visual but not the spatial memory task, and achromatic flicker

interfere with the spatial but not the visual task was observed in two experiments.

Hecker and Mapperson explained their findings in terms of the parvocellular and

magnocellular pathways, or *what* and *where* systems, whereby the visual perceptual

system responds differently according to exposure to either colour or achromatic

flicker. However, although this study provided convincing evidence for a visual-

spatial dissociation, Klauer and Zhao (2004) have pointed out that it is not possible to

draw conclusions about the actual locus of the interference because flicker conditions were present throughout the encoding, maintenance, and recall stages of presentation. Other studies have employed an interference paradigm using two types of tasks believed to selectively tap into either spatial or visual memory processes. The Corsi blocks task (Milner, 1971) which involves memory for locations, and the Visual Patterns Test (Della Sala, Gray, Baddeley, Allamano & Wilson, 1999) which requires memory for abstract patterns have both been used extensively in visuospatial memory research. Della Sala and colleagues used an interference paradigm to show that performance on the Corsi and visual pattern tasks was selectively disrupted by combining each primary task with a secondary task that involved similar processes. They found that while performance on the Corsi task was disrupted by tapping, and the visual patterns task was disrupted by presentation of abstract pictures, no such disruption occurred for the opposite combination, thus confirming a double dissociation.

Additional evidence to support the separation of visual and spatial abilities in working memory has been provided by correlational data. As part of their study described above, and using both brain impaired and healthy subjects, Della Sala et.al (1999) found low correlations between the Corsi task and visual patterns test which supports the view that each test is indeed measuring a different function. Furthermore, they found that parallel versions of the visual patterns test correlated highly with each other, but not with the Corsi task and concluded that these findings, along with the evidence from the interference experiment, provided sound support for distinct visual and spatial components in working memory.

Additional correlational studies using both the Corsi and patterns tasks have shown similar results (Smyth and Scholey 1996; Logie & Pearson, 1997).

In summary, the accumulated evidence from both correlational and experimental data supports the contention that the visual spatial sketchpad is not a unitary component, but most likely involves two clearly separable processes; one responsible for visual, and one for spatial processing in working memory.

3.2 Evidence from neuropsychology

An important, and in some way the most compelling source of evidence to support the distinction of spatial and visual processes in working memory has been derived from studies of brain function. Neuropsychological double dissociations have been observed in numerous case studies where individuals have displayed specific visual or spatial deficits. For example, Farah, Hammond, Levine and Calvanio (1998) described a patient (L.H.) with head injuries following a car accident who performed poorly on visual imagery but not spatial imagery tasks (see Pickering, 2001). In contrast, Luzzati et al. (1998) reported preserved visual but impaired spatial imagery processing in an elderly woman (E.P.) who was subsequently diagnosed with dementia of the Alzheimer's type. The authors concluded that this pattern reflected separate cortical pathways for visual and spatial processing in working memory.

Carlesimo, Perri, Turriziani, Tomaiuolo & Caltagirone, (2001) described specific working memory deficits in the patient M.V. who performed normally on verbal and visual memory tasks but showed impaired ability to recall spatial locations.

In a recent study of 17 brain-injured patients, Darling, Della Sala, Logie and Cantagallo (2006) reported data from two individuals that supported a distinction between memory for appearance versus memory for spatial location. The authors were careful to minimise the effect of mode of presentation by presenting only a single to-be-remembered item at one time. They found that one patient (A) demonstrated a specific memory deficit for spatial location, while another patient (B)

demonstrated a specific deficit for the visual appearance of the presented item, and concluded that segregation of the visuospatial system can be upheld on the basis of this visual versus spatial demarcation (Darling et al. 2006). This finding is consistent with Logie's functional conceptualisation of a visual cache and inner scribe (Logie & Marchetti, 1991; Logie, 1995), and also fits with the 'what' and 'where' distinction as outlined previously.

3.3 Evidence from developmental psychology

Additional functional evidence to support the fractionation of the visuospatial sketchpad has been derived from the observation of different rates of working memory development in children, although interpretation of the evidence differs somewhat between researchers. Logie and Pearson (1997) used the developmental fractionation approach described by Hitch (1990) to examine different developmental trajectories in children aged between five and 11 years of age. They found that performance on the Corsi blocks and pattern span tasks differed according to the ages of the children, with memory for pattern span developing at a faster rate than memory for spatial sequences, and with the difference particularly notable in the older age group. Logie and Pearson (1997) concluded that this difference in maturation rate implied the operation of two distinct cognitive systems, one for retention of a static pattern and one for retention of sequential information. They interpreted this segregation in relation to the model of visuospatial memory proposed by Logie (1995), namely a 'visual cache' for storing visual form and 'inner scribe' for storing spatial information.

Hamilton, Coates and Heffernan (2003) also employed a developmental approach to investigate rates of visual and spatial span development in adults and children. Their first experiment confirmed a pattern similar to Logie and Pearson (1997) in that

spatial span was slower to develop than visual span. However, the second

experiment, which utilised a number of interference measures to tap into visual and

spatial processes, found that both verbal and executive processes were also implicated

in span memory thus ruling out a purely visual or purely spatial system.

Pickering, Gathercole, Hall and Lloyd (2001) reported similar results using the

developmental fractionation approach described above. However, they interpreted

their findings not as evidence of a visual or spatial dichotomy, but as a demonstration

of how the underlying static and dynamic nature of a task causes activation of

different subsystems in working memory and thus draw on different cognitive

resources (Pickering, et al., 2001).

3.4 Alternative explanations for dissociations in visuospatial memory

Although Logie's model has been widely accepted as a useful account of visual-

spatial dissociations in working memory, alternative perspectives have been put

forward. As already noted, Pickering et al. (2001) have suggested that the visual-

spatial distinction are interpreted as static or dynamic. This perspective hinges on the

observation that both the tasks commonly used to differentiate visual from spatial

working memory processes differ in the way information is presented. That is, the

Corsi task is presented in a dynamic format as sequences, while the visual patterns

test is presented in a static form as fixed patterns (Pickering 2001). The authors

suggest that performance on these two tasks differ because of the nature of the format

rather than the visual or spatial aspect of the tasks. However, Klauer and Zhao (2004)

take issue with this proposal and point out that in their series of experiments, both

static and dynamic displays were utilised, with the visual-spatial double dissociation

still observed.

Vecchi and colleagues, (Vecchi, 1998; Vecchi & Cornoldi, 1999) present an alternative view in which distinctions occur based on the type of information presented rather than the visual or spatial nature of the information. With regard to the Corsi and pattern span tasks, they propose that as the information presented is in the same format at encoding and recall these tasks should be interpreted as passive. Conversely, an active task is one in which mental transformations take place as with for example, a mental rotation task. However, this interpretation does not account for visual spatial double dissociations as already established on the Corsi and pattern span tasks, and could instead be explained by central executive input as proposed by both Baddeley and Logie's models of working memory.

In general, although opinions differ as to the interpretation of the evidence from fractionation studies reviewed thus far, most researchers agree that there are at least two separable components in the sketchpad. Although debate about task characteristics and differing cognitive processes are ongoing, the majority of research indicates that a visual-spatial dichotomy is the most plausible explanation for dissociations found in visuospatial working memory.

However, although an extensive body of literature has emerged to support a distinction between visual and spatial processes in working memory, unresolved issues remain that highlight the difficulty associated with understanding and investigating these. For example, it has been acknowledged that there is not yet a clear understanding of rehearsal processes within the sketchpad (Baddeley & Hitch, 1994; Baddeley, 2001) nor is there agreement regarding the reliability or consistency of many of the experimental tasks used to explore these processes. Indeed one such criticism of the approach taken to investigate the sketchpad is that unlike research into the phonological loop that was largely conducted to explain experimental data

(Pearson, 2001), sketch pad research has been motivated by attempts to show symmetry with the loop. Consequently, there is a danger that researchers look for evidence to support the theory rather than approaching the visuospatial sketchpad as a special case with complexities that do not necessarily fit with a symmetrical model. Moreover, although much of the research acknowledges a close link between visuospatial processes and the function of the central executive, the degree of this relationship is far from clear. This final section of the literature under review will attempt to address these areas of concern.

3.5 The role of movement in visuospatial rehearsal

As already noted in section 2.5.2, Baddeley (1986) suggested that some form of movement-based mechanism could be involved in visuospatial rehearsal, and postulated that a process analogous to sub-vocal articulation, but perhaps involving oculomotor control is involved in maintenance of non-verbal information in working memory. This view arose from an early series of unpublished studies by Idzikowski, Baddeley, Dimbleby and Park reported in Baddeley, (1986) and which found that concurrent eye movements to visual targets disrupted spatial working memory on the Brooks task. However, subsequent research has been equivocal with regard to the effect of eye movements on visuospatial rehearsal. Some researchers have found evidence for disruption of spatial span memory (Lawrence, Myerson, Oonk, & Abrams, 2001; Pearson & Sahraie, 2003), and serial recall of dot-location (Tremblay, Saint-Aubin & Jalbert, 2006) while others have found no specific effect of eye movement on spatial span (e.g. Smyth, 1996) or memory for dot location (Klauer & Zhao, 2004).

Other studies have demonstrated that alternative forms of body movement also interfere with activity in the visuospatial sketchpad. This connection has been

investigated in numerous experiments that require participants to make deliberate

movements to spatial locations with their hands or upper limbs while concurrently

performing a memory task. For instance, Baddeley and Lieberman (1980) found that

pointing towards a sound disrupted performance on the Brooks task, while Farmer,

Berman and Fletcher (1986) established that tapping could interfere with performance

on a spatial reasoning task during encoding of the to-be-remembered items.

And curiously, in a study that investigated the effects of a visual interference task on

memory for movements, Johnson (1982) found that memory for locations was

disrupted by asking participants to merely imagine moving a limb, which suggests

that even thinking about planning a movement is enough to cause interference in

spatial working memory.

Quinn & Ralston (1986) addressed the specific question of arm movement by

employing a variation of the Brooks task whereupon participants heard a series of

spoken sentences containing digits that they had to keep in mind by placing on an

imagined matrix prior to recalling them in written format. The sentences were

presented under four different conditions: tapping on the table with one hand,

compatible movement (tracing the pattern on a visible matrix in line with the sentence

instructions) incompatible movement (tapping in a pre-ordained pattern around a

covered square matrix), and no movement (sitting with hands quite still). Results

showed that while compatible movement sequences did not disturb performance,

incompatible movements and even passive movements of a participants' arm by the

experimenter were enough to cause disruption to spatial memory (Quinn and Ralston,

1986). In a follow up study Quinn, (1994) showed that disruption to spatial memory

is dependant on a combination of two factors, firstly, movement must be to a

sequence of specified targets, and secondly, the target sequence must be already

known to the participant in advance. Taken altogether, these findings suggest that both real and imagined movements to pre-ordained locations disrupt spatial working memory. This evidence is consistent with Logie's conceptualisation of the inner scribe as a spatially based rehearsal mechanism disrupted by both production of movement and movement planning, and which disturbs the maintenance of a series of sequences or locations in working memory (Logie, 1995).

3.6 Links with attention and rehearsal in the visuospatial sketchpad

However, some researchers have argued that it is attention to movement rather than movement per se that is responsible for interference effects in spatial working memory, and this argument has gained momentum over the past decade. Smyth and Scholey (1994) demonstrated that memory for spatial span, as measured by the Corsi blocks task, was significantly impaired when shifts of attention to visual and auditory stimuli was required, and that performance was further diminished by the requirement to make motor responses. In a follow up study that controlled for the effect of eye movements, Smyth (1996) found that neither restricting the participant's ability to make eye movements nor allowing them freedom to do so disrupted recall on the Corsi task, but auditory spatial stimuli requiring a response to left-right tones did cause interference. Smyth and colleagues concluded that disruption to spatial memory occurs because of shifting spatial attention to any designated point in space as part of a strategic response, rather than by motor responses of eye or limb movements alone. Therefore, the implication is that the system involved in the maintenance and recall of movement sequences involves the allocation of spatial attention over and above the effect of movement only.

In line with this approach, Awh and colleagues have proposed that rehearsal in the visual-spatial sketchpad is mediated by covert shifts of spatial selective

attention. Using an interference paradigm Awh, Jonides and Reuter-Lorenz (1998) demonstrated that spatial memory accuracy was impaired by a secondary task requiring attentional shifts, but not to the same extent if shifts of attention were absent, a finding consistent with Smyth and Scholey (1994). A series of neuroimaging studies that showed cortical overlap between areas of spatial attention and spatial working memory (Awh & Jonides, 1998; Smith & Jonides, 1999), indicate that these two mechanisms are closely related. Subsequently it has been proposed that spatial information is stored in the right parietal region of the brain, and is maintained through activation in the pre-frontal region in a process akin to controlled attention (Smith & Jonides, 1999; Hartley & Speer, 2000).

3.7 Rehearsal and central executive involvement

Others have suggested that central executive resources in addition to or in concert with spatial attention play an important role in visuospatial rehearsal. Baddeley (1996a) explained that due to the less practised nature of the use of visual imagery compared with phonological coding in working memory, tasks utilising the sketchpad, such as the Brooks task, were inclined to demand more input from the central executive. Early research using variations of the Brooks (1967) task indicated that central executive processes were indeed implicated, but only during the encoding phase of the task (e.g. Morris, 1987; Quinn, 1991) and not during rehearsal. Notably however, the Brooks task does not require the maintenance of order information which, it has been suggested, is necessary to provide an interference effect during retention in spatial memory (Toms, Morris & Foley, 1994).

Subsequently, and using alternative tasks, it has been established that executive involvement can influence spatial recall during the rehearsal phase in working memory (Smyth & Pelky, 1992; Klauer & Stegmaier, 1997; Fisk & Sharp, 2003).

For example, Klauer and Stegmaier (1997), presented evidence for central executive involvement in spatial working memory by demonstrating that spatial span memory was selectively disrupted by attention to left-right tones as well as by an added requirement to make decisions about pitch discrimination. A requirement to repeat heard words did not impair memory, thus ruling out a generalised interference effect and suggesting that spatial memory is vulnerable not only to shifts in spatial attention (as established by Smyth & Scholey, 1994) but is also affected when extra demands are placed on the executive in the form of decision-making (Klauer & Stegmaier, 1997).

Klauer and Zhao, (2004) used an interference paradigm in a series of studies that investigated the strength of visual spatial double dissociations, and in their sixth experiment focussed specifically on executive involvement in visuospatial memory. They employed two tasks, mental arithmetic and random interval repetition (RIR) both of which require executive input, and crossed them with a selection of visual and spatial memory tasks. For the visual condition, the results showed that memory for Chinese characters was disrupted by a colour discrimination task but not significantly impaired by arithmetic or RIR, while mental arithmetic was disrupted by RIR more than colour discrimination. Similarly, in the spatial condition, memory for dot locations was more disrupted by spatial tapping than by either RIR or mental arithmetic, which in turn was more impaired by RIR than by tapping (Klauer & Zhao, 2004). In addition to confirming a visual-spatial dissociation, these results also suggest that dissociations in visuospatial working memory may not be due to central executive involvement but can be supported by specific same system resources, in line with the model proposed by Logie (1995).

A further study that investigated the role of executive processes in visuospatial working memory used a computerised running memory task to demonstrate interference for spatial sequences (Fisk & Sharp, 2003). Participants were presented with a series of squares of between 4 and 10 cells that were highlighted in different spatial locations on a matrix. The list length was unknown to the participant who was required to recall, in order, the last 4 cells highlighted. Secondary interference tasks included simple tapping, planned tapping and random letter generation, a task known to load onto the central executive. The results showed that random generation disrupted spatial memory to a greater degree than either of the secondary spatial tasks. In order to rule out a possible effect of phonological rather than executive interference by the random generation task they carried out a second study using alphabetic generation as an additional primary task. The results again showed greater disruption of recall of spatial sequences by the random generation task, again indicating that central executive input is required when processing order information in visuospatial working memory (Fisk & Sharp, 2003).

More recently, Kondo and Osaka (2004) investigated the degree to which spatial and verbal working memory are reliant on executive resources. Within a dual task paradigm, participants were required to retain either verbal or spatial information while performing a secondary concurrent arithmetical task designed to load selectively onto the central executive (single addition and carry-addition) or the phonological loop (digit reading). Results of the study showed that while the ability to store verbal information was impaired by digit-reading, spatial storage remained unaffected, and conversely, performance on the spatial storage task was disrupted by the single-addition task while verbal storage was not affected. Furthermore, both verbal and spatial memory performance was reduced by the more difficult carry-

addition task. Kondo and Osaka (2004) interpreted these results as supporting an asymmetry between verbal and spatial storage processes in working memory, and suggested that as the central executive is most likely involved in maintenance of spatial material, any extra load on resources will cause failure of the system. In contrast, failure does not occur for verbal material because the rehearsal mechanism of the phonological loop is much less reliant on the central executive, and will only succumb if the load becomes excessive (Kondo and Osaka, 2004). However, as with Fisk and Sharp's study, they were unable to provide direct evidence for this viewpoint as their experiments were designed with primary and secondary tasks performed concurrently so as to rule out any observation on performance exclusively during rehearsal.

A comprehensive study using structural equation modelling and factor analysis (Miyake, Friedman, Rettinger, Shah & Hegarty, 2001) investigated the relationship between spatial abilities, visuospatial memory tasks and executive functioning. The researchers found that all measures of visuospatial memory used in their study, whether simple or complex, related to central executive function to some degree. These results contrast with those from a study from the verbal domain that showed a clear separation between simple storage and more complex processing tasks where the latter required additional executive input in the form of controlled attention (Engle, Tuholski, Laughlin & Conway, 1999). The implication that performance on even basic spatial tasks requires executive involvement gives rise to difficulties when making assumptions about the mechanisms underlying rehearsal in the sketchpad. It is difficult to reconcile these findings with a view of the sketchpad as symmetrical with the phonological loop, which does not appear to require the same level of executive dependency. Moreover, there is still a lack of consensus in the literature as

disrupted by movement, which is thought to be involved in the mechanism of rehearsal (Baddeley, 1986).

In order to demonstrate selective interference experimentally, it is necessary to show that disruption occurs when the to-be-remembered information is being rehearsed, and this can be directly tested by presenting a secondary task during the retention phase of memory.

The starting point for the experiments presented in this thesis is Logie and Marchetti's (1991) well known study, the results from which have been used as evidence to support the revised model of visuospatial working memory as outlined above. Logie and Marchetti (1991) used an interference paradigm to show that performing a series of unseen arm movements during a retention interval disrupted memory for spatial sequences but not for colour hues, while conversely, colour memory was impaired by viewing irrelevant pictures. They interpreted these results firstly, as evidence of a visual-spatial dissociation in the visuospatial sketchpad, and secondly speculated that a spatial rehearsal mechanism able to hold spatial representations and refresh material from the visual store, but also able to plan movement processes was responsible for rehearsal in the sketchpad. Furthermore, they suggested that this mechanism, along with the visual cache, operated more or less independently from the central executive (Logie and Marchetti, 1991). However, although a few studies have reported similar findings none has precisely replicated the procedure of the original study. Although both Tresch, Sinnamon and Seamon (1993) and Klauer and Zhao (2004) used similar methodology, they employed a different selection of tasks to show that memory for dot location was disrupted by movement discrimination (identifying a stationary object within a moving field),

while memory for geometric shapes was impaired by a secondary colour

discrimination task (deciding whether a colour hue was more red than blue).

With regard to the role of movement, several studies have supported the finding

that gestures such as tapping or pointing disrupts spatial memory during a retention

interval (e.g. Smyth & Pelky, 1992; Smyth & Scholey, 1994; Della Sala et al., 1999)

but there is considerable debate about how the findings should be interpreted. An

influential line of research has emerged that argues that movement per se is not the

cause of disruption in spatial memory, but rather the need to allocate attentional

resources causes interference. Smyth and Scholey (1994) showed that memory for

spatial span was selectively impaired by a variety of secondary tasks that made

demands on spatial attention but did not necessarily require movement. They found

that when participants had to read words, or listen to and respond to tones spatial

memory span was impaired but the requirement to repeat heard words had no such

effect. Smyth and Scholey (1994) suggested that any spatially directed action

interferes with spatial working memory because of the need to draw on additional

cognitive resources to assist with planning the required action. A more recent study

by Lawrence et al. (2001) which investigated the role of eye and limb movements in

spatial working memory endorsed this view. They found that both eye and limb

movements disrupted spatial memory to the same degree and suggested that rather

than an underlying motor-related process, a common mechanism associated with

either movement planning or shifts in spatial attention might be responsible for

interference in rehearsal.

An alternative but related interpretation of the role of movement is that

rehearsal of spatial information in the sketchpad is not part of a specialised system but

draws on resources of the central executive. As presented in Section 3.7, several

studies have presented evidence to show that central executive processes are more closely aligned with functions of the visuospatial sketchpad than with its counterpart, the phonological loop (Fisk & Sharp, 2003; Kondo & Osaka, 2004) but few have specifically addressed the role of the executive during rehearsal only. One exception is an earlier study by Smyth and Pelky (1992) who used an interference paradigm to investigate memory for spatial span, and found that maintenance of a short series of spatial items was impaired both by spatial interference in the form of a tapping task, and counting backwards in threes, a task requiring additional cognitive resources. These results led them to speculate that this effect is unlikely to be purely spatial, and that central executive processes must be involved in tasks that require the maintenance of order information in visuospatial working memory.

Because of reservations about compromising the parsimony of the tripartite model, it can be argued that working memory researchers are reluctant to challenge the view that promotes the functions of the sketchpad as analogous with those of the phonological loop. While this idea has somewhat seductive qualities, there is danger that, as previously noted in Chapter 3, research in this area will be slow to move beyond it and become entrenched in trying to find evidence for similarities rather than explanations for differences. In addition, it has been suggested that an acknowledgement of individual differences in performance of working memory tasks would be useful when interpreting results from working memory research (Miyake, 2001).

The current study

In order to address these issues, the first experiment in the current research was designed to closely replicate Logie and Marchetti (1991) to see whether their results, particularly the disruption of spatial memory by planned movement, were stable.

Therefore, it was hypothesised that, if there are two separate systems involved in the retention of visual and spatial material in working memory, each system should be disrupted by same system but not separate system interference when a secondary task is presented during the rehearsal period. Specifically, a movement task in this case planned tapping around an array, should disrupt memory for spatial but not visual material. Conversely, looking at a series of irrelevant pictures should disrupt memory for colour hues.

Method

Participants

Participants were 30 undergraduate psychology students (10 males and 20 females) with an age range of 18 to 35 years ($M = 21$ years, $SD = 4.60$ years). Participation in the study was voluntary with students receiving two hours of course credit for their time. All participants were right-handed and had normal or corrected to normal vision. All were familiar with a computer keyboard, and none reported any history of neurological impairment or colour-blindness.

All three studies were approved by the Southern Tasmanian Social Sciences Human Research Ethics Committee and written consent obtained from all participants

(Appendix A). Thirty participants were recruited for Experiment 1, and an additional thirty students participated in Experiments 2 and 3.

Apparatus & Materials

Two primary tasks were utilised and these were designed to be as closely similar to Logie and Marchetti (1991) as could be judged from their published research paper.

1. Colour shade task.

2. Spatial sequence task

3. Interference tasks (three conditions).

Procedure

All participants were tested individually, and on arrival at the Neuropsychology Laboratory at the University of Tasmania, read the information sheet and signed the consent form (Appendix A). They were then seated in front of a computer monitor and told that they were to perform a computerised task, which involved remembering either a colour shade or a sequence of squares. Instructions for the relevant task were given by the experimenter and visual prompts for 'recall now' were displayed at the bottom of the computer screen following the retention interval. After a short series of practise trials (three for each condition), 40 experimental trials were presented for each condition (120 trials in total). Participants were advised that they could take a short break at the end of each condition-set to prevent fatigue.

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An alternative but related interpretation of the role of movement is that rehearsal of spatial information in the sketchpad is not part of a specialised system but draws on resources of the central executive. As presented in Section 3.7, several studies have presented evidence to show that central executive processes are more closely aligned with functions of the visuospatial sketchpad than with its counterpart, the phonological loop (Fisk & Sharp, 2003; Kondo & Osaka, 2004) but few have specifically addressed the role of the executive during rehearsal only. One exception is an earlier study by Smyth and Pelky (1992) who used an interference paradigm to investigate memory for spatial span, and found that maintenance of a short series of spatial items was impaired both by spatial interference in the form of a tapping task, and counting backwards in threes, a task requiring additional cognitive resources. These results led them to speculate that this effect is unlikely to be purely spatial, and that central executive processes must be involved in tasks that require the maintenance of order information in visuospatial working memory.

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Colour shade task

When performing the colour shade task, participants were shown four coloured squares on the screen. On any one trial, each square which measured 21mm x 21mm appeared in a different shade of the same basic colour. Four basic colours were used; yellow, blue, red or green. The squares appeared consecutively at the rate of one square per second until all four were present on the screen. One second after the final square appeared a low warning tone was heard and the squares vanished from the screen. After the ten second interval, during which the participant performed the relevant interference task, another warning tone was heard and the squares reappeared all at the same time. On half the trials one of the squares had changed to a different shade of the same basic colour. The participant then responded by striking the relevant key ('z' for changed colour or '/' for same colour).

<u>Spatial Sequence task</u>

This task is similar to the Corsi task in that participants are required to remember both the location and order of a sequence of items, in this case blue squares. However, unlike the Corsi task, in this experiment there was no requirement to indicate the correct order by pointing. Instead a 'yes' or 'no' decision was required. When performing the spatial sequence task participants were shown six blue squares (21mm x 21mm) which appeared one after the other on the screen, and were instructed to remember the sequence in which they appeared. After a low warning tone the squares then disappeared from the screen and the participant performed the relevant interference task during the interval. As with the colour patch task, a warning tone was heard after ten seconds, following which the squares reappeared and the participant responded by striking the key ('z' for changed sequence '/' for same sequence).

Each participant was exposed to three conditions of 40 trials each (120 trials in total).

Control Condition: During the retention interval the participant was instructed to look straight ahead at the blank computer screen and do nothing but memorise the shades of the squares or remember the order of the squares presented in the spatial task.

Movement Condition: The participant placed his or her right hand on the second square of a matrix located to their right side and enclosed by a wooden barrier. The barrier was designed so that the instructor could watch the participant move their hand along the rows, but the participant was prevented from watching their own hand. When the warning tone signalling the beginning of the retention interval was heard, the participant was required to move their hand in a tapping motion along the row of

counters to the right until they reached the end, and then to move to the row below and move to the left, thus continuing along and down each row at about one tap per second until the warning tone indicated the end of the retention interval. While moving their hand the participant was instructed to look straight ahead at the blank computer screen. Prior to the start of the experimental phase participants were given the opportunity to familiarise themselves with the task so as to be able to make an error free sequence of unseen movements. At the end of the retention interval the participants were instructed to stop tapping and recall either the colour shade or the sequence of squares.

Irrelevant Pictures Condition:

As soon as the retention interval began, the participant was presented with a series of five pictures which were presented on the screen at a rate of one image every two seconds. The participant was required to look at these but instructed to ignore them and try to remember either the colour shades or the spatial sequence. The pictures used were a series of black and white silhouettes of easily recognized objects taken from a website specialising in clipart (http://www.arthursclipart.com/). The pictures were selected from a total of 25 images and randomly presented at a rate of one every two seconds.

Design and Data Analysis

Unlike Logie and Marchetti (1991) who used a two-group design in their study, the present experiment utilised a repeated measures design where the independent variables were type of interference (none, tapping, pictures) and the dependent variables were the number of recognition errors of spatial sequences and colour

patches. A repeated measures design was chosen in order to minimise intra-subject variations and thus reduce error variance (Graziano & Raulin, 2000).

Means were calculated and analysed using repeated measures ANOVA with an alpha significance level of .05.

All participants completed both experimental tasks, with half the group of students completing the colour task first, while half completed the spatial task first. The three interference conditions were counterbalanced accordingly.

Results

The data were analysed by calculating the means and standard deviations for the number of recognition errors for each memory task and submitting these to a 2 (primary task: visual/spatial) x 3 (interference task: none, irrelevant pictures, planned movement) analysis of variance with repeated measures on all variables. The mean number of errors for both primary memory tasks are shown in Table 4.1. For comparison, results from the Logie and Marchetti (1991) experiment (standard deviations not reported) are displayed in Table 4.2.

Table 4.1.

Mean number of errors (maximum 40) for each primary memory task and each interference task for all 30 participants (SD's in parentheses).

	Control	Pictures	Movement
Spatial Sequences Task	8.87 (3.69)	10.57 (4.51)	11.27 (3.32)
Colour Patches Task	9.40 (3.31)	10.87 (4.43)	11.20 (4.79)

Table 4.2.

Results from Logie and Marchetti (1991) showing mean number of recognition errors (maximum 40) for each primary memory task and each interference task. Standard deviations not reported.

	Control	Pictures	Movement
Spatial Task (n =12)	7.58	7.17	12.33
Visual Task (n =12)	8.08	10.08	7.92

Within subjects ANOVA revealed a significant main effect for interference F, (2, 28) = 5.78, p=.007, partial eta squared = .296. However, unlike the results reported by Logie and Marchetti (1991) and contrary to expectation, a double dissociation was not confirmed (F, (2, 28) p=.800. That is, there was no significant interaction between the type of memory task and type of interference task (Figure 4.1).

Figure 4.1. Mean number of recognition errors made by 30 participants on the control (1), irrelevant pictures (2) and movement/tapping (3) conditions for both the visual and spatial primary tasks.

It was observed that a small subset of participants (n = 7) had consistently performed poorly (scored above the mean number of errors) across all conditions. To investigate this anomaly further, the decision was made to exclude from analysis those participants, whose scores when compared with the remaining group (n = 23), were at least one full standard deviation above the mean number of errors than those of the other group on both of the control conditions. These higher error participants had made at least three errors more than the lower error group in both the visual control

condition (M = 14.29, SD = 2.49), and in the spatial control condition (M = 13.43, SD = 2.37).

The data for the remaining 23 participants (16 females and seven males) was then reanalysed and the means and standard deviations for this group are displayed in table 4.3.

Table 4.3.

Mean number of recognition errors (maximum trials 40) made by low error participants (N=23) following exclusion of high error participant subset (n=7).

	Control	Pictures	Movement
Spatial sequences	7.48 (2.79)	9.57 (4.33)	10.83 (3.39)
Colour patches	7.91 (1.70)	9.91 (3.99)	9.57 (3.64)

* *(Standard deviations in parentheses)*

As the results were expected to replicate Logie's findings, a one-tailed hypothesis was employed. Again, there was a significant effect of interference, F (2, 21) = 6.31, p = .003 (one-tailed). Partial eta squared (.375) indicated a moderate effect size. Whilst the expected interaction did not reach significance there was evidence of a trend in the expected direction F (2, 21) p= .09, (one-tailed) as demonstrated in Figure 4.2.
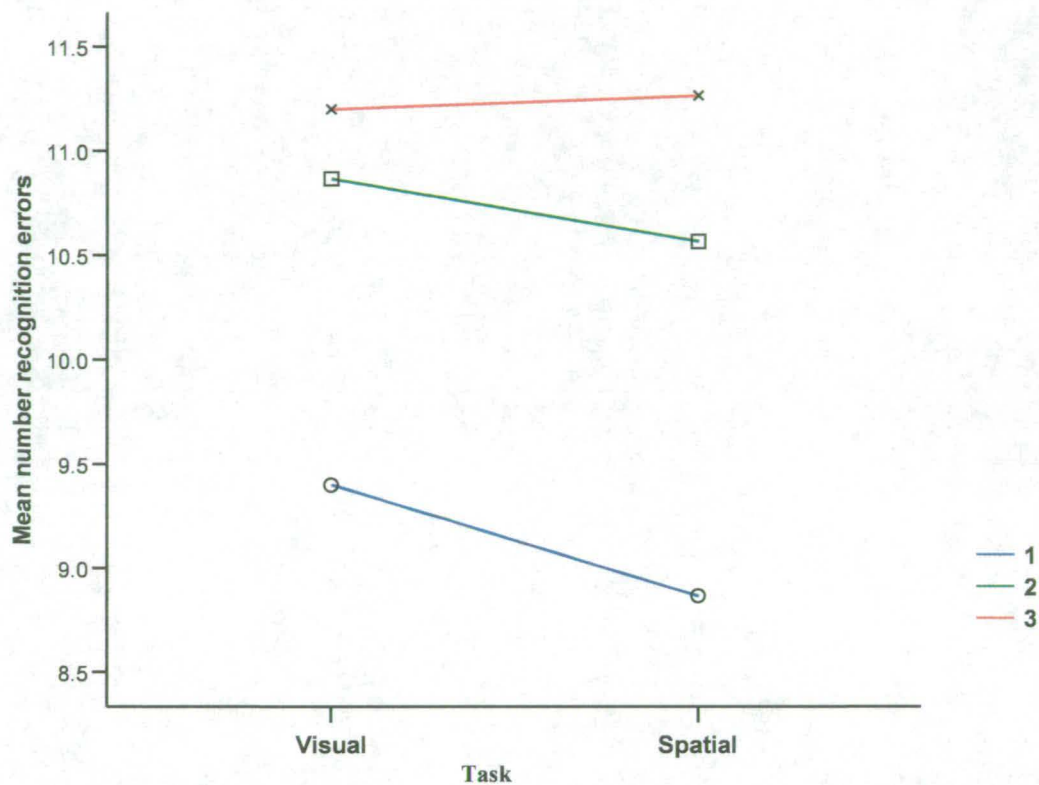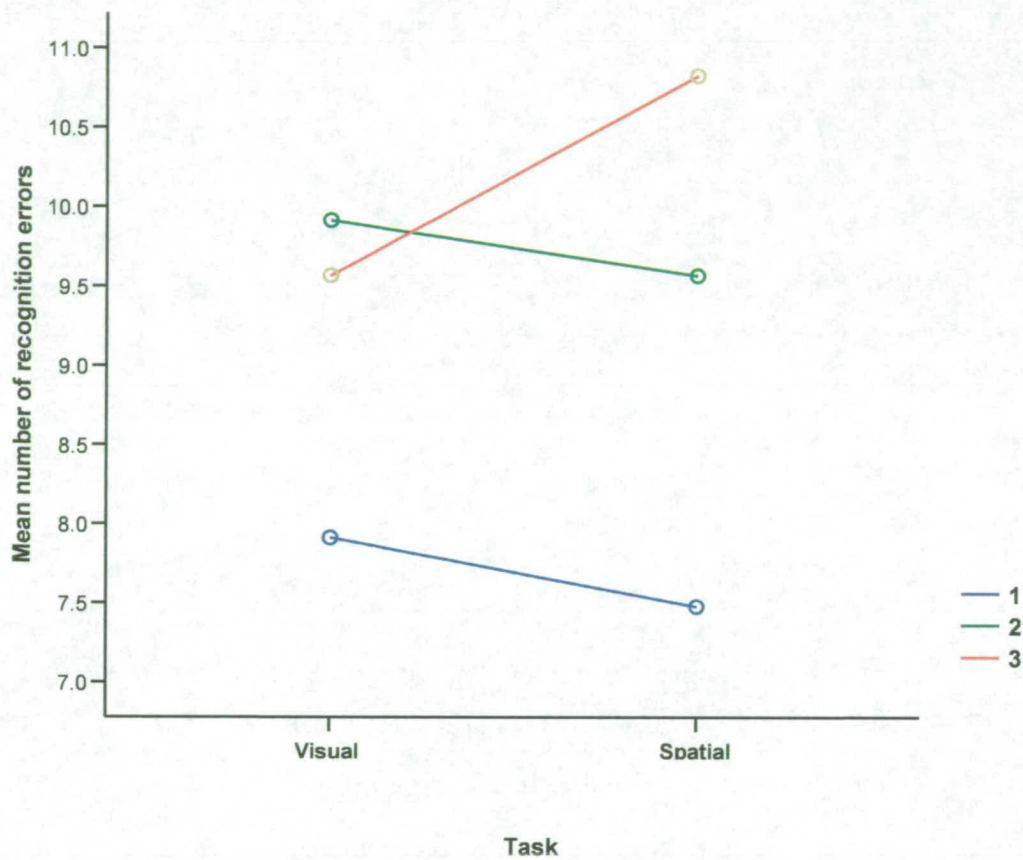
Figure 4.2. Mean number of errors made by 23 participants on the control (1) irrelevant pictures (2) and movement/tapping (3) conditions for both visual and spatial primary tasks.

Post-hoc analyses using paired sample t-tests were conducted in order to evaluate the extent of same and different system interference on both visual and spatial memory. In line with predictions, paired t-tests revealed significant same-system effects with a highly significant effect of movement (planned tapping) on spatial memory [t (-4.089) $p = .0001$] and a significant effect of irrelevant pictures on visual memory [t (-2.261) $p = .034$]. Different system interference effects were also evident with a trend for

movement to disrupt visual memory [t (-1.894) p = .072] and a strong trend towards

disruption of spatial memory by the irrelevant pictures condition [t (-2.051) p = .052].

The spatial simple effect which contrasts performance on the spatial memory task

under spatial interference (tapping) with performance on the visual interference task

(pictures) was not significant [t (-1.537) p = .139], confirming that both types of

interference tasks caused disruption to spatial memory.

Discussion

The overall aim of the first experiment was to confirm previous findings that the

retention of visual and spatial material in the visuospatial sketchpad are vulnerable to

same but not different system interference. It was expected that a secondary visual

task would disrupt visual memory, and a secondary spatial task interfere with spatial

memory, thus demonstrating a double dissociation and providing evidence that the

visuospatial sketchpad is comprised of two separable components. Somewhat

surprisingly, the replication of the experiment by Logie and Marchetti (1991) was not

successful. Contrary to the results obtained in that study, in this experiment, the

expected double dissociation between visual and spatial memory did not occur, but

instead, a general distraction effect of interference was observed. How can this be

accounted for?

The first possibility that needs to be considered is that the current study utilised a

different visual interference task from that employed by Logie and Marchetti (1991),

and perhaps this task did not provide a purely visual interference effect. Logie and

Marchetti (1991) used line drawings as their visual interference task, while in the

current experiment, a series of black and white silhouettes were employed. As the

number of silhouettes displayed were limited in number (25 in total), it is possible

that participants became familiar with them to the extent that they were more easily

able to ignore them during the retention intervals. However, although this task

difference may be a contributory factor in the failure to find a robust visual

interference effect, it does not fully explain the results. It was evident that the

silhouette task used in this experiment did in fact cause disruption to the recall of

visual material. When the data was re-analysed after excluding the high-error sub-set

of participants, although a trend remained for movement to disrupt visual memory

performance, post-hoc analyses showed that viewing irrelevant pictures while

performing the primary visual task did cause a significant drop-off in performance.

It is also entirely possible that the failure to successfully replicate a selective

visual interference effect reflects the inherent unreliability of the irrelevant pictures

task; a problem that has been reported by other researchers. As described in Chapter

2, Quinn and McConnell (1996a) developed an alternative visual noise task to

demonstrate interference in visual memory after they found the line drawing task

difficult to replicate. They suggested that the shifting nature of the line drawings task

could draw on attentional resources and thus tap into the central executive rather than

load exclusively onto visual processes in the sketchpad. This too could have been

the case with the task used in the current study. Although, as noted, the number and

range of pictures were limited, many participants commented that they became

familiar with the characteristics of each or certain items and 'mentally waited' for

said item to appear. This activity could have provided an extra cognitive load,

perhaps enough to draw on resources apart from those required to merely retain visual

information in the passive store and could explain why the generalised effect of

interference occurred.

The prediction that spatial interference in the form of planned movement would significantly disrupt spatial memory was upheld, and therefore consistent with previous findings that show rehearsal of spatial material in the visuospatial sketchpad to be linked with a movement-based process (Baddeley & Lieberman, 1980; Logie and Marchetti, 1991; Smyth & Scholey, 1994). However, because there was also a disruptive effect of pictures on memory for spatial sequences, it is not possible to confirm that two clearly separate mechanisms are responsible for retention of visual or spatial material in the sketchpad. One possible explanation for the lack of a clear dissociation could be that the spatial task used in this study, unlike the Corsi task, does not require a motor response during retrieval and thus performance demands on the inner scribe are reduced (Logie & Pearson, 1997). However, this task even without the motor aspect still involves a mental process involving serial maintenance of a pattern in one's mind, which presumably would place some demand on the inner scribe. Furthermore, this explanation does not explain the pattern of results found by Logie and Marchetti (1991) so it would seem unlikely that a problem with the choice of task alone can account for the findings.

Overall, the results of Study 1 do not convincingly support the existence of a visual store for the retention of visual images along with an inner scribe responsible for the rehearsal of spatial sequences, with both operating independently from the central executive (Logie & Marchetti, 1991). As reviewed previously, there is ample evidence from working memory literature to indicate that visuospatial working memory tasks require more input from executive resources than verbal memory tasks (Smyth & Scholey, 1994; Klauer & Stegmaier, 1997; Fisk & Sharp, 2003; Kondo & Osaka, 2004). Moreover, it has been demonstrated that in the visuospatial domain, both short term span tasks (storage only) and working memory span tasks (storage

and processing) are equally closely related to executive functioning (Miyake,

Friedman, Rettinger, Shah & Hegarty, 2001). Miyake et al. (2001) speculate that an

asymmetry between verbal and visuospatial processing in working memory occurs

because attention is required to manipulate spatial items and may therefore be

important even at a fundamental storage level. This view is consistent with the

argument that the requirement to allocate spatial attention causes interference in

spatial memory (Smyth & Scholey, 1994; Awh, Jonides & Reuter-Lorenz, 1998) and

with regard to the current experiment adds support to the view that visuospatial

rehearsal is more likely to be closely linked to the central executive than controlled by

a separate mechanism.

As reported in the results, the predicted selective effects of visual interference on

visual memory and spatial interference on spatial memory emerged when a small

group of error-prone participants were excluded from the analyses. This exclusion

did to some extent reduce the generalised effect of interference and suggests that for

certain individuals, the ability to discriminate between visual and spatial interference

when manipulating information in the visual-spatial sketchpad is less efficient than in

other individuals. Certainly, the error-prone participants in this experiment were more

vulnerable to the effects of interference than the group who made fewer mistakes.

Overall, this group made more errors that their lower-error counterparts, and were

less able to differentiate between types of interference, being susceptible to all types

despite the level of difficulty. Logie and Marchetti (1991) used two small groups of

participants that included a combination of undergraduate and postgraduate students

and medical staff. Selection procedures were not described in their study, but

possibly their groups consisted of very cognitively capable high functioning adults

with intrinsically 'good' working memory. In contrast, in the current study first year

university students were recruited and possibly the range of cognitive abilities were more varied in these individuals than with Logie and Marchetti's participants. Perhaps some of these individuals differed in their ability to efficiently deploy cognitive resources in when required; that is, their overall working memory capacity and/or executive processes may have been more easily compromised than in the other, more efficient group when responding to dual task demands.

On the other hand, the lack of a clear effect for the impact of spatial interference on spatial memory could also be interpreted as the utilisation of a an underlying single resource consistent with the models proposed by Cowan (1988; 1999) and Engle, Kane and Tuholski (1999). As discussed in Section 2.8, this perspective emphasises that differences in performance on working memory tasks depend upon the allocation of attention towards whatever cognitive demands are being placed upon the individual at any given time, and are thus considered to be domain general rather than modality specific demands.

The issue of subject variability is often unacknowledged when interpreting results from working memory research. Miyake (2001) commented that very few studies explicitly address individual difference factors that could influence results such as restricted participant samples, motivation and ability to understand instructions. Moreover, some participants use idiosyncratic strategies that could be cognitively demanding to rehearse spatial material and therefore require additional executive input (Logie, 1995; Miyake et al., 2001) while others do not need or choose to deploy the same resources. As Miyake (2001) suggests these variations can bias results towards domain generality or domain specificity. In other words, if participants do not perform according to instructions, or use cognitive strategies that require extra

attentional input, they are less likely to show differential processing but more likely, as in the current experiment, to show less differentiation of working memory resources.

Given that differences in cognitive efficiency among participants is a possible reason for the failure to replicate Logie and Marchetti's (1991) study, it makes sense to investigate some aspects of cognition that could influence an individual's ability to resist interference in order to retain information in working memory. This approach is useful from the point of view of clarifying visuospatial rehearsal processes, and may have implications for subject selection in experimental working memory studies.

Therefore, the aim of the next two studies was to explore possible reasons for individual variations in rehearsal of visuospatial material in memory by investigating differences in executive ability. This approach is consistent with the perspective discussed in Chapter 3 of the thesis that deployment of executive resources may have an underestimated role in rehearsal in the VSSP.

Chapter 5

Experiment 2: Memory for Spatial Sequences and Span Performance

Findings from the previous experiment indicated that when attempts are made to

differentiate the processes involved in storage and rehearsal of information in

visuospatial memory, individual differences can influence the outcome. This raises

the question of how exactly these individuals differ in their ability to process

information efficiently in response to dual task demands?

One area that has generated much interest is the relationship between memory

span and general aptitudes. Recent research by Colom, Rebollo, Abad & Shih

(2006) addressed the question of the role of individual differences in memory span by

examining research that used short term memory (storage tasks) and working memory

(processing tasks) measures to explore the underlying correlations between these

groups of tasks and cognitive abilities. Colom et al. (2006) reanalysed several key

studies that had examined the relationships between simple span, complex span and

cognitive abilities and as a result of this reanalysis, proposed that individual

differences across the domains of short term memory and working memory are more

likely to be attributable to a general component rather than specific components per

se. Moreover, they also observed that both complex and simple span measures were

not clearly distinguishable but shared a common element that in turn can be

associated with measures of cognitive ability. They concluded that memory span

tasks probably depend on a 'unitary cognitive system comprising a strong component

used to temporarily preserve a reliable mental representation of information about *any*

task' and that individual differences appear to arise 'primarily (although not

exclusively) from the overall capacity and efficiency of this unitary system' (p.169). In other words, although both storage and processing in short term memory are influenced by individual differences, these differences may depend upon an overall efficiency in cognitive ability or general underlying capacity that influences the efficacy of the entire system.

The role of span and its relationship to academic abilities has been the subject of a recent study by Bayliss, Jarrold, Baddeley & Gunn (2005). They approached the question of complex span as a predictor of higher-order cognition by designing a study that separated out the processing and storage requirements of verbal and visuo-spatial tasks. The aim of the study was to examine complex span as a predictor of academic abilities in children and how this might be influenced by individual differences in storage capacity and efficiency of processing. The results of this study were intriguing. It found that the simple span tasks were no better or worse at predicting academic abilities than the complex span tasks, and that neither did individual differences in processing efficiency contribute to the prediction of complex span performance (Bayliss et al., 2005). However, the pattern of results also suggested that although storage capacity was a factor in performance, analysis of residual variance indicated that a separable component independent of storage capacity was present in complex span performance and related to academic achievement as measured in the study. What could this component be? Given that Bayliss and colleagues used a combination of verbal and visuospatial span tasks, they suggested that the variance noted above could reflect a difference between the requirements of the different systems, and that even *simple* span tasks in the visuospatial domain might recruit executive resources that are not necessary for verbal storage tasks. This proposal is consistent with other studies that have

investigated the fractionation of verbal from visuospatial memory and concluded that visuospatial working memory tasks require greater input from the central executive than verbal tasks (e.g. Baddeley, 1996b; Miyake et al., 2001).

A different perspective is offered by Engle (2002) who has suggested that performance on working memory tasks is dependent upon individual differences in the ability to control attention, rather than differences in the number of items that can be stored at any one time. In this conceptualisation, superior working memory capacity depends on a 'greater ability to use attention to avoid distraction' (Engle, 2002, p. 20). As a demonstration of this, Kane and Engle (2000) used high and low span subjects to investigate the effect of proactive interference and found that low span subjects performed more poorly when recalling words from successive lists, but when a secondary task was added, both high and low span subjects performed at the same level. The authors interpreted this as evidence that high span subjects would normally allocate attention to resist interference but under a condition of increased cognitive load, were unable to utilise this ability (Kane & Engle, 2000). However, this interpretation is at odds with Colom et al., (2006) who contend that general capacity, not attentional ability is the element that provides the main source of individual differences on working memory tasks.

However, it can be argued that both these viewpoints have merit when examining the link between working memory performance and individual differences in experimental research. As already acknowledged, rehearsal of visuospatial information in working memory appears to be closely linked to executive processes, and previous research has implicated attentional deployment with the disruption of spatial rehearsal (Smyth & Scholey, 1994; Awh et al., 1998). Therefore, it seems

evident that executive efficiency in some form is instrumental to successful performance on working memory tasks, and if this is compromised in some individuals who may be more vulnerable to task demands than others, performance will diminish.

In order to try to discover why the first experiment did not replicate Logie and Marchetti (1991), it therefore makes sense to investigate the link between the ability to rehearse information in the visuospatial sketchpad and executive function efficiency. Thus, it was decided to investigate one aspect of visuospatial memory function; the ability to rehearse information in the sketchpad utilising the inner scribe (Logie, 1995; 2003). The rationale for this approach came from results from the first experiment, namely, that some participants exhibited poor visuospatial recall across varying levels of interference. One possible reason for this could be that poor executive control in some people leads to a reduced ability to store and recall items from short-term visual-spatial memory especially under dual task conditions. Two areas that could contribute to differences in task responses when rehearsing information in working memory are the ability to store information (memory span), and executive efficiency (ability to divide and sustain attention). Thus, the first of two exploratory experiments will use a digit span task to assess memory span and simple attentional ability, while the second exploratory experiment will use a more demanding attentional task the Paced Auditory Serial Addition Test (PASAT) that will be described in more detail in Chapter 6.

As the general aim was to assess the simplest form of executive input and how this might relate to rehearsal in the VSSP, a reliable phonological task was chosen to place some (small) demand on working memory in order to evaluate memory span.

This task was selected because of its reliability (Lezak, Howieson, Loring, Hannay & Fischer, 2004) and also because of potential difficulties with choosing a spatial span task that is purely spatial in nature and not too demanding on working memory (see Section 2.4). Thus if differences in spatial memory performance emerge according to span ability this would support the view that there is an underlying single resource (such as attention) that mediates task performance in the VSSP (Cowan, 1988; 1999; Engle, Kane & Tuholski, 1999). Furthermore, if differences emerge based on interference type this would provide evidence for modality specific processes in visuospatial memory consistent with Logie's (1995) model.

Firstly, it is predicted that those participants with higher span capacity will perform at a superior level to lower span subjects and that this will be observed across all conditions. In addition, it is hypothesised that planned movement (tapping around an array) will disrupt recall in both lower and higher span subjects, but this difference will be significantly greater in the lower span group because of less efficient ability to respond to dual task demands in the face of same and different types of interference.

Simple movement (tapping with a forefinger) is not expected to disrupt performance to a significant degree. This hypothesis is based on Smyth and Scholey's (1994) observation that movement alone is not sufficient to cause disruption to spatial memory. They proposed that planned movement requires attention to be allocated to the activity and hence it is this deployment of resources that cause a decrement in performance in visuospatial working memory.

Thirdly, it is predicted that counting backwards will disrupt recall in both higher and lower span participants, but more so in the lower span group. Smyth & Pelky, (1992) found that recall for a set of only three spatial items was affected equally by counting

backwards as by tapping, and concluded that non-spatial as well as spatial resources are involved in the maintenance of spatial information in memory. Therefore, if a decrement in performance is observed in the current experiment, this will provide further evidence for the view that spatial rehearsal processes and executive resources are closely interactive. Alternatively, if participants perform better under the spatial (planned tapping) condition, this would support Logie's (1995) contention that the inner scribe is largely functionally separated from central executive processes.

Accordingly, the first of two exploratory experiments will include three groups of participants selected according to memory span capacity who will complete a primary spatial memory task embedded in an interference paradigm.

Method

Participants performed the spatial sequence task used in Experiment 1 as the primary task, and three interference conditions as described below.

Participants

Participants were 30 first year male and female undergraduate psychology students from the University of Tasmania whose ages ranged between 18 and 24 ($M = 19.27$, $SD = 1.55$). Students received ninety minutes course credit in exchange for their involvement and participation was voluntary. All participants were right handed, had normal or corrected to normal vision and were familiar with a computer keyboard. None reported any history of neurological abnormalities. All participants completed the spatial task with the three interference conditions counterbalanced accordingly.

Procedure

Participants were tested individually in the same location used in Experiment 1. On arrival, each student read an information sheet, signed a consent form and were given the opportunity to ask any questions. Next, they were advised that they would be required to complete a short task to test their memory and concentration before completing a computerized memory task.

Forward Digit-Span (Wechsler Scales)

As noted above, the span measure used was the forward digit span task from the Wechsler Memory Scales, 3rd Edition (WMS III). This task is well-standardised and commonly used as a measure of short term storage capacity but is also considered to be closely related to attention (Lezak et al., 2004).

All participants listened to a series of digits read by the experimenter and then verbally repeated these in exact order of presentation. Presentation began at two trials of four digits, and continued until the maximum of nine digits was successfully completed or until participants failed two consecutive trials. Span score was calculated from the average number of digits recalled over the last two correctly recalled trials.

Following completion of the digit span task, participants were seated in front of a computer monitor at comfortable viewing distance and told that they were to perform a task that involved remembering a sequence of squares. All participants were required to keep their eyes fixed on the screen during presentation of the primary tasks and during the retention intervals. They were instructed not to close their eyes or to move any parts of their bodies when not performing the tapping conditions.

Instructions for the relevant task were then given by the experimenter and participants familiarised themselves with the task by completing a short sequence of six trials.

Spatial Sequence Task

As for Experiment 1, participants watched six blue squares, which appeared one after the other on the screen (as described in Experiment 1), and were instructed to remember the sequence in which the squares appeared. Apart from different instructions given for each of the three interference conditions, this task was presented as in the first experiment with 40 trials per condition (N=120). Participants completed a short series of two trials per condition to familiarise themselves with the task before they began the experimental trials.

Simple Tapping (Control) Condition: During the retention interval, each participant was instructed to keep their eyes fixed on the blank computer screen and try to remember the order of presentation of the squares while tapping the index finger of their right hand on the desktop, but not moving their eyes or any other part of their body. These instructions were given to rule out as far as possible, the unintended effect of eye or limb movement on rehearsal.

Planned Tapping Condition: Each participant placed his or her right hand on a 10 cm square wooden board with four raised round pegs (2 cm x 2cm diameter) at each corner. They were required to tap in a clockwise direction using the forefinger and touching each block at about one tap per second while fixating on the blank computer screen. The matrix was covered by a wooden frame, opened at one end to allow the experimenter to observe the participants' hand, but positioned so that the participants

were able to move their hands over the matrix without being able to observe their movements.

Counting Backwards Condition: As soon as the retention interval began (screen blanked) a three-digit number was spoken aloud by the experimenter, and the participant told to count backwards in threes. Participants were instructed to perform this task as quickly and accurately as possible and to respond aloud so that the experimenter could write down their answers (this instruction was given to encourage compliance). As in all other conditions, participants were told to keep their eyes on the blank screen, keep their eyes and body as still as possible and to try and remember the sequences while doing so.

Design and data analysis

A 3 (Group: low span, medium span, high span) x 3 (Interference: simple tapping, planned tapping, counting backwards) mixed factorial design was used with the within subjects factor as interference-type, and the between subjects factor being low, medium or high span length. The dependent variables were, as in the first experiment, the number of recognition errors made on each interference condition.

Means and standard deviations were calculated and analysed using repeated measures analysis of variance on the dependent variables. The alpha significance level was set at .05.

Results

Data from all 30 participants was analysed. Participants were allocated to three groups based on their performance on the digit span task so that span length and

number of errors on the spatial sequence task could be compared. Span length ranged

from four to nine, (M = 6.70, SD = 1.19). Participants were allocated into three

groups based on span length; a low span group (span 4-6), a medium span group

(span 7), and a high span group (span 8-9). The means and standard deviations of

error scores for all groups and conditions are displayed in Table 5.1.

Table 5.1.

Means and standard deviations of incorrect recall of spatial sequences (max.40) for low (n = 13) medium (n = 8) and high (n = 9) span groups across all interference conditions.

	Simple Tapping	Planned Tapping	Counting Back
Low Span	8.15 (4.12)	10.15 (5.03)	11.62 (2.93)
Medium Span	8.89 (4.73)	11.88 (4.61)	12.13 (4.64)
High Span	7.44 (3.43)	9.00 (4.61)	9.78 (2.11)

The data was then submitted to a 3 (Group: low, medium and high span) x 3

(Interference Task: simple tapping, planned tapping, counting back) repeated

measures ANOVA with the between subject factor being group and the within

subjects factor being interference-type.

Repeated measures ANOVA revealed a highly significant main effect for interference

F, (2, 26) = 7.87, p = .002, which confirmed that both planned tapping and counting

backwards significantly impaired recall for spatial sequences, while simple tapping

had no such effect. There was a moderate effect size (.377 partial eta squared).

Pairwise comparisons confirmed that there were significantly fewer errors made on

the simple tapping condition compared with planned tapping, p=.023 or counting

back, *p*= .001. Results of between subjects effects revealed a non-significant main

effect for span F, $(2, 27)$ =.1.12, p=.342, partial eta squared =.076.
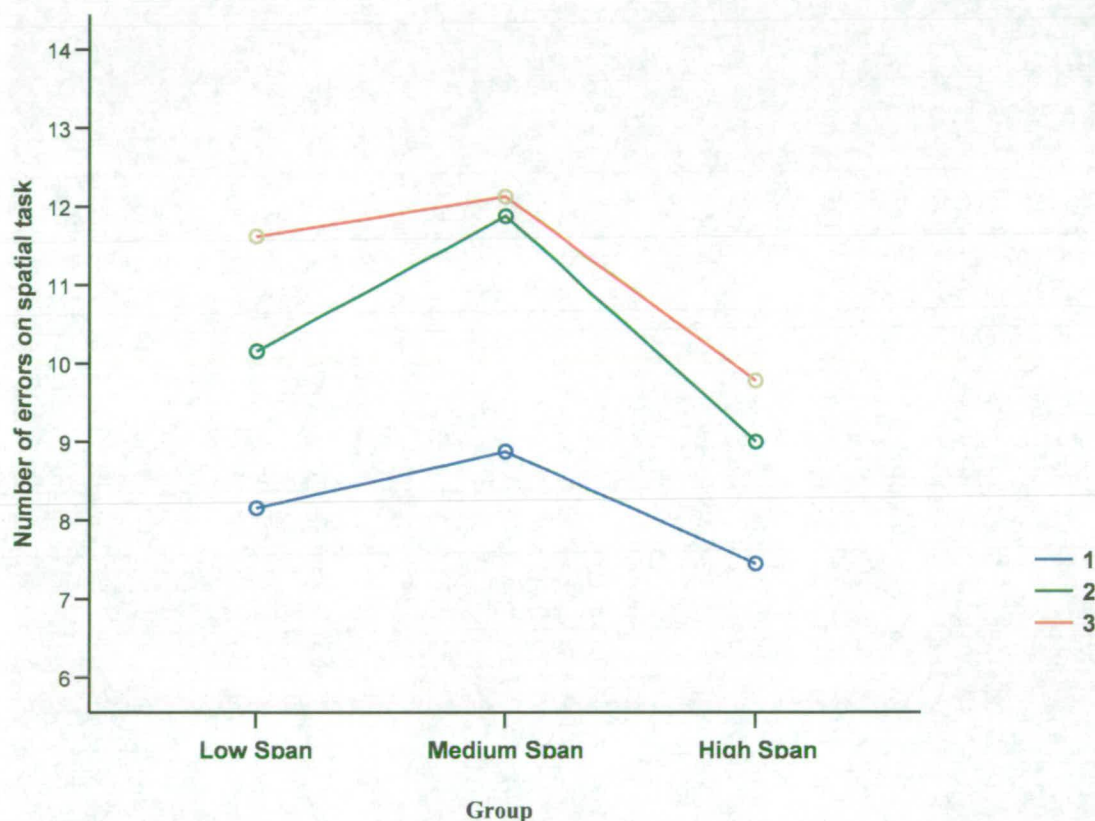
Figure 5.1. Mean number of errors on spatial sequence task for simple tapping (1),
planned tapping (2), and counting back (3) conditions for low, medium and high span
groups.

As illustrated in Figure 5.1, although the high span group made fewer errors under all

three interference conditions than either of the other two groups, the interaction

between group and interference type was not significant F, $(4, 52)$ = .180, p=.948.

Further analyses using paired sample t-tests confirmed that although both the high

and low span groups were susceptible to the effects of executive interference

(counting back), this effect was greater for individuals with low span [t(-3.23) p =

.007] than individuals with high span capacity [t (-2.92) p = .019]. The non-significant spatial simple effect (the contrast between the tapping and counting back conditions) confirmed that neither span group was able to effectively discriminate between same system and different system interference under dual task conditions.

Discussion

The aim of the second experiment was to investigate whether individuals with higher memory span capacity would show superior ability to rehearse a series of spatial sequences compared with lower span individuals. Contrary to expectations however, the hypothesis that individuals with higher span ability would perform significantly better than lower span individuals was not supported. Although the higher span group did make fewer errors over all the interference conditions than either the medium or the low span groups, the differences were not statistically significant. This suggests that although these individuals did demonstrate less vulnerability to interference under dual task conditions, memory span alone is not enough to explain poorer spatial working memory performance. One reason could be that there simply were not enough low span participants to compare with the higher span group, and data from a larger sample of participants may have given different results.

The hypothesis that simple movement performed during a retention interval would have little impact on recall was supported by pairwise analysis. This finding is consistent with previous research (Smyth & Scholey, 1994) which found that movement by itself does not disrupt rehearsal in the visuospatial sketchpad. Similarly, as predicted, both planned movement and counting backwards had a significant detrimental effect on recall, and were equally disruptive, a finding consistent with Smyth & Pelky, (1992). This result reinforces the argument that

rehearsal of sequence information draws on other resources beyond purely spatial processes and suggests that more effortful processing is required when retaining information in the visuospatial sketchpad. Overall, the results from Experiment 2 provide some evidence for a unitary view of working memory whereby a single resource such as attention (Cowan, 1999; Engle, Kane & Tuholski, 1999) underpins performance on working memory tasks. Moreover, the absence of performance differences based on modality-type (tapping and counting back), casts doubt on Logie's (1995) conceptualisation of an inner scribe process which maintains spatially-based information relatively independently from the central executive.

Chapter 6

Experiment 3: Memory for Spatial Sequences and PASAT performance

As with experiment 2, the overall goal of the next experiment was to try to determine why Experiment 1 did not replicate Logie and Marchetti's (1991) study by investigating individual variations in levels of cognitive efficiency. Experiment 2 used a simple digit span task to assess low-level attentional ability in order to explore the view that central executive ability is involved in spatial rehearsal processes in the VSSP. Therefore, in line with the exploratory nature of the two final studies, the aim of the third experiment was to investigate the impact of PASAT performance on spatial memory, with a view to establishing if high-level attentional efficiency is a factor in the ability to deal with competing task demands when rehearsing spatial information in working memory.

The Paced Auditory Serial Addition Test (PASAT).

The Paced Auditory Serial Addition Test PASAT (Gronwall, 1977) is a serial addition task that requires the examinee to consecutively add pairs of numbers in such a way that each number is added to the one that is presented immediately before it (see appendices for instructions). A random series of numbers from 1 to 9 are administered in audio CD format at a rate of one number every 2 seconds, with the test result being the number of correct responses out of a possible 60. The PASAT is considered a robust test of sustained and divided attention due to the high demand on task-switching ability (Strauss, Sherman & Spreen, 2006), and has been used extensively in neuropsychology research to assess the effects of head injury (see

Lezak, et al., 2004). Extensive normative data is available (e.g. Roman, Edwall,

Buchanan & Patton, 1991; Wiens, Fuller & Crossen, 1997).

However, the PASAT is acknowledged to be a challenging and difficult task, and

some have suggested that it may be a more suitable test for intact rather than head-

injured subjects (Sherman, Strauss, Slick & Spellacy, 1997). To the author's

knowledge, the PASAT has rarely if ever been used as an instrument to assess

attentional efficiency in experimental working memory research such as the current

study.

The PASAT version used in the current experiment was adapted for use in Australia

and the audio CD featured a male Australian accent. Because the PASAT is

acknowledged to be anxiety-provoking (Lezak et al, 2004) participants were given

reassurance before they started and advised, "most people would find this task is

difficult, try not to worry just do your best."

All participants were given a maximum of three practice trials before attempting the

PASAT task proper, and then completed the 61- item format with 2 second

interstimulus intervals.

After completion of the PASAT participants performed the computerized spatial

sequence task as in Experiments 1 and 2.

The participants and analyses were identical to those used in Experiment 2, but with

the hypotheses relating to PASAT performance rather than span performance.

Results

Data from the PASAT was analysed so that PASAT performance could be compared with the number of errors made on all three interference conditions on the spatial sequence task. Participants were allocated to three groups based on the cumulative frequencies of correct PASAT responses (M=34.50, SD= 10.62) with cut off points at 33% and 70% (see Appendix C). This left a low PASAT group (scores 0-28) a medium PASAT group (scores 29-40) and high PASAT group (scores 41-60). Means and standard deviations showing errors made on the spatial sequence task for all three groups are displayed in Table 6.1.

Table 6.1.

Means and standard deviations of incorrect recall of spatial sequences (max. 40) for low (n=9) medium (n=12) and high (n=9) PASAT groups across all interference conditions.

	Simple tapping	Planned Tapping	Counting Back
Low PASAT	9.22 (4.35)	13.44 (4.88)	12.89 (4.94)
Medium PASAT	7.83 (413)	10.33 (4.20)	10.67 (2.10)
High PASAT	7.44 (3.77)	7.00 (3.29)	10.22 (2.10)

The data was analysed using repeated measures ANOVA which revealed a highly significant main effect for type of interference, F (2,26) = 8.45, p = .001. Partial eta squared showed a moderate effect size of .394.

Again, pairwise comparisons confirmed that participants made significantly fewer errors in the simple tapping condition than either the planned tapping condition p=.017, or counting back p=.0001.

Results of between subjects effects showed a significant main effect for PASAT score

F, (2, 27) = 3.79, p= .035 indicating that high scoring PASAT participants performed

at a superior level overall compared with either the low or medium groups.

The interaction between PASAT performance and type of interference did not reach

significance, F (4,52) =1.23, p=.310, partial eta squared .086. However, when a less

stringent multivariate test was used a trend was observed [Roy's Largest Root = .19,

F, (2, 27) p =.092] indicating that the high PASAT group made notably fewer errors

on the planned tapping condition as demonstrated in Figure 6.1.
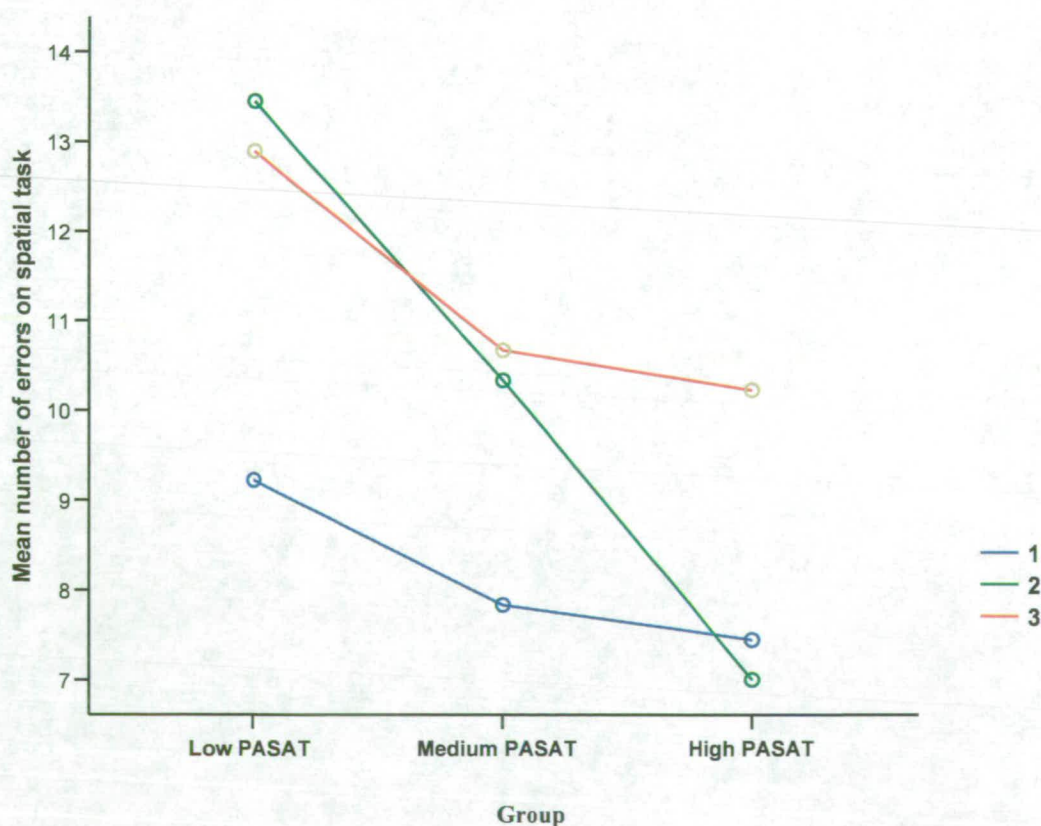
Figure 6.1. Mean number of errors on spatial sequence task for simple tapping (1),
planned tapping (2), and counting back (3) conditions for low, medium and high
PASAT groups.

Post hoc comparisons using the Tukey HSD test indicated that the mean score of the high PASAT group was significantly different from the low PASAT group, *p*=.029 confirming that the former group made fewer spatial sequence errors over all the conditions. Furthermore, using the LSD test a trend emerged indicating that the medium PASAT group had also performed better than the low PASAT group, (*p*=.083).

In addition, Figure 6.1 suggests that not only did the high PASAT groups make fewer errors overall, their ability to resist same-system interference as evidenced by mean error scores on the planned tapping condition was notably better than either of the other two groups.

In order to explore the data further paired sample t-tests were conducted on the low and high PASAT groups. These confirmed that individuals with low PASAT scores made significantly more spatial sequence errors when tapping around an array [*t* (-2.35) *p* = .046] and counting back [*t* (-3.05) *p* = .016] than when simply tapping a finger. The spatial simple effect for this group (planned tapping compared with counting back) was non-significant indicating that this group made about the same number of errors on both conditions.

The high PASAT group also made more errors when counting back than simply tapping a finger [*t* (-.2.83) *p* = .022] but in contrast with the low PASAT group there was no significant effect of planned tapping on spatial memory. This finding was supported by the significant simple spatial effect for this group [*t* -3.33) *p* = .010] indicating that fewer errors were made under same system compared with different system interference.

<u>Qualitative data</u>

Use of Strategy

In an attempt to understand the strategic cognitive responses used, participants were asked if they used any particular method or strategy to remember the order of the squares, e.g. "what strategy did you use to help you remember the order of the squares?"

Some described a combination of verbal and imagery strategies:

Examples: "I tried to keep a pattern in my mind or thought two at the top first " *(subject 11)*.

Others built pictorial images example; "I tried to remember the squares as 'left, right, centre' or imagined them as patterns like a slide or castle"*(subject 25)*.

"I tried to connect the squares in my mind, like drawing a line between each one." *(subject 29)*.

"I tried to map them (the squares) sort of like drawing a line between them to remember."*(subject 28)*.

Another commented; "I tried to remember them (the squares) in threes, or in shapes like a fish." *(subject 27)*.

Others were not aware of any particular strategy but most commented that they tried to form a picture or shape in mind to help them to remember the order of the sequences.

Discussion

The purpose of the current experiment was to investigate the effect of PASAT

performance on the ability to retain a set of spatial sequences in memory under three

different interference conditions. The overall aim was to try to provide an

explanation for the failure in Experiment 1 to replicate Logie and Marchetti's (1991)

findings by investigating individual differences in cognitive efficiency under dual

task conditions.

Results indicated firstly, that the high PASAT group performed more efficiently

overall. Post hoc analyses showed that this group made significantly fewer errors

than either the medium or the low PASAT groups across all conditions. Moreover,

the high PASAT group made significantly fewer spatial sequence errors than the low

PASAT group when tapping around an array than when counting backwards. These

results suggest that individuals who perform well on the PASAT are also better at

discriminating between spatially based and phonologically based material in working

memory under dual task conditions. In contrast, the low PASAT group, perhaps

because of less-efficient attentional capacity, are more vulnerable to interference,

show less discriminatory ability, and are therefore less able to perform effectively

when required to divide their attention between two different tasks.

The ability to divide attention has been identified as an important sub process

of the central executive (Baddeley, et al., 1991). In the original conceptualisation of

the working memory model (Chapter 2), the role of the central executive was

somewhat underspecified, however more recently this has been revised to encompass

a mechanism consisting of a range of different components including the ability to

allocate attention in response to task demands (Baddeley, 2001; 2003). In the case of

the present experiment, the overall results suggest that individuals who possess better attentional (and thus executive) skills are more successful at maintaining information in spatial memory. This finding is consistent with the viewpoint that executive processes are involved in a wide range of spatial tasks, even, as in the current experiment, relatively basic ones (Miyake et al., 2001). Additionally, the results imply that although central executive processes are an important ingredient for rehearsal in the visuospatial sketchpad, separate spatial processes may also be involved. This finding is consistent with the model of visuospatial rehearsal as proposed by Logie (1995; 2003; Logie & Marchetti, 1991) but there is a caveat in that results from the current study suggest that only individuals with well-developed attentional abilities demonstrate this propensity. In this case, perhaps the most important contribution of the current study has been to link attentional ability as assessed by the PASAT to the successful retention of sequence information in visuospatial memory. Although a possible limitation of this study (as with Experiment 2) is that the group sizes were quite small, these findings indicate that successful performance on a Corsi-type task such as that used by Logie and Marchetti (1991), and in the current series of experiments, is mediated by the ability to sustain and divide attention.

Finally, results from qualitative data suggest that when material is manipulated in visuospatial memory, individuals draw on resources from a variety of sources. The responses given by participants in the current study indicate that verbal, visuospatial and long-term memory are utilised when formulating a strategy for maintaining information temporarily in memory. This observation adds to the quantitative evidence to show that rehearsal in the visuospatial sketchpad is not a purely spatial process but probably draws on different mechanisms in response to task

demands. These findings are also congruent with Baddeley's (2003) revised and extended framework (see Chapter 2) which suggests that an 'episodic buffer' facilitates interaction between the different modalities and long-term memory when responding to task-dependent requirements in working memory.

Chapter 7

General Discussion

Broadly, the aim of the series of experiments described in the present thesis was to investigate the nature of visuospatial rehearsal in working memory. Initially, the purpose was to confirm by replication, the presence of a visual-spatial distinction based upon selective interference in the sketchpad, and specifically, to examine the role of movement. However, in response to unexpected results from the first experiment, the direction of the research altered in order to investigate possible reasons for these findings. Experiments 2 and 3 focussed on the rehearsal of spatial information in order to determine if the kind of performance variations observed in the first experiment could be explained by individual differences in the deployment of cognitive resources when performing a working memory task under dual task demands.

7.1 Overview of the findings

The first experiment was a close replication of Logie and Marchetti (1991), and used an interference paradigm with a repeated measures design to assess memory for visual and spatial information in a group of university students. However, whereas Logie and Marchetti's experiment clearly showed a selective interference effect of visual memory by visual interference, and spatial memory by spatial interference thus establishing a double dissociation, Experiment 1 failed to replicate these findings, instead, the results showed a general effect of interference across both the visual and spatial primary tasks on all conditions. The results indicated that a small sub-group of participants had made a higher than average number of errors

compared with the other group, over all types of interference including the control conditions, which presumably were the least demanding or difficult. When these higher error participants were excluded and the data reanalysed, although the expected interaction for task type still did not reach significance, there was evidence of a trend towards a selective effect of interference. When other explanations such as task differences were ruled out as a reason for the failure to establish a double dissociation, the findings were interpreted as evidence that some individuals have less well-developed ability to rehearse visuospatial information when coping with dual task demands, perhaps because of less efficient use of cognitive resources.

Given that Experiment 1 yielded some interesting and unexpected information about individual variability, two experiments investigated different but related aspects of human cognition; span capacity and attentional efficiency in order to determine how they might influence ability to maintain spatial information in working memory. In Experiments 2 and 3, participants were allocated to three groups based on digit span capacity and performance on the PASAT, a task that assesses high-level attentional skills. They performed a spatial sequence task under three different interference conditions to determine the effect of memory span and attention on their ability to maintain spatial information in working memory. The results supported the hypotheses that both planned movement and counting backwards would disrupt spatial memory significantly more than a simple movement task. These findings provided evidence for the view firstly, that movement alone cannot explain disruption during rehearsal in the visuospatial sketchpad, or inner scribe as per Logie's (1995; 2003) model, and secondly, that rehearsal processes are not limited to a purely spatial mechanism, but require contribution from the central executive. Results from Experiment 2 suggested that although individuals with higher span capacity were

generally better able to perform under dual task conditions than lower span individuals this difference did not reach significance. Post hoc analyses from the third and final experiment found that individuals with superior PASAT scores made significantly fewer errors overall, with post-hoc analyses confirming that this group are less vulnerable to same-system interference when rehearsing information in visuospatial memory.

These results are interpreted as support for the view that rehearsal processes in the visuospatial sketchpad are largely reliant on central executive resources. Firstly, there was evidence that individuals with more efficient attention are generally more able to cope with dual task demands and appear to demonstrate better discriminatory ability, that is, they are less susceptible to same-system interference. In addition, the finding that both counting back and planned tapping caused significant disruption while a simple repetitive tapping movement had no effect on performance supports previous research (Chapter 3), suggesting that movement alone cannot account for disruption in the sketchpad.

7.2 Links with executive processes & attention

As noted in Chapter 3, much of the research aimed at investigating the visuospatial sketchpad has been driven by attempts to show symmetry with the phonological loop. However, although both systems rely on the central executive when rehearsing information on a task-demand basis (see Vallar & Baddeley, 1982), the visuospatial system has been consistently shown to be more dependent on executive resources (Chapters 3 & 4). Both models of working memory as described by Baddeley (1986) and Logie (1995; 2003) acknowledge the role of a central attentional mechanism as being responsible for coordinating the two slave systems (the phonological loop and

visuospatial sketchpad). However, the models diverge with Logie's clear

specification of the structure of the visuospatial sketchpad comprising a passive store

for static visual information, and an active spatial system for rehearsal of sequential

information (Chapters 2 & 3). With regard to interpreting the current findings within

the framework of the working memory model, on the face of it the results of the

present series of experiments do not convincingly support the concept of an inner

scribe, or separate spatial rehearsal mechanism in the visuospatial sketchpad as

proposed by Logie (1995; 2003). Instead, the results from Experiments 1 and 2

suggests that rehearsal of spatial information relies heavily on central executive input

by way of the participants' ability to deploy attention in the face of competing dual-

task demands and is consistent with the single resource perspectives offered by Engle

and Cowan as outlined in Chapter 2. However, there are also commonalities with

Baddeley's (2001) proposal that the central executive, by means of deployment of

attention, may in fact be a "typical mechanism for maintenance rehearsal" (p. 854).

More recently, Logie has acknowledged the role of executive functions in spatial

immediate memory and commented that the inner scribe "may draw heavily on

aspects of attentional control" (2003, p.64). However, to date his model has not

clearly stipulated how or to what extent this might occur. The overall findings from

the present series of studies are mixed in that although there is some evidence to

support separate visual and spatial storage systems in the VSSP, rehearsal of

spatially-based information in the sketchpad appears to be mediated by the

deployment of executive resources.

In Experiments 2 and 3, both planned movement and counting backwards

diminished performance, which suggests that each of these tasks require extra

processing resources beyond the capacity of the inner scribe. This finding is

consistent with Smyth and Pelky (1992) who found that even sub-span recall of only

three spatial locations was disrupted by counting back as well as by spatial tapping

during maintenance. If this disruption occurs because of the necessity to deploy

attention as has been suggested (Chapter 3) the current results indicate that the ability

to do this effectively varies between individuals who have a greater or lesser ability to

deal with conflicting task demands when maintaining sequence information in the

sketchpad. Perhaps the participants in the current studies performed successfully

because they were better able to divide their attention efficiently when faced with the

requirements of a dual task scenario. As previously noted, the ability to divide

attention has been identified as a crucial aspect of central executive function by

Baddeley and colleagues (1986; 1991) after they demonstrated that a group of

Alzheimer's sufferers with damaged frontal lobe function were severely restricted in

their ability to perform dual tasks (Chapter 2).

From a neuroanatomical perspective, the substrates of working memory have

become increasingly well established by way of fMRI and PET technology, as

reviewed in Chapter 3, with consensus in the literature that executive processes are

coordinated in the dorsolateral pre-frontal cortex (Smith and Jonides, 1999; Hartley &

Speer, 2000). Using fMRI, D'Esposito et al., (1995) found that when subjects

performed a single task (either verbal or spatial) only areas in the central and

posterior cortex were activated, but when the tasks were performed simultaneously

both dorsolateral pre-frontal cortex and anterior cingulate areas showed significantly

increased activity. An important characteristic of the PASAT task used in Experiment

3 is that it requires divided attention, and a recent PET study found that

administration of the PASAT causes activation in a variety of brain sites including

bifrontal and biparietal areas and the anterior cingulate (Lockwood, Linn, Szymanski,

Coad & Wack, 2004). Moreover, a further fMRI study has suggested that PASAT performance stimulates a wide range of brain regions, notably frontal and parietal areas associated with working memory and attention (Lazeron, Rombouts, de Sonneville, Barkhof & Scheltens, 2003). Evidently, the PASAT is a task that draws heavily on the central executive, and the findings from Experiment 3 would suggest that there is a strong link between the successful maintenance of a set of sequences in spatial memory, and the ability to allocate attention to conflicting tasks demands. Moreover, evidence from brain imaging studies suggests that a common network of neural pathways situated in the dorsolateral prefrontal cortex subserves these abilities.

Engle and colleagues have put forward a behavioural framework consistent with this perspective (Kane and Engle, 2002; Engle & Kane et al., 1999; Engle & Tuholski et al., 1999). They argue that working memory capacity, executive attention and general fluid intelligence are all subserved by a common neuroanatomical mechanism that resides in the dorsolateral prefrontal cortex. The critical element is attention, which they describe as the individual's ability to actively maintain information in memory in the face of interference (Kane & Engle, 2002). According to this approach, working memory capacity is part of the working memory system and involves "the capacity for controlled, sustained attention in the face of interference or distraction" (Engle, Kane & Tuholski, 1999, p.103) and corresponds conceptually to the central executive component as proposed by Baddeley and Hitch, (1974). Although the existence of domain-specific codes in working memory including the phonological loop and visuospatial sketchpad (among others) is acknowledged in this framework, the emphasis is on the individual's ability to control attention which is seen as being a domain-free characteristic and the basis for individual differences in performance on working memory tasks (Engle, Kane &

Tuholski, 1999). In addition, Engle and colleagues view this characteristic as predictive of success across a wide range of cognitive domains including general intelligence (Engle, 2002; Kane & Engle, 2002). The present study cannot make any claims in this last regard, as the participants were not evaluated psychometrically. Indeed, a possible limitation of all three of the current studies was that an assumption was made that the university students who participated were all of at least average intellectual ability. Perhaps in future research it would be helpful to screen participants on a measure of intelligence in order to clarify if this is an instrumental factor in performance outcome.

On the face of it, the results of the current series of studies would seem to support a single resource view of working memory such as proposed by Cowan (1988; 1999) and Engle (1999), that the ability to deploy attention in the face of interference is crucial to successful working memory performance. On the other hand, the findings from Study 3 also provide support for the argument that domain specific components are involved (e.g. spatial processes). However, indications from the current series of studies also point towards the domain-specific components of working memory being contingent on the cognitive efficiency of the participants. The overall results from the three experiments described in this thesis suggest strongly that in order to achieve the same pattern of results as those reported by Logie and Marchetti (1991), participants need to be selected from a sample of cognitively high functioning individuals with well developed attentional abilities.

It is also possible that the results of the current series of studies reflect idiosyncratic use of strategy between participants, which may or may not be linked to underlying differences in cognitive capacity. Individuals will use different strategies to solve tasks, and sometimes this means that a small group of participants will show

a different pattern of results from the rest of the group (Logie, 1995). Participants in the current study commented that they used strategies along the lines of creating shapes or patterns 'in the mind's eye' which helped them to remember the sequences. Possibly this reflects the contribution of various aspects of working memory including verbal strategies, imagery generation and activation of long-term memory all of which are called upon in order to solve tasks (Baddeley, 2003). Alternatively, it could be that some participants use idiosyncratic decision-making strategies that involve extra demand on resources, thus making the task more difficult for them than for others.

It is acknowledged that an additional limitation of the current research is that since only one spatial task was used to investigate rehearsal in Experiments 2 and 3, the conclusions cannot be generalised to include other aspects of spatial memory other than the ability to retain a set of spatial sequences. Utilisation of a variety of spatial primary tasks in future studies would help to extend the findings further by confirming and clarifying to what extent central executive interference impacts on rehearsal of spatially-based information in working memory.

7.3 Implications of findings for future research

The findings reported in this thesis have contributed to an area of working memory research that has traditionally been problematic to investigate, rehearsal in the visuospatial sketchpad. Because many studies have investigated rehearsal using dual task paradigms in which interference is present during both encoding maintenance and retrieval phases (e.g. Fisk & Sharp, 2003; Kondo & Osaka, 2004) it has been difficult to clarify the mechanism by which disruption occurs. The current series of studies have focussed on one area only, the ability to rehearse spatial information in the face of varying types of interference, and the findings have contributed to a

growing body of research that has implicated the central executive in spatial rehearsal (Smyth & Pelky, 1992; Klauer & Stegmaier, 1997; Klauer & Zhao, 2004).

In addition, results from Experiment 3 suggest that performance on the PASAT, a task that requires high-level attentional skills, is linked to the ability to successfully maintain and retrieve sequential information from memory, and therefore suggests that the ability to deploy attention is a critical factor in visuospatial rehearsal. The current findings also point to the PASAT as being a useful task to use in future research if differentiation of high-level attentional abilities is required. It is well established that working memory deficits and problems with attention are common following traumatic brain injury (e.g. Serino, Ciaramelli, Di Santantonio, Malagu, Servadei & Ladavas, 2007), and have also been observed in mildly head injured individuals whose results from other neuropsychological tests have been within normal limits (Cicerone, 1996). However, this aspect of subject variability is largely unexplored in the normal population, so in future research it may be useful to screen out distractible subjects before participation in working memory experiments.

One implication of the present findings is that there is a danger that results from working memory research will be vulnerable to bias if consideration is not given to the potential impact of individual variability. This is especially relevant if results are interpreted in terms of domain specific or domain general characteristics, but also applies to any research that aims to investigate the cognitive processes underlying working memory. It is even possible that there may not be a 'typical' rehearsal process but rather one that is mediated by a variety of factors including individual characteristics that need to be considered when planning and designing experimental research.

More than thirty years on, Baddeley and Hitch's (1974) theoretical construct "working memory" remains a most influential explanation for the temporary storage and processing of information in human cognition, and perhaps the most impressive aspect of the model aside from its durability is the potential for both expansion and specification. In terms of specifying a mechanism for rehearsal in the sketchpad, an approach that looks for commonalities that parallel those of the phonological loop may be less useful than an alternative approach that takes into consideration the distinctive characteristics of this visuospatial system. Within the cognitive architecture of working memory, the central executive is gaining more prominence and in terms of contribution to visuospatial rehearsal should perhaps be seen as central rather than peripheral.

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APPENDIX A

Experiment 1

Statement of Informed Consent

An Investigation of Short-term Non-verbal Memory Processes

Ms Peggy Foreman, Dr Clive Skilbeck, Dr Iain Montgomery
School of Psychology, University of Tasmania

- I have read and understood the 'Information Sheet' for this study. The nature and possible effects of the study have been explained to me. I understand that the study involves the following procedures:

- I will be asked to complete a series of tasks on a computer that are designed to assess my non-verbal memory skills

- While completing these computer tasks I will be asked to perform another simple task such as moving my hand and arm or looking at a series of pictures

- I understand that there are no foreseeable risks involved or anticipated in the project, but I can take rest breaks as necessary

- I understand that all research data will be securely stored on the University of Tasmania premises for a period of at least 5 years. Any hard-copy of data will be destroyed at the end of 5 years

- I agree that research data gathered for the study may be published provided that I cannot be identified as a participant

- Any questions that I have asked have been answered to my satisfaction.

- I agree to participate in this investigation and understand that I may withdraw at any time without prejudice

Name of participant————————————————————————

Signature of participant_____ Date _____

I have explained this project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

Name of investigator _____

Signature of investigator _____ Date _____

University of Tasmania
School of Psychology
GPO Box 252-30
Hobart Tasmania 7001
Tel: 03 6226 2807 Fax: 03 6226 2883
Email: pforeman@utas.edu.au

Date:

Information Sheet for Potential Participants:
An Investigation of Non-verbal memory processes in short-term memory

My name is Peggy Foreman and this study is being conducted as part of my post-graduate Doctoral degree at the School of Psychology. I am interested, along with my supervisors Dr Clive Skilbeck and Dr Iain Montgomery, in the factors that influence short-term non-verbal memory processes. We would like to invite you to participate in an area of research that potentially may contribute significantly towards the expansion of knowledge in the working memory field. There has been extensive research in the area of verbal working memory but the mechanism of non-verbal spatial processes is largely unexplored. Some studies have indicated that certain movements can disrupt the ability to remember visual information but this has not yet been clarified.

If you decide to participate in the project, you will be asked to complete some computer tasks that require you to remember a series of shapes and patterns. You will also be asked to complete various other tasks such as looking at pictures or moving your upper limbs. It is anticipated that you will need to attend two sessions lasting approximately 40-60 minutes. Before you decide to participate you should know that your participation is completely voluntary and you are free to cease your involvement at any time without prejudice or penalty from myself, my supervisors or any member of the School of Psychology.

Confidentiality will be maintained at all times. The information you submit will only be available to be accessed by the investigators directly involved with the study. Your name and other identifying details will not be recorded on any data sheet, instead individual results will be coded to ensure that all information remains anonymous. Any published results will only refer to group data.

This project has received approval from the Southern Tasmania Social Sciences Human Research Ethics Committee, and while no adverse effects are anticipated, if you do have any questions or concerns about the study either before during or after participation please do not hesitate to contact Peggy Foreman (details above) Dr Clive Skilbeck (6226 7459) or Dr Iain Montgomery (6226 2386). If you have any concerns about the ethical nature of this study, please contact the Chair (A/Professor Gino Dalpont: 6226 2078) or the Executive Officer (Amanda McAully: 6226 2763).of the Southern Tasmania Social Sciences Human Research Ethics Committee. Please keep this information sheet. If you do agree to participate, you will be asked to sign a statement of informed consent, a copy of which will be supplied to you.

Thank you for considering this proposal.
Peggy Foreman   Dr Clive Skilbeck   Dr Iain Montgomery

Key to the Raw Data - Experiment 1

colourcon   Control Condition Visual Task

colourpic   Irrelevant Pictures Condition Visual Task

colourmov   Tapping Condition Visual Task

spatcon   Control Condition Spatial Task

spatpic   Irrelevant Pictures Condition Spatial Task

spatmove   Tapping Condition Spatial Task

Raw Data Experiment 1 (30 subjects)

subject	gender	age	Number colourcon	Errors colourpic	colourmov	spatcon	spatpic	spatmove
dp1	male	24	7	12	12	8	12	9
hd2	female	18	9	7	7	10	8	11
mb3	female	19	6	4	9	3	11	7
gm4	female	27	7	12	10	7	10	15
pm5	male	18	8	4	7	5	9	9
gw6	female	19	11	10	14	7	14	11
lc7	female	18	5	9	9	9	8	13
sh8	female	18	7	17	13	5	13	17
ks9	female	18	12	10	10	13	17	10
sc10	male	18	8	10	8	13	8	7
as11	male	19	16	8	22	13	17	8
sk12	male	19	8	8	8	5	13	17
ad13	male	20	9	9	6	4	11	7
sf14	female	18	8	6	6	10	12	10
rs15	female	20	5	7	18	3	5	9
rx16	female	18	19	15	17	18	13	15
sm17	female	26	8	11	10	10	6	11
ch19	female	18	9	11	8	9	10	11
lh20	male	19	9	9	7	10	4	11
rg21	female	18	7	16	16	10	11	13
kb22	female	31	13	17	16	11	17	13
mp23	female	18	9	16	14	5	12	9
aw24	female	28	5	6	3	5	0	5
dl25	male	26	12	12	14	12	7	14
jw26	female	20	11	3	7	6	7	11
kf27	male	18	14	14	15	15	13	13
as28	male	18	10	15	12	10	9	15
sr29	female	35	7	13	10	11	22	15
am30	female	18	9	13	6	7	5	6
de31	female	26	14	22	22	12	13	16

Raw Data Experiment 1 (23 subjects)

subject	gender	age	Number colourcon	Errors colourpic	colourmov	spatcon	spatpic	spatmove
dp1	male	24	7	12	12	8	12	9
hd2	female	18	9	7	7	10	8	11
mb3	female	19	6	4	9	3	11	7
gm4	female	27	7	12	10	7	10	15
pm5	male	18	8	4	7	5	9	9
gw6	female	19	11	10	14	7	14	11
lc7	female	18	5	9	9	9	8	13
sh8	female	18	7	17	13	5	13	17
sc10	male	18	8	10	8	13	8	7
sk12	male	19	8	8	8	5	13	17
ad13	male	20	9	9	6	4	11	7
sf14	female	18	8	6	6	10	12	10
rs15	female	20	5	7	18	3	5	9
sm17	female	26	8	11	10	10	6	11
ch19	female	18	9	11	8	9	10	11
lh20	male	19	9	9	7	10	4	11
rg21	female	18	7	16	16	10	11	13
mp23	female	18	9	16	14	5	12	9
aw24	female	28	5	6	3	5	0	5
jw26	female	20	11	3	7	6	7	11
as28	male	18	10	15	12	10	9	15
sr29	female	35	7	13	10	11	22	15
am30	female	18	9	13	6	7	5	6

Silhouette Shapes used in Visual Primary Task - Experiment 1

Leaf	Club (suite in cards)	Scales
Donkey	Crown	Cup & saucer
Truck	Elephant	Teapot
Camera	Fish	Heart
Rabbit	Egg timer	Flag
Galleon	Lobster	Pencil
Butterfly	Onion	Wishing well
Bow	Diamond	Spades
Tree		

APPENDIX B

Experiments 2 & 3

Statement of Informed Consent

An Investigation of Short-term Non-verbal Memory Processes

Ms Peggy Foreman, Dr Clive Skilbeck, Dr Iain Montgomery
School of Psychology, University of Tasmania

- I have read and understood the 'Information Sheet' for this study. The nature and possible effects of the study have been explained to me. I understand that the study involves the following procedures:

- I will be asked to perform some memory tasks such as remembering numbers and adding numbers together

- I will be asked to complete a series of tasks on a computer that are designed to assess my non-verbal memory skills

- While completing these computer tasks I will be asked to perform another simple task such as moving my hand and arm, counting or looking at a series of pictures

- I understand that there are no foreseeable risks involved or anticipated in the project, but I can take rest breaks as necessary

- I understand that all research data will be securely stored on the University of Tasmania premises for a period of at least 5 years. Any hard-copy of data will be destroyed at the end of 5 years

- I agree that research data gathered for the study may be published provided that I cannot be identified as a participant

- Any questions that I have asked have been answered to my satisfaction.

- I agree to participate in this investigation and understand that I may withdraw at any time without prejudice

Name of participant _____

Signature of participant _____ Date _____

I have explained this project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

Name of investigator _____

Signature of investigator _____ Date _____

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Date:

Information Sheet for Potential Participants:
An Investigation of Non-verbal memory processes in short-term memory

My name is Peggy Foreman and this study is being conducted as part of my post-graduate Doctoral degree at the School of Psychology. I am interested, along with my supervisors Dr Clive Skilbeck and Dr Iain Montgomery, in the factors that influence short-term non-verbal memory processes. We would like to invite you to participate in an area of research that potentially may contribute significantly towards the expansion of knowledge in the working memory field. There has been extensive research in the area of verbal working memory but the mechanism of non-verbal spatial processes is largely unexplored. Some studies have indicated that certain movements can disrupt the ability to remember visual information but this has not yet been clarified.

If you decide to participate in the project, you will be asked to complete some memory tasks such as remembering numbers and adding numbers together. You will also complete some computer tasks that require you to remember a series of shapes and patterns, and while doing this you will be asked to complete various other tasks such as looking at pictures, counting aloud or moving your upper limbs. It is anticipated that you will need to attend at least one and possibly two sessions lasting approximately 60 minutes. Before you decide to participate you should know that your participation is completely voluntary and you are free to cease your involvement at any time without prejudice or penalty from myself, my supervisors or any member of the School of Psychology.

Confidentiality will be maintained at all times. The information you submit will only be available to be accessed by the investigators directly involved with the study. Your name and other identifying details will not be recorded on any data sheet, instead individual results will be coded to ensure that all information remains anonymous. Any published results will only refer to group data.

This project has received approval from the Tasmanian Social Sciences Human Research Ethics Committee, and while no adverse effects are anticipated, if you do have any questions or concerns about the study either before during or after participation please do not hesitate to contact Peggy Foreman (details above) Dr Clive Skilbeck (6226 7459) or Dr Iain Montgomery (6226 2386). If you have any concerns about the ethical nature of this study, please contact the Ethics Executive Officer, Human Research Ethics (Tasmania) Network: 6226 7479: Human.Ethics@utas.edu.au . Please keep this information sheet. If you do agree to participate, you will be asked to sign a statement of informed consent, a copy of which will be supplied to you.
Thank you for considering this proposal.

Peggy Foreman   Dr Clive Skilbeck   Dr Iain Montgomery

Key to the Raw Data - Experiments 2 & 3

errcon   spatial sequence errors on simple tapping condition

errmove   spatial sequence errors on planned movement condition

errcount   spatial sequence errors on counting back condition

span   total span length on digit span task

PASATscore   total PASAT correct score

ID#	Age	Gender	errcon	errmove	errcount	span	PASAT score
el1	19	female	2	9	9	7	40
ag2	18	male	4	6	11	6	48
lw3	18	female	14	12	13	6	47
rd4	18	female	6	2	10	9	59
cs5	18	female	8	8	12	6	30
lf6	18	female	2	9	15	6.5	34
eg7	18	female	11	12	18	6.5	28
ma8	24	male	12	18	14	5.5	21
ec9	19	female	12	20	12	6.5	33
rm10	19	female	4	5	9	6	41
stu11	19	male	5	3	8	8	44
eh12	20	female	7	10	12	5.5	53
jr13	18	female	10	4	18	5.5	17
vb14	18	female	14	17	18	7	28
cv15	18	female	7	8	6	7	17
cm16	19	female	15	19	15	4	28
ed17	18	female	9	10	8	6	30
rc18	22	male	13	7	7	6.5	31
sr19	22	male	3	13	12	5	16
ev20	19	male	10	7	11	7.5	39
sbs21	19	male	6	11	11	8	35
iw22	19	male	12	8	13	9	43
sn23	19	male	7	15	11	8.5	36
ac24	20	male	2	4	10	6	39
hr25	19	female	10	13	12	7	31
mk26	20	male	8	15	9	6	23
rm27	23	female	10	8	8	6	46
em28	19	female	3	15	6	8	27
cl29	19	female	13	11	10	7.5	30
clx30	19	female	5	9	8	8	41

APPENDIX C
(Compact Disc)

Experiment 1

SPSS files:

Descriptive statistics

Multivariate statistics

Repeated Measures ANOVA (30 participants)

Repeated Measures ANOVA (23 participants)

Experiment 2

Descriptive Statistics

Multivariate statistics

ANOVA for Span - High/Medium/Low Groups x Interference - Experiment 2

Tukey Post hoc tests - Span

Experiment 3

Descriptive Statistics

Multivariate statistics

ANOVA for PASAT - High/Medium/Low Groups x Interference

Tukey Post hoc Tests - PASAT