

An exploration of representation and maintenance in visuo-spatial
working memory for simultaneously and sequentially presented
information.

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DECLARATION

I declare that this thesis is my own composition, and that the material contained in it describes my own work. It has not been submitted for any other degree or professional qualification. All quotations have been distinguished by quotation marks and the sources of information acknowledged.

Elaine Niven

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Abstract

Multiple lines of evidence have indicated that the system responsible for the short term representation and maintenance of visually presented, non-verbal information - Visuo-Spatial Working Memory - is not unitary. One of the most influential dissociations observed is that between performance on a task requiring memory for patterns within a matrix (visual patterns task) and memory for sequences of locations (Corsi blocks task). A growing body of research suggests the difference of importance between these two tasks is manner of presentation - whether information is simultaneously or sequentially presented. It has been proposed that visuo-spatial working memory can be fractionated into two components - a visual and a spatial subsystem, which are considered to support memory for visual matrix patterns and sequences of locations respectively. The extent to which these components are thought to interact varies between models, and recent questions have been raised over differential use of executive resources.

The current thesis investigated whether the same visual information was represented by separate subsystems on the basis of the format in which it was presented. Experiments 1-3 used interference methodology, employed during the retention interval of a recognition task which required the locations of three dots to be remembered. Presentation of primary task stimuli was of either a simultaneous or a sequential format and interference stimuli were designed to target possible visual or spatial subsystems. Passive viewing of simultaneous or sequential interference stimuli was not found to produce a reliable disruption to memory performance. A typical spatial interference task and a novel visual task requiring detection of images were found to disrupt memory for both simultaneously and sequentially presented information. There was, however, no evidence of selective interference. Experiment 4 employed memory for the appearance of a series of items to provide further evidence that the novel visual paradigm affects visuo-spatial memory rather than an imagery strategy.

Experiments 5-8 investigated memory for static arrays and sequences consisting of a greater number of locations. It was found that emphasis on retaining order in sequence recall did not exacerbate differences in performance level between memory for arrays and sequences. An individual differences approach including seven other measures revealed recall of simultaneously presented information and recall of

sequentially presented information were best predicted by each other, and then by different predictors.

The results from the above studies suggest common resources support memory for static arrays and sequences of locations as well as indicating use of different resources. That memory for simultaneously and sequentially presented information was equally disrupted by a primarily visual and a primarily spatial interference task suggests maintenance of information may employ overlapping processes regardless of presentation format. Models of visuo-spatial working memory which advocate sequences of locations are maintained in memory by processes operating separately from those maintaining static arrays of information are hard to reconcile with the current data; it is suggested that a model which proposes separable yet interdependent subsystems provides the best account of both the results obtained and the literature reviewed.

Chapter One

One of the most influential models of the way in which information is represented and maintained, in an active, readily accessible state, is not unitary. Baddeley and Hitch (1974) conceptualised a model in which two domain specific, limited capacity, subsystems could each function independently of the other. A third component – a general-purpose control mechanism termed the central executive – was tasked with managing these ‘slave’ components and allowing the system to work together in support of complex cognitive activity. The idea of a working memory system which underlies both simple temporary storage and manipulation of represented information has spawned many further models which vary in their similarity and differences (for reviews see e.g. Miyake & Shah, 1999; Osaka, Logie & D’Esposito, 2007; Conway, Jarrold, Kane, Miyake & Towse, 2008). The original model (Baddeley & Hitch, 1974) and subsequent development (Baddeley, 1986) of working memory has proved a successful framework under which to conduct research (e.g. Andrade, 2001).

The means by which temporary memory for verbal material is maintained has been proposed as consisting of a limited capacity, phonologically based, storage system that can be supported by a rehearsal process akin to subvocalisation (Baddeley & Hitch, 1974; Baddeley, 1986). This characterisation has long received tremendous amounts of attention (for reviews see e.g. Baddeley 2003a,b; 2007). In comparison, the role of the central executive has remained somewhat ambiguous; however, attributed operations currently include the focusing and switching of attention, retrieval from long term memory (LTM) and the coordination of performing two tasks at the same time (e.g. Baddeley, 1996; Logie, Cocchini, Della Sala & Baddeley, 2004). It is also currently considered probable that executive functions for which a central control mechanism could be expected to account - including monitoring and updating of information, inhibition and mental shifting - are functions which could be supported by dissociable resources (Miyake et al., 2000). There is, therefore, ongoing consideration of fractionation of the central executive (Baddeley, 2007).

The development of a domain specific visuo-spatial system, termed the visuo-spatial sketchpad (Baddeley & Hitch, 1974), as distinct from its proposed verbal counterpart has received much subsequent support. An abundance of evidence now

exists which suggests that memory for verbal and visuo-spatial information is supported by independent components. For example, interference tasks targeted at disrupting suggested rehearsal mechanisms have shown selective impairment whereby repeated articulation of words disrupts memory for serial verbal information while showing no effect on recall of serial visuo-spatial material; the reverse pattern is found when repeated movements to targeted locations is employed - suppression of the visuo-spatial rehearsal system is shown while serial recall of verbal items is unaffected (Smyth, Pearson & Pendleton, 1988; Smyth & Scholey 1994a; Pickering, Gathercole, Hall & Lloyd, 2001; Pearson & Sahraie, 2003; Vandierendonck, Kemps, Fastame & Szmalec, 2004; Logie & Vecchi 2006; Alloway, Kerr & Langheinrich, 2010, though see Jones, Farrand, Stuart & Morris, 1995). Such selective interference from articulatory and spatial tapping suppression has also been demonstrated for verbal and spatial reasoning tasks (Farmer, Berman & Fletcher, 1986) and for remembering a series of letters versus generating a mental image of a path through a matrix (Logie, Zucco & Baddeley, 1990; Salway & Logie, 1995). The ability to successfully perform two memory tasks corresponding to the verbal and visuo-spatial domain respectively, with little decrement as compared to when each task is performed alone, provides further support for dissociable verbal and visuo-spatial systems (e.g. Cocchini, Logie, Della Sala, MacPherson & Baddeley, 2002). Moreover, a recent study has demonstrated the concurrent use of separable visual and verbal codes supporting short term storage of the same memory items (Saito, Logie, Morita & Law, 2008), although this remains a topic of debate (Depoorter & Vandierendonck, 2009).

Visuo-spatial working memory (VSWM)

A number of disparate paradigms have been used to investigate visuo-spatial working memory. While the majority of interference studies mentioned directly above have shown domain specific retention and rehearsal resources, early experiments influencing model development often required participants to generate and manipulate mental images in the visuo-spatial domain in comparison to retention tasks in the verbal domain (for a review see e.g. Pearson, 2001). This approach was reflected in changeable emphasis of the visuo-spatial slave system as more visual or more spatial in nature. For example, Baddeley and Lieberman (1980) employed tasks in which

participants were required to generate a mental path through an unseen matrix on the basis of verbal instructions, to remember a series of items by association with imagined locations in a mental path or to remember a series of words through association with visual mental images. Comparison of the relative disruption of these three tasks by a (non-visual) spatial tracking task, which had disrupted visuo-spatial but not verbal tasks, revealed that associations based on visual mental images were less susceptible to interference. As a result, the spatial nature of the visuo-spatial system was emphasised. Subsequent research (Logie, 1986), however, showed that memory for words in association with an image was disrupted more by a visual matching task and presentation of irrelevant visual images, than was a verbal rehearsal task. Conversely, verbal rehearsal was affected more by presentation of irrelevant speech than irrelevant images. Such results highlighted the need to account for visual information within the visuo-spatial sketchpad. The concept of a visuo-spatial system has progressed in this manner from a visuo-spatial store (Baddeley & Hitch, 1974) to a spatial rehearsal dominant system (Baddeley, 1986) to a visuo-spatial rehearsal mechanism responsible for both visual and spatial material. While Baddeley (1986) proposed a possibly perceptually based store and a rehearsal mechanism which might employ eye movement or attention mechanisms, the visuo-spatial component remained underspecified.

Appearance and location.

One line of research into the possible functional organisation of VSWM assesses memory for the appearance of a visually presented stimulus and memory for the location of a presented stimulus. Such experiments have found evidence that memory for appearance can function under interference considered spatial in nature, while interference considered visual in nature impairs performance. The opposite is true for memory for location information. For example, Tresch, Sinnamon and Seamon (1993) found that memory for single geometric forms was impaired when a colour discrimination task was to be performed during a retention interval, yet performance of a movement discrimination task showed little effect in comparison. Memory for a single dot location was conversely impaired by performance of the movement discrimination task yet unaffected by the colour discrimination task. Klauer and Zhao (2004) replicated this dissociation with memory for Chinese ideographs in place of geometric forms, and further revealed that this interference was not due to perceptual

masking effects or to differential performance of interference tasks (e.g. abandoning colour discrimination requirements to maintain location information). Neuropsychological data is also available suggesting this dissociation – for example, Darling, Della Sala, Logie and Cantagallo (2006) report two brain injured patients who show opposite patterns of impairment. Patient A was impaired when memory for the location of a single letter presented within an array was tested after a fifteen second delay interval compared to when performed immediately. This delay did not, however, affect performance when appearance of the letter presented (size and font of an otherwise constant letter) was tested. In contrast, patient B was impaired by an interpolated delay when tested for appearance information but not location information. The drop in performance observed in each selectively impaired condition was significantly different from that observed in both healthy and brain injured control groups.

Neuroanatomical studies employing Positron Emission Topography (PET) and Functional Magnetic Resonance Imaging (fMRI) techniques have, in a number of cases, focused on investigating an account in which organisation of perceptual systems is mirrored in frontal cortex supporting maintenance of object identity and location in VSWM (e.g. Courtney, Petit, Maisog, Ungerleider & Haxby, 1998; Courtney, Ungerleider, Keil & Haxby, 1996; Haxby, Pitt, Ungerleider & Courtney, 2000; McCarthy et al., 1996). Process specific organisation rather than domain specific organisation of the frontal cortex (Petrides, 1995; Kessels, Postma, Wijnalda & de Haan, 2000; Owen, 1997; Owen et al., 1998; D’Esposito & Postle, 1999; Postle & D’Esposito, 2000), with the possibility of secondary specialisation according to modality of information, or with equivalent links to modality specific posterior cortex, has since been proposed (though see Courtney, 2004). As pointed out by Della Sala and Logie (2002), however, object *identity* is not necessarily an attribute of VSWM – rather, only the *appearance* of an item falls within the larger agreement in cognitive psychology as to what constitutes retained visual information (i.e. the visual properties of an image).

The development of VSWM has been much informed by the investigation of dissociable resources supporting item appearance versus location retention. The present thesis, however, is concerned with a possible dissociation of resources as produced on the basis of a particular task property – that of presentation. More specifically, the evidence reviewed concerns the influence of presentation on memory for location of largely uniform, characterless stimuli. Consequently, the mechanisms by which specific objects are associated with specific positions will not be addressed (for

early discussions on this issue see e.g. Postma & De Haan, 1996; Zimmer, Speiser & Seidler, 2003); only specific studies concerning memory for item appearance information will be discussed where pertinent. A recent review of the literature on how varied features (e.g. shape, size, colour, location) of a stimulus are represented for an item can be found in Jiang, Makovski and Shim (2009). Additionally, recent discussion on this issue from the perspective of the most prominent model (Logie, 1995; 2003) featured in this thesis can be found in Logie and van der Meulen (2009). Of note, the importance of considering presentation, as discussed in the current thesis, has recently been recognised within the aforementioned binding literature (e.g. Allen, Baddeley & Hitch, 2006; Blalock & Clegg, 2010).

Fractionation of visuo-spatial working memory

The first detailed conception of the visuo-spatial system (Logie, 1995) was proposed within the framework of the working memory multiple component model (Baddeley & Hitch, 1974; Baddeley, 1986). Architecture functionally analogous to that demonstrated in the phonological system (see e.g. Baddeley, 2007 for a recent review) was proposed: storage and rehearsal functions which can act in concert or largely independently of each other. A so-called visual cache was postulated as a passive store to retain visual information which was supported by the rehearsal function in the manner of refreshing information; the rehearsal function itself – termed the inner scribe – was proposed both as the component responsible for maintaining sequence properties of visual information and as a means of representing visuo-spatial information which involves movement or changing properties. The extent to which a process or operation within the system would be involved in task performance was posited as dependent on the characteristics of the task the system is undertaking: “when ... long-term memory representations are activated, the information enters the visual or the spatial part of the system. Which system it enters is determined by the nature of the information activated” (Logie 1995, p126). As this description implies, all information represented in working memory was considered to have passed through long term memory before being registered by the cache or the scribe; in contrast to previous conceptualisations of working memory (e.g. Baddeley & Hitch, 1974; Baddeley, 1986) Logie rejected the idea of direct access of perceptual information to the system (e.g. Logie, 1995; 2003; Logie & van der Meulen, 2009).

Involvement of general purpose resources in the form of the central executive was proposed as minimal, dependent on task demands (difficulty) rather than task construction or task properties, and equally unlikely to be used for predominantly 'visual' or predominantly 'spatial' tasks (Logie, 1995). A fourth, less specified, feature was suggested as a means by which conscious images are represented. Termed as a buffer, it was suggested that this could provide a workspace within which visual images could be manipulated by the central executive. However, this buffer was not explicitly included in the model.

The initial model of working memory (Baddeley & Hitch, 1974) entertained the idea that central executive resources could be flexibly allocated between processing and storage; refinement of the role of the executive system conceptualised a component (possibly comprising a number of control processes) which was not endowed with storage capability (Baddeley & Logie, 1999). Central executive input in short term *memory* tasks was therefore thought to be in the form of initiation and operation of strategies for encoding and retrieval, activation of representations from long term memory, and focusing and switching of attention (Baddeley & Logie, 1999). Maintenance within the visuo-spatial slave system (Logie, 1995) was thought to be comparable to that postulated in the phonological system, with the stores and rehearsal functions of each system operating under only minimal governance from the central executive. That is, while executive resources might be employed in encoding, and in initiating subsequent rehearsal, processes constituting rehearsal were considered autonomous. Processing and manipulation of information in a task requiring more than simply retention would employ central executive resources to a much greater degree, with the slave systems acting as support for on-line processing (Logie, 1995; Logie, 2003).

A number of modifications to the above model have subsequently been proposed. Baddeley (2007; Repovs & Baddeley, 2006) has suggested there may be independent stores, with complementary rehearsal mechanisms, for visual and spatial information respectively. Baddeley (2000; 2001) also proposed a fourth component in revision of the original tripartite model (Baddeley & Hitch, 1974; Baddeley, 1986) of working memory - the episodic buffer, which is considered responsible for maintaining multimodal information and is accessible by conscious awareness (see e.g. Baddeley, 2007). The introduction of the episodic buffer, however, again introduced a storage system tightly linked with the resource capacity of the central executive (Repovs & Baddeley, 2006) which diverges again from the model of Logie (1995; 2003; Logie &

van der Meulen, 2009). Of note, visual storage and rehearsal processes were suggested (Repovs & Baddeley, 2006) as possibly more closely linked to this episodic buffer than their respective spatial counterparts.

Pearson (2001) also proposed a distinct separation between maintenance of visual and spatial information; under this model the inner scribe is separate from the visual cache, and both are accessible by the central executive. The visual cache was suggested as possessing its own rehearsal functions, though this was tentative. The interaction of material otherwise held in the visual cache and the functions of the inner scribe occurs only within an additionally proposed component, the visual buffer. The visual buffer (after Kosslyn, 1980, 1994 as cited in Pearson, 2001) was considered a component in which conscious mental images were held; the capacity of the visual buffer was only one single image, and the manipulation of information therein was carried out by the inner scribe. Of particular note in this model therefore, the inner scribe does not maintain any information other than that considered spatial; *maintenance* of visual information in the visual buffer is supported by central executive resources. As proposed by Logie (1995), Pearson (2001) considered storage of items in the visual cache as impervious to irrelevant perceptual input; however, Pearson (2001) explicitly proposes perceptual access to the images held in the visual buffer. Quinn and McConnell (2006; Quinn, 2008; after McConnell and Quinn, 2000) support the concept of maintenance of a conscious visual image in a buffer as distinct from the retention of visual information not in conscious awareness. The format and mechanisms that support visual information outside of conscious awareness are not, however, necessarily aligned with the concept of short term retention in the visual cache (see Quinn, 2008).

Visuo-spatial working memory: dissociation in performance of pattern and sequence recall.

Memory for the proportion of filled and unfilled squares in a viewed matrix, presented as one image, has long been considered a 'visual' memory task (e.g. Phillips, 1974; Phillips & Christie, 1977a,b). A second frequently employed test of nonverbal memory - the Corsi blocks task (CBT; Milner, 1971) - has been used as a measure of visuo-spatial ability or short term memory capability in both developmental and neuropsychological assessment. CBT also features heavily in cognitive and experimental psychology studies (e.g., see Berch, Krikorian & Huha, 1998 and Fischer,

2001 for early reviews). In Corsi blocks performance participants are faced with a fixed array of nine irregularly arranged cubes and sequences of increasing length are tapped out by the experimenter (at a rate of one per second). The participant must then reproduce this sequence. In the context of the recently developed model of Logie (1995), Logie and Pearson (1997) sought to investigate whether completion of these two tasks reflected the operation of a unitary VSWM system or whether there was a suggestion of dissociable resources supporting matrix pattern and CBT performance.

Logie and Pearson (1997) assessed memory for matrix patterns in a study with children spanning three age groups (5-6, 8-9 and 11-12 years); Corsi blocks performance was also assessed. The test of memory for visual patterns was equivalent to that of a then recently standardised Visual Patterns Test (VPT; Della Sala, Gray, Baddeley & Wilson, 1997) which requires participants view and subsequently reproduce matrix compositions. Matrices comprised an even number of squares, fifty percent of which are 'filled' (i.e. shaded). Filled squares were to be replicated at recall, with participants marking the required squares in an empty grid equivalent to the size and dimensions of the presentation matrix (e.g. a two by three or a four by five grid, as befitting the initial stimuli). Difficulty of task was increased from level to level by the addition of two squares to the previous matrix grid – one of these squares was filled and the other empty (thus an equal number of filled and unfilled squares on each trial was retained). Logie and Pearson (1997) had participants perform at each level of recall three times until patterns could no longer be recalled correctly in two out of three of the trials. Span was determined by taking a mean from the last three trials in which all cells in a matrix were correctly reproduced. CBT performance was assessed using a similar span measure – CBT task difficulty was increased by including one more block in a to-be-remembered sequence; participants were required to perform each level of difficulty three times and span was determined as mean of the last three correctly recalled sequences before two out of three sequences could not be recalled. Logie and Pearson (1997) also employed recognition measures of these tasks which required that the children identify the 'missing square' in a re-presented pattern (VPT) and a re-presented series of blocks (CBT). In both recognition and recall versions of VPT and CBT, higher performance was found in the patterns test than in Corsi blocks – of specific importance, this disparity was found to increase with age group, reflecting a steeper increase in pattern memory performance. Such a demonstration of separate developmental trajectories for performance in these tasks suggests operation of a non-unitary system (developmental fractionation, after Hitch, 1990). Logie and Pearson

(1997) further demonstrated the extent of disconnect between VPT and CBT performance by revealing that – in both recall and recognition conditions – these spans frequently did not correlate within age groups. In comparison, despite the differences in response requirements, recall and recognition versions of CBT did correlate significantly with each other (in all but the youngest group) as did recall and recognition versions of VPT. Taken together, these results question the possibility that the primary cognitive processes which underlie VPT and CBT performance are shared between the two tasks – rather, it is suggested the main determinants of respective performances constitute separable components.

Pickering, Gathercole, Hall and Lloyd (2001) report results comparable to those of Logie and Pearson (1997) when testing children of 5, 8 and 10 years of age. Recall was tested for half filled matrices which were presented and reproduced as in the VPT and recall of the same matrix information in a task more akin to the CBT – that is, sequential presentation of items and reproduction of the same sequence at test. Pickering et al. found that VPT performance was higher than that in the sequentially presented-serially recalled version for each age group tested, moreover, this difference increased with age; VPT performance increased more rapidly between the age groups than did the sequential-serial version of the task. Zoelch and Schumann-Hengsteler (2006) also recently reported of different patterns of development in VPT and CBT performance in this age group. Krikorian, Bartok and Gay (1996) employed CBT and introduced a measure of memory for simultaneously presented locations within a matrix termed the Configural Attention Test. This latter task required participants to view a five by five grid - a number of cells of which contained black circles. Participants were to reproduce the filled matrix after five seconds, and level of difficulty of memory load corresponded to the number of dots to remember. Krikorian et al. assessed performance in children (7-14 years) and young adults (mean age 21 years) and revealed through multiple regression analysis that once variance associated with effects of age and with performance in a verbal ability test were accounted for, CBT performance only accounted for 13% of the variance in Configural Attention performance. Krikorian et al. point out that around 35% of Configural Attention performance remained unexplained and proposed it is precisely the configural nature of the task that renders it subserved by resources unshared with the other tasks tested (a receptive vocabulary test, CBT and digit recall).

Della Sala and colleagues (Della Sala, Gray, Baddeley, Allamano & Wilson, 1999) provided further evidence of fractionation within VSWM for resources supporting VPT

and CBT performance. The authors demonstrated this as a robust dissociation using three lines of investigation – correlations, neuropsychological evidence and interference studies. Significantly lower correlations between CBT and VPT performance than between two versions of the VPT were found for healthy participants. This significant difference was replicated using performance measures from 45 brain-damaged participants (group comprising right, left and bi-lateral hemisphere lesion patients). Such results suggest that the CBT and VPT are either measuring two different abilities or are two tasks which engage one or more separate abilities, in addition to a common ability.

The utility of VPT and CBT comparison was further supported by a double dissociation (after Shallice, 1988) of performance ability demonstrated through three patients from the larger patient sample of Della Sala et al. (1999). Two patients were found to perform below the fifth percentile in CBT while performing above the median score in the VPT, a third patient showed the opposite pattern of impairment and preservation – performing above the median in CBT yet below cut off in the VPT. This finding again suggests that abilities measured are not entirely common to both tasks and extends a previous report (Grossi et al., 1993) of two patients with Alzheimer's disease who exhibited contrasting selective impairment (poor performance on one task while within normal range performance on the other) in CBT and recall of patterns in a matrix. As concluded by Della Sala et al. (1999), two opposing demonstrations of intact or better than average ability in one task concurrent with severe impairment in a second task provides substantial evidence that performance in the two tasks is not supported by entirely the same resources.

Della Sala et al. (1999) subsequently employed interference task methodology using a healthy, young adult population. Visual interference in the form of viewing an abstract image – one of a number of colourful paintings, which were considered resistant to verbal coding - was employed per trial whereby participants were to look at, but not attend to, the image. Spatial interference was adapted from that used in previous studies (Smyth et al., 1988; Smyth & Pendleton, 1989) requiring participants to continually move their hand around four fixed locations (marked by pegs) without visual guidance. Participants' spans on each of the memory tasks - as performed with a 10 second delay between presentation and recall - was first determined, then performance levels on the same tasks were assessed when interference tasks were inserted in the delay period. It was observed that visual interference impaired VPT

performance more than did the spatial interference task, and spatial tapping impaired CBT more than did viewing irrelevant images.

Della Sala et al. (1999) concluded that the above findings are informative of abilities measured in the tasks to the extent that the observation “suggests...that the principal components of performance on non-verbal short-term memory tests have been identified” (p1197, Della Sala et al., 1999). Specifically, VPT performance was emphasised as supported more by visual working memory than is CBT, with minimal spatio-sequential involvement. In the model of Logie (1995; 2003) memory for VPT images – that is, memory for a statically presented image – has been suggested as supported primarily by the visual cache; CBT performance – incorporating dynamic presentation and temporal information in the form of retaining sequences - would be considered as supported primarily by the inner scribe. The alternative proposal of Baddeley (2007; Repovs & Baddeley, 2006), whereby retention of visual and spatial information is considered separate and supported by separable rehearsal mechanisms, also attributes VPT performance to the visual system and CBT performance to the spatial system. The basis for this dissociation, however, is based on conceptualising memory of a filled and unfilled matrix as pattern memory, which falls under memory for appearance of an image, and CBT is attributed to the spatial system due to requirements to remember location information (e.g. Repovs & Baddeley, 2006, p8; Baddeley, 2007, p10, p63-83). The distinct visual and spatial components proposal of Pearson (2001) attributes retention of cells in a matrix, when held in a static format, to a visual retention store (e.g. Pearson, 2001, p51-53) while CBT would fall under the inner scribe function of rehearsal of spatial sequences. As will be discussed, there is also an increase in research concerned with executive resource contributions to CBT performance which has been taken to undermine the need to account for ‘spatial’ resources in a CBT task (e.g. Holmes, Gathercole & Dunning, 2009; Quinn, 2008).

Consideration of presentation differences.

A number of procedural and task requirement differences exist between Corsi block and Visual Patterns tasks (Rudkin, Pearson & Logie, 2007; Pickering, 2001; Pickering et al., 2001; Della Sala et al., 1999). CBT requires participants to maintain order of a series of presented blocks, while VPT requires memory for information presented in one image. In CBT the array used for presentation and recall is constant for all spans – that is, blocks stay in the same place and are of the same number

throughout all trials and levels of a task. This means that the proportion of relevant to irrelevant stimuli in a task changes as a function of level of difficulty, and high numbers of irrelevant stimuli could be detrimental to performance of early sequences. Additionally, this point also highlights that matrix pattern performance is based on a constantly changing structure (due to increasing array size in relation to increasing difficulty), which Rudkin et al. (2007) suggest may influence the way in which participants approach encoding information. A further issue for consideration when comparing matrix pattern and CBT performance relates to method of recall – specifically, differing response requirements. Marking all recall locations on a single matrix response grid in the VPT could enable participants to rely on this visual aid to chart their progress in a given recall situation so that they need not mentally keep track of what items they have and have not yet recalled. In CBT, however, performance requires participants to mentally keep track, during output, of both recalled and to-be-recalled items. Moreover, CBT entails viewing items presented in three dimensional space and subsequently requires motor responses targeted to locations within this space; VPT presentation and response requirements use largely two dimensional space – motor response at recall is minimal with only the requirement to shade target squares on a sheet of paper.

Pickering (2001; Pickering et al., 2001) proposed that the important attribute on which these two tasks differ is the manner of presentation – specifically, that presentation of VPT stimuli is static whereas that of Corsi blocks stimuli is dynamic. CBT presentation, in which an experimenter traditionally taps out a series of locations, could be considered as presenting paths of movement that are progressively built up in view of the participant. Evidence for this interpretation was provided through the demonstration of different developmental patterns for static and for dynamic information. Children of 5, 8 and 10 years of age performed two versions of a task in which paths through a visually presented, two-dimensional maze were to be memorised; paths were either pre-drawn when children viewed them, or were traced through the maze in view of the child (using a finger, leaving no mark on the page). Increase in difficulty level was manipulated by adding further partitions to navigate and in both conditions children were to immediately draw the route from memory. Performance was better in the static condition for all but the youngest group, and the difference between static and dynamic recall increased with age.

A related yet distinct conceptualisation of VSWM (Cattaneo, Fastame, Vecchi & Cornoldi, 2006; Cornoldi & Vecchi, 2003 after Pazzaglia & Cornoldi, 1999) details a

system in which properties of tasks would invoke varying degrees of active or passive processes (posited as a vertical continuum) and visual, spatial-simultaneous and spatial-sequential tasks could be associated with distinct processing (horizontal continuum). The extent to which processes for visual, spatial-simultaneous and spatial-sequential tasks are separate, rather than the same process being used with different materials, is represented in a conical structure. This structure illustrates that at a passive, and perhaps primitive, level of dealing with information, processing may be functionally separate. The way in which information is managed in the system will be progressively indistinguishable when requirements of a task are more active, requiring 'higher level' processing. The degree to which a task is considered active or passive should not, however, be conflated with degree of difficulty (e.g. Cornoldi, Rigoni, Venneri & Vecchi, 2000) – rather, position on this axis relates to extent of control and manipulation of information required to complete the task. With regard to the specific issue of maintenance and rehearsal information, the authors suggest “a general rehearsing capacity might combine with different material (e.g. verbal, visual, spatial) to give rise to similar, but peculiar and specific, processes” (Cornoldi & Vecchi, 2003, p123). It is important to note that, by this model, rehearsal or immediate maintenance of information without transformation is thought to be a passive and low-level activity task. The aforementioned VPT and CBT are both considered passive tasks, of the spatial-simultaneous and spatial-sequential class respectively.

In an individual differences study with children (mean age 8.5 years), Mammarella, Pazzaglia and Cornoldi (2008) employed a battery of tests constructed and detailed in Mammarella, Pazzaglia and Cornoldi (2006). This battery comprised 13 tests which were termed visual, spatial-simultaneous, spatial-sequential and verbal, as determined by the properties of stimuli and presentation methods of each task. The three verbal tasks were forward and backward digit recall and forward recall of sequences of syllables. Three visual tasks required memory for visual appearance (two of which were recognition of item tests), four spatial-simultaneous tasks required memory for statically presented location information (three of which employed reconstruction of otherwise featureless arrays: VPT, static maze and dot array tasks), and three spatial-sequential tasks required memory for dynamically presented location information (two of which were reconstruction of order of location for featureless stimuli: CBT and path traced through a maze). The three of the 13 tasks not listed above - one visual, one spatial-simultaneous and one spatial-sequential - were considered active tasks; in comparison to the other tasks described which required

straightforward reproduction of previously seen information, the active tasks required manipulation of the information presented. This was in the form of mentally rearranging presented information to create a unified, meaningful whole (visual), translating the array presented to a different position within a matrix (spatial-simultaneous), and mentally generating a path through a maze on the basis of verbal description (spatial-sequential). Each task was scored representing each participant's maximum span level (the last three successful trials before being unable to respond correctly in two out of three trials) and performance was analysed using a series of structural equation models. The best representation of the data was found to be a model which attributed performance on each of the above classifications of tasks to respective factors – that is, a verbal, a spatial-sequential, a spatial-simultaneous, a visual and an active factor. This final model was preferable to any other fit tested including a tripartite model structure (a verbal, a visual-spatial factor and an active factor corresponding to executive involvement, after Baddeley, 1986) and models which included divisions on the basis of visual as distinct from spatial, or static (collapsed across visual and spatial-simultaneous) as distinct from dynamic¹. In consideration of tasks used, it could be argued that the active tasks required imagery processes and hence could be distinguishable on the basis of imagery processes rather than on the basis of passive versus active distinctions, however, a more general interpretation of a manipulated or controlled construction of an image could be applied.

The argument for presence of processes specific to verbal, visual, spatial-simultaneous and spatial-sequential task performance (Mammarella, Pazzaglia et al., 2008; Cornoldi & Vecchi, 2003) is supported by a number of studies conducted on participants and populations who have been found to exhibit deficits in one of these classifications while demonstrating relatively preserved ability in one or all of the other tasks tested. For example, Lafranchi, Carretti, Spanò and Cornoldi (2009) compared visuo-spatial performance in a group of children with Down Syndrome (mean age 12.5 years) and a group of typically developing children (mean age 4.5 years) matched for receptive vocabulary and Raven's coloured matrices performance. An impairment in spatial-simultaneous, but not in spatial-sequential, recall was evident in the children

¹ It should be noted that in these visual versus spatial and static versus dynamic divisions of the visuo-spatial tasks symbol reproduction is attributed to spatial and dynamic factors respectively, presumably on the basis of requirements for maintaining serial order. In the chosen model, however, serial symbol reproduction is attributed to a visual factor, presumably on the basis of requiring appearance memory.

with Down Syndrome relative to the matched controls. Furthermore, this pattern of performance held true when visually presented processing speed measures were used to factor out processing speed differences; this indicates that the impairment in spatial-simultaneous performance was not due to an inability to encode information quickly enough, rather it is apparently due to the nature of presentation of information. Mammarella, Coltri, Lucangeli and Cornoldi (2009) present a case study of a child B.A. (age 11) with a Nonverbal Learning Disability which is distinguished by impaired visuo-spatial abilities yet comparatively preserved verbal abilities, including impaired VSWM with comparatively unimpaired verbal recall performance. B.A. was tested on three visual identity, three spatial-simultaneous and three spatial-sequential recognition tasks. The spatial tasks used the same stimuli across presentation methods, differing only in format of presentation and the additional requirement of memory for order in spatial-sequential presentation. Performance was significantly impaired in two of the three spatial-simultaneous tasks relative to normative data established for these tasks (Mammarella, Toso, Pazzaglia & Cornoldi, 2008) while performance on all other tasks was not significantly below normal performance. Mammarella et al. (2006) also reported two children – L.P. (age 11 years) and F.S. (age 8 years) - with Nonverbal Learning Disability who performed at a level of, or worse than, 1.5 SD below mean normative performance on two out of four (L.P) and three out of four (F.S) spatial-simultaneous tasks. This impairment is in contrast to performance within the normal range (L.P.) or which was not impaired to the same extent (F.S.) in visual and spatial-sequential tasks. A third child B.L. (age 12 years) demonstrated a reversed pattern of impairment; B.L produced performance more than 1.5 SD below the normative mean in two out of three spatial sequential tasks yet displayed only slight impairment in spatial-simultaneous tasks. A third division of performance was demonstrated (Mammarella, Cornoldi & Donadello, 2003) in a comparison between a group of children with Spina Bifida and an age matched group of typically developing controls: impairment in a task requiring visual recall of items presented amongst distractors was evident in the group of children with Spina Bifida compared to the control group, however, no difference in VPT or CBT (forward or backward) performance was observed between the groups. This pattern of results held true when analysis controlled for the disparity in I.Q. between the two groups. Taken together these results of impairment in one task with comparative preserved ability in other tasks tested (Lafranchi et al., 2009; Mammarella et al., 2003; Mammarella et al., 2006; Mammarella et al., 2009) are framed as double dissociations (though see Shallice, 1988) within VSWM between processes required for

each of the material and presentation categories investigated: visual, spatial-simultaneous and spatial-sequential.

A recent interference study by Darling, Della Sala and Logie (2009) addressed both the possibility of dissociation in performance on the basis of appearance and location of item information as well as the possibility of dissociation in performance on the basis of presentation. Participants were required to remember either the appearance (font) or location of a variety of letter 'P' stimuli which were displayed within a complex array of 30 randomly arranged squares; of note, participants knew for each trial which aspect they would be tested on and therefore did not need to retain appearance information in location trials nor location information in appearance trials. Items were either presented all at once (simultaneous, four items used) or one after the other (sequential, three items used); the sequential condition contained no requirement for order memory as all items were presented for recognition judgement in a simultaneous format. In interference conditions either dynamic visual noise (DVN; Quinn and McConnell, 1996a) or complex spatial tapping (a specific pattern within a three by three array) were performed during a ten second retention interval. Use of dynamic visual noise involves participants passively viewing a rapidly changing array of black and white dots, which has been found to disrupt the generation and manipulation of conscious visual images (for a review see e.g. Quinn, 2008). While Darling et al. found that DVN affected appearance memory more than tapping did, and location memory was affected more by tapping than by DVN, there was no evidence of an interaction on the basis of presentation condition and interference task – nor was there a three way interaction of presentation, appearance versus location and interference. Despite the lack of indication of differing maintenance on the basis of presentation in this recent study, as Dent (2010) highlights, effects of DVN on retention are currently characterised by, at best, impairing (possibly fine grained) detail and vividness of appearance of stimuli (Andrade, Kemps, Werniers, May & Szmalec, 2002; Quinn & McConnell, 2006). Dent (2010) for example, found DVN to affect the retention of exact colour identification of a single dot yet found no effect of DVN on retention of four simultaneously presented spatial locations (identified by identical dots) in conditions of either recognition of locations or reproduction of positions. The latter measure incorporated analysis of distance of reproduction from presented locations, giving a sensitive measure of precision of memory representations. As in Darling et al. (2009) Dent (2010) found no evidence that DVN affects retention of positional information. Pearson and Sahraie (2003) also found no effect of visual noise on

retention of a sequence of locations in a computerised CBT procedure. The use of DVN for investigating presentation differences as pertaining to location information is therefore limited.

On encoding simultaneous and sequential presentation.

An assessment of the influence of presentation was conducted by Lecerf and de Ribaupierre (2005). Using a recognition procedure, presentation format was manipulated both at presentation and, independently, at test. Two variations of to-be-remembered information were compared for cells occupied within a matrix grid: simultaneous and sequential (only one highlighted cell shown at once) presentation. Recognition performance was higher, and faster, for simultaneous compared to sequential presentation when information was shown simultaneously at test – that is, as a pattern. In a second experiment where test was via a single probe cell which participants had to identify as part of initial stimuli or not, judgement was again found to be more accurate for information which had been presented in a simultaneous format compared to that which had been sequentially presented. Simultaneous presentation did not, however, produce higher performance than a third format: ordered sequential presentation (where highlighted cells were shown in a left-to-right, top-to-bottom order). While, in the first experiment, sequential presentation had shown slowed reaction time with increasing number of to-be-remembered cells and simultaneous presentation had not, this trend was evident in both simultaneous and ordered sequential formats in the second experiment. Moreover, when test was by a single probe item, reaction time was found to be faster in the condition where stimuli had been sequentially presented compared to when it had been presented in a simultaneous format (ordered sequential presentation did not differ from either of the other conditions). The results were interpreted within proposed limits and opportunities available to encoding on the basis of presentation; Lecerf and de Ribaupierre (2005) suggest simultaneous presentation enables three methods of encoding while sequential presentation largely only enables two. Presentation of visual stimuli will, in both cases, allow *extrafigural* encoding of each individual location – that is, encoding with respect to surrounding reference frames (e.g. the computer screen). Sequential presentation creates *path* encoding – links between items are mentally formed, possibly represented as spatio-temporal associations. Simultaneous

presentation can enable endogenously generated as opposed to externally dictated path encoding, moreover, simultaneous presentation is proposed to benefit from *pattern* encoding – configural representation of multiple locations as a single form. *Path* and *pattern* encoding are termed *intrafigural*, and it is proposed that all forms of encoding can act in isolation (e.g. that a path is often represented without being based upon a pattern). The results detailed suggest extrafigural and pattern encoding are the predominant contributors to simultaneously presented information, creating a stable, accurate representation against which the pattern shown at test is evaluated. In comparison, sequential presentation – in which a path through locations is created, and possibly anchored in respect to external frames of reference – makes it difficult to compare presented information with whole pattern presentation at test; the time taken to perform this task increases with the number of individual locations which must be searched through in order to determine whether one of the cells has been changed. In the second experiment, where a single probe item is used, the pattern representation of simultaneous presentation must be broken down in order to compare individual cells which constitute the whole. This takes an increasingly longer time with more elements; high accuracy is maintained, however, reflecting the stability of the intrafigural pattern encoding. Sequential presentation enables quicker comparison of individual items as no ‘whole’ is held, however, accuracy is lower than that of simultaneous presentation suggesting path encoding is not enough to enable fine grained location information. Ordered sequential presentation suggests flexibility in the system; extrafigural and efficient path encoding will be enabled, moreover, it is possible that the structured order of items enables pattern encoding to be built up. The accuracy displayed in the second experiment for ordered sequential presentation supports this idea. Finally, an explicit comparison is made whereby Lecerf and de Ribaupierre (2005) propose the encoding afforded by simultaneous and sequential presentations would engage the visual cache and inner scribe of Logie’s (1995) model, respectively.

With respect to sequences only, further studies examined the extent to which presented locations are tied to absolute coordinates (determined relative to extrinsic reference frames, on the basis of egocentric or surrounding environment detail) or are processed in association with other items such that location is determined relative to other display stimuli (Avons & Trew, 2006; Avons, 2007). Avons and Trew (2006) found that movement of a computerised corsi array –where arrangement of blocks is maintained and the whole template moves as one – in each inter-stimulus interval at presentation caused sequences of seven items to be more poorly recalled than when

arrays were stationary throughout presentation. Movement of the template array between each response at recall did not, however, disrupt performance when presentation array had been constant at presentation; movement of array throughout a retention interval caused only a small, non-significant impairment. It was thus concluded that while extrinsic encoding appears to contribute to encoding sequential stimuli – such that positional information encoded when the array was in different locations does not enable accurate recall – subsequent representation of information at test, and possibly during retention, is based more on what Avons and Trew (2006; Avons, 2007) term *template centred* representations. This representation holds positional information as relative to either the array or other items presented, therefore movement of the template at recall does not disrupt performance due to the ability to shift whole array representations to match the new array position. Avons (2007) further assessed the contribution of extrinsic positional information. In two experiments, shifting of array at presentation matched shifting of array at test within a given trial. It was found that repetition of sequences of locations across trials in an experiment did not benefit performance when this repetition was on the basis of absolute coordinates (and so the relative items within a template were not repeated across trials; Experiment 3). Repetition across trials of sequences of locations within a template, however, quickly produced improved and then ceiling performance (despite these locations differing in absolute coordinates across trials; Experiment 4). Emphasis is therefore placed on intrinsic, template centred representation of sequences of locations. It is possible that the previously described detrimental effect observed for array movement during encoding, when test arrays are held still, is due to poor encoding of visual information as a result of eye movement; it appears any impediment of this sort to encoding is counteracted by repetition of sequences within an array. Further factors have also been found to affect adoption of a reference frame including the proximity or size and stationary or moving nature of possible available templates, as well as initial strategy choice (Avons & Oswald, 2008).

There is thus mounting evidence that a series of locations are represented not simply as single discrete items tied only to absolute coordinates, rather, in relation to the display in which they are presented (Avons & Trew, 2006, Avons, 2007) and in relation to other locations in the sequence (Lecerf & de Ribaupierre, 2005). In a complementary line of enquiry, long held divisions of complexity pertaining to visual arrays have been identified in their relevance to visuo-spatial sequence recall. Moreover, the consideration of complexity has been extended to the structure of paths

created by successive items in a sequence, highlighting the consequences to encoding and recall when information is provided in a consecutive, dictated manner (e.g. Kemps, 1999, 2001).

Memory for simultaneous presentation affected by array complexity.

Pattern complexity has been identified as defined through both the number and the organisation of elements constituting the pattern (see e.g. Chipman, 1977; Ichikawa, 1985). As with perceptual organisation, internal redundancy (see Attneave, 1954) benefits memory such that patterns with the same number of individual items are better remembered when organised according to good gestalt principles (see e.g. Attneave, 1955). Such pattern construction includes incorporating symmetry or repetition of elements, thereby creating redundancy and reduced potential memory load. Within working memory literature complexity of static, visually presented location information has largely been manipulated through the former, quantitative factor. An increase in memory load for a matrix task, for example, is made by addition of cells which make up the to-be-remembered stimuli (e.g. Phillips, 1974; Logie, et al., 1990; Wilson, Scott & Power, 1987). Recently, however, Zoelch and Schumann-Hengsteler (2006) reported beneficial effects of reduced complexity in matrix recall for patterns of equal number of cells, with complexity manipulated through presence of pattern symmetry and amenability to unified configuration.

Memory for sequences affected by presentation array.

The unintentional variability in sequence - specifically, CBT - administration has previously been noted and cautioned against (e.g. Fischer, 2001; Berch et al, 1998). Increased path length - as defined by number of items - has been shown to negatively affect performance, while increased encoding time (three seconds compared to one second) can lead to improved performance (Fischer, 2001). Further to these somewhat intuitive findings, structure of presentation array, composition of path - that is, the structure of a path generated by the successive locations of a sequence - and characteristics of a sequence that emerge from a combination of these two factors, have all been shown to affect recall performance. Smirni, Villardita and Zappala (1983) provided early evidence that sequences comprising the same number of elements but a varied composition can produce differential recall.

Kemps (1999) revealed effects of *array* complexity on serial recall of block locations, when manipulating both quantitative and structural factors. Increase in the number of blocks present in an array was found to produce poorer performance (see also e.g. Smyth & Scholey, 1994 a, Experiment 3; Logie & Vecchi, 2006). Kemps (1999) also found uniformity of structure – such as that present in a $n \times n$ matrix - produced better recall performance than either semi-structured or random arrays for arrays comprising both nine and 16 blocks. When arrays consisted of 25 blocks, however, this difference was no longer present - suggesting that at a certain level quantitative complexity can override advantages present in structured arrays. The relationship between quantitative and structural complexity effects on recall was further explored through a manipulation which saw participants exposed to sequences which used only the same nine blocks as stimuli throughout a structured condition and throughout a random condition respectively (with infrequent filler trials using additional blocks as stimuli). Participants were not made aware of, and subsequently reported no knowledge of, this manipulation. Structured (matrix) recall produced better performance than random array recall, and quantitative factors produced an effect: as the number of irrelevant items increased – that is, as array size increased from nine to 16 to 25 blocks while the task only used nine of these stimuli – performance decreased. It was shown that matrix recall remained more stable across array size while random array recall decreased with increasing array size from nine to 16 or 25 blocks. Furthermore, an experiment in which number of blocks present (25) was held constant while the number of blocks *used* for presentation (9,16,25) was manipulated between subjects found better performance in matrix compared to random array conditions for use of nine and 16 relevant items but not for 25 relevant items. Matrix recall also demonstrated an effect of number of relevant items while random array recall did not. These results suggest that uniform display arrangement (simple structure) can support a form of implicit learning in the case of memory for relevant items being used, while random array presentation cannot. Moreover, quantitative factors are again shown to reduce the beneficial effects of simpler structure. The disadvantage of an increasing number of items in an array is posited as linked to the need for more exact encoding, rehearsal and confusability at recall (Kemps, 1999). The advantage offered by structured arrays, meanwhile, is suggested as linked to a different system; support from long term memory is one possible explanation whereby a parallel has been drawn between superior recall in the verbal system for words compared to non-words and

superior recall in the visuo-spatial system for structured compared to non-structured arrays (Kemps, 1999, 2001).

Memory for sequences can incorporate array complexity.

The influence of structure of a spatial array on serial recall has also been demonstrated by De Lillo (2004) and, moreover, this influence has provided evidence of hierarchical organisation within representations in serial spatial memory. A single spatial array comprising nine blocks of the structure of three identical groups of three was used as a base on which to manipulate presentation of a sequence of locations to be recalled (De Lillo, 2004). Sequences in which order of presentation coincided with completing a single grouping of blocks before moving on to the next were shown to be recalled better (at the same list length) than sequences which crossed groupings without any adherence to array structure. Furthermore, response time measures indicated organisation or grouping within memory: measures of response time were shown to be larger, in the sequence adhering to array structure, for the first responses of each grouping compared to response times for recalling items within each grouping. Unstructured presentation did not result in any discernable pattern of response times – with only the very first response in a sequence providing longer times than other items (De Lillo, 2004, Experiment 1). Initiation time of the first response of a sequence has previously been shown to be related to the number of items contained in the sequence such that more items produce longer response times (Fischer, 2001). A subsequent experiment (De Lillo, 2004, Experiment 2) with the task of pointing to the next item in a re-presented sequence in place of sequence reproduction again found first items of groups produced the longest response times in sequences which adhered to grouping structure; such evidence suggests that structure can be incorporated within sequence representation.

Incorporation of organisation within the representation of a sequence to be remembered was further shown through use of repetition in presentation– that is, repetition in each grouping, of the order in which items within a group appear in the presented sequence (De Lillo, 2004, Experiment 1). Presence of this manipulation was shown to promote better recall than both a sequence which did not adhere to grouping and a sequence which used all locations in one group - with each grouping containing different internal order - before moving on to the next. De Lillo (2004) notes that such

an effect of redundancy of sequence suggests involvement of “additional rule based organising factors” (De Lillo, 2004, p425) not necessary for the effect of structured grouping to take place. Using a variety of grouping structures of blocks (number and spatial layout) De Lillo and Lesk (2010) provided further evidence for hierarchical organisation within visuo-spatial serial recall (Experiments 2 & 3) and recognition (Experiment 4). Reaction time measures were taken for recall of sequences adhering to array structure; arrays comprised either four groups of three blocks or three groups of four blocks and sequences used all items in a group before items in another group. Overall response times were found to be longer for recall in sequences for the four groups of three – that is, sequences which contained more elements when segmented at a secondary level. Group initiation response times were longer in both sequences compared to their respective intra-group response times, yet overall the response times for first items in a group were longer in the array with three groups of four blocks than that with four groups of three blocks. This was taken as reflecting that the stage of the sequence about to be embarked on required longer planning/scanning of the ‘cluster’ in the groups which contained more items. Moreover, initiation of sequence times - derived from overall initiation times with grouping initiation times subtracted out to remove the effect of first group size complexity – were longer in the four groups of three blocks sequences than in the three groups of four blocks sequences. This indicated that planning or scanning of clusters was more complex or detailed in the sequence which could be segmented into four constituent parts (before being broken down further) compared to those with three. All this can be taken to indicate that hierarchical organisation can exist in sequence representation – for example, in the form of chunking, with further organisation within a termed ‘subordinate’ level. Differences in reaction times of recognition tasks (Experiment 4) - whereby sequences which tap subordinate sequence structure are responded to slower than those which tap super-ordinate organisation - led De Lillo & Lesk (2010) to suggest that such organisation can take place at encoding and/or rehearsal and need not involve motor programming of response.

Parmentier, Andres, Elford and Jones (2006) investigated concordance of sequences with array grouping (using computerised presentation of dots instead of blocks) when the metric distance covered by a path to be recalled was equalled between conditions. Discordant sequences on a grouped array and neutral sequences on a neutral array were found to produce comparable recall attainment. Recall of items is not shown to be *equivalent* across conditions, however, as a serial order influence

was evident in neutral array errors. That is, incorrectly recalled items were shown to be of a close serial position - as determined by presentation order - to the target item. This error pattern was not evident in the discordant sequences presented on grouped arrays (errors occur for all items at chance level). Moreover, the experiments of De Lillo and Lesk (2010) controlled for distance between groups of blocks (Experiment 2 & 3) and also used a procedure in which distance was not a factor as all sequences were compatible with the presented array (Experiment 4). In this latter task, two different recognition conditions existed for the same presented sequence of locations which was tested for either verification of order pertaining to super-ordinate (order of groups) or subordinate (order within a grouping) organisation. The effect of spatial grouping on sequence recall therefore does not seem to be due only to differences in metric path length, rather to incorporation of structural properties within encoded representations.

Memory for sequences can incorporate imposed temporal organisation.

Parmentier et al. (2006) investigated temporal grouping as a factor for hierarchical organisation. Sequences of nine locations presented on an evenly distributed array were either presented for an equal time per item with constantly equal inter-item timing (neutral condition) or were presented for an equal time with two instances of longer between-item intervals (temporal group condition: increased time between items 3 and 4, and 6 and 7). Induced temporal grouping was observed in performance whereby grouped sequences produced higher recall accuracy than neutral sequences; error data further indicated induced organisation in the grouped condition by revealing items produced in error were more often from within the same temporal group as the target item than from the other temporally defined group. Temporal effects were also evident in a study in which a four cell by four cell touch screen was used to present and record recall of location information (Bor, Duncan, Wiseman & Owen, 2003). Presence or absence of structure was manipulated such that items must always (structured) or must never (unstructured) occur within the same row, column or diagonal as their predecessor in the sequence. Presented sentences adhering to the structured organisation were acknowledged as creating more identifiable forms which could also incorporate symmetry. Two further conditions used a composite sequence construction which was composed of two sections of a structured sequence separated by use of an unstructured rule. Temporal factors were incorporated into these latter

two conditions whereby a longer inter-stimuli interval than an otherwise constant interval either coincided with (concordant) or was a step in the sequence away from (discordant) the transition between locations representing the break in structure. A benefit of structure as compared to lack of structure and a benefit of concordant temporal segregation as compared to discordant segregation of the sequence was reported. While not a reported analysis, graphical presentation of data reveals that introduction of temporal demarcation, regardless of where it occurred, benefited performance as discordant sequences appeared to produce higher span performance than unstructured sequences with no pause in presentation times. Spatial and temporal presentation manipulations could therefore be interpreted as inducing chunking within representation of the to-be-recalled sequence (Bor et al., 2003).

Memory for sequences is affected by path complexity.

Kemps (2001) examined the complexity of path structure when complexity of spatial array is held constant. Using a uniform matrix presentation Kemps varied path complexity using three Gestalt principles: *Symmetry*, *Repetition* and *Continuation*. Symmetry and repetition principles correspond to previously recounted principles of array structure of the same name which can be said to represent redundancy within a presentation; within this study symmetry within a path was defined along vertical, horizontal or diagonal axes, and repetition could correspond to replicated or mirrored portions of sequences. Continuation was defined as sequences in which an imagined line created between two locations was not crossed by a subsequently created line within the sequence. Participants were found to better recall sequences when one of these principles was present. As found elsewhere for structure of array (Kemps, 1999; De Lillo, 2004; De Lillo & Lesk, 2010), structure within a path appears to reduce the requirements on memory, enabling longer lists to be recalled. Completion of a visuo-spatial interference task throughout presentation, in the form of repeated tapping of a simple pattern, was found to impair recall performance, however, the beneficial effect of structure persisted. Presence of this effect under conditions of reduced working memory resources availability suggests that long term support is involved in short term serial recall, specifically, in support of structured path construction or reproduction (Kemps, 2001).

Kemps (2001, Experiments 3&4) trained participants on complex sequences in which they initially performed poorly; it was revealed that this training resulted in

improved performance on the trained sequences but that performance on new sequences of the same complexity was not enhanced. Training elevated performance to the level of that of structured sequences and this benefit was shown to persist 24 hours after initial testing, again suggesting that provision of some form of long term memory (LTM) representation can support performance. The lack of improvement on completely novel complex sequences suggests that pre-existing representations of trained and previously presented sequences, rather than development of techniques or strategies, produced the improved recall ability. There exists the possibility (Kemps, 2001) that demonstrated effects of structural redundancy are largely limited to rudimentary perceptual encoding effects, or occur at recall as has been reported in the verbal domain (Hulme et al., 1997). Evidence is also consistent, however, with a model whereby information entering into working memory has been interpreted through LTM (Logie, 1995; 2003; Logie & van der Meulen, 2009) and effects of symmetry, repetition and continuation in representation of structural information can occur through concepts within LTM representing redundancy (Kemps, 1999; 2001). Tremblay and Saint-Aubin (2009) find that interpretation of the role of LTM in exposure effects (e.g. Kemps, 2001) need also account for the learned feature of temporal order. Such learning is evident in demonstrations of the rapid learning for repeated sequences of spatial locations and anticipatory eye movements to locations which will be next presented in such sequences (Tremblay & Saint-Aubin, 2009). Further evidence for LTM support in structured sequence performance can be found in a recent study (Imbo, Szmalec & Vandierendonck, in press, using stimuli of Kemps, 2001) which assessed recall of structured and unstructured sequences for a variety of age groups (spanning 9-19 years of age). Performance was found to be better for structured compared to unstructured sequences and older compared to younger participants – with age effects following a linear trend; moreover, the disparity between structured and unstructured sequences increased with age effects – that is, structure present in sequences was better taken advantage of by older participants. Imbo et al. point to development and accumulated experience as necessary to provide the foundations both for concepts of structure and for advances in strategies; additionally, knowledge of structure could potentially allow for structure present to induce complementary strategy use.

In an fMRI investigation Bor et al. (2003) presented participants with sequences of a fixed list length (4 items) which could, on any given trial, conform to a structured (successive items occur in same row, column, or diagonal) or unstructured

nature. Beneficial effects of structure were evident in recall accuracy, and in this case the sequences were held over a retention interval (varying in delay time between 6 and 10 seconds). Analysis of activity during encoding, retention and recall periods revealed no difference between conditions at recall. Unstructured sequences provided higher activation during the retention interval in regions associated with storage demands (parietal, occipital and premotor regions: see e.g. Smith & Jonides, 1999), which suggested reduction in general storage requirements in the condition which benefits from structure. Structured sequences, however, produced increased activity compared to unstructured sequences during encoding; most notably, activation in the prefrontal cortex. It was suggested (see Bor, Duncan, Lee, Parr & Owen, 2006) that the demonstration of prefrontal cortex involvement in sequence reproduction could be interpreted as relating to goal maintenance, strategy or organisation rather than storage as prefrontal activity is present in a number of varied tasks (see e.g. Duncan & Owen, 2000; Postle, 2006, also Curtis & D'Esposito, 2003, for reviews). Recent evidence has suggested, however, that the benefit to performance of structure within a sequence need not be linked to executive resource involvement. For example, Rossi-Arnaud, Pieroni and Baddeley (2006) found presence of symmetry in a sequence along a vertical axis – but not along a horizontal or diagonal axis – improved recall of sequences of block locations presented within a uniform matrix. While a verbal interference task completed throughout sequence presentation did not produce an effect on performance, executive interference (a verbal trails task requiring repeated utterance of items in highly familiar sequences, alternating responses between two such sequences, Baddeley, Emslie, Kolodny & Duncan, 1998) led to poorer recall. The effect of performance of this executive interference task, however, did not interact with the beneficial effect of vertical symmetry. It was thus concluded that the effect of symmetry on encoding was due to automatic processes rather than processes which use executive resources, the latter of which are evident in more complex forms of visuo-spatial recall where manipulation of information is required (Robbins et al., 1996).

Presence of crosses within a created path was clarified (Parmentier, Elford & Maybery, 2005 after Kemps, 2001) as detrimental to performance for sequences of seven locations and subsequently localised to an effect occurring at encoding. Participants were presented with the sequential appearance of single dots at various locations (locations determined by experimental design with no perceptible structure and locations changed on a trial by trial basis) and at recall were provided with the

locations used, upon which they were to reconstruct order of presentation. Recall accuracy was better in a condition in which no crosses were present compared to presence of either three or six crosses. The effect of crossing was linear: the more crosses present, the poorer performance. Parmentier and Andres (2006) explored the relationship of path crossing to rehearsal by comparison of immediate versus a delayed (10 second delay) recall of sequences which either did or did not contain path crosses (three crosses per sequence when present). It was observed that while the presence of crossing produced poorer recall relative to no crossings, and presence of a delay negatively impacted recall, there was no interaction of these two effects; of specific importance, there was no increase in the effect of path crossing with the introduction of a delay and associated rehearsal requirements. A second experiment (Parmentier & Andres, 2006) reinforced the independence of rehearsal and effect of path crossing: performance of a spatial tapping task (clockwise tapping of a two by two block matrix) throughout the retention interval was found to impair recall yet did not interact with the significant effect of path crossing. Taken together these findings highlight the importance of rehearsal to recall, while demonstrating that effect of path crossing is neither created nor exacerbated by rehearsal. Parmentier et al. (2005) also conducted an investigation of path crossing in which path length was also manipulated: short, medium and long metric distances traversed by paths of a sequence of locations were contrasted and within these divisions' presence or absence of path crossing was manipulated (three crosses when present). Detrimental effects of both crossing and path length were found. Path length effects reflected better performance of short compared to medium or long sequences; this did not extend to a difference between medium and long sequences. Presence of crossing and path length did not produce an interaction, however, inclusion of serial position did produce a three way interaction reflecting the presence of flatter serial position curves in the no crossing conditions, particularly for the short path length.

It is possible that effects of path crossing are determined by processes at recall, however, an encoding centred theory is suggested which resonates with findings recounted above (e.g. Lecerf & de Ribaupierre, 2005; Pickering et al., 2001). The detrimental presence of path crossing is suggested (Parmentier and Andres, 2006, after Slamecka & Graf, 1978) as intensifying a difference between remembering self-generated and dictated information. Presence of path crossing is linked with more unpredictability in sequences, and with presence of acute angles created by path trajectory, due to necessary changes in direction to create crossings (see Parmentier et

al., 2005, Experiment 3; Parmentier & Andres, 2006). Parmentier et al. (2005, Experiment 4) demonstrated that the angles created by successive trajectories influenced performance even when path length and path crossing are controlled: presence of more acute angles (20-40 degrees) produced poorer recall than larger angles (60-80 degrees). Parmentier and Andres (2006) suggest unpredictable trajectories may clash with instinctive expectations of more ordered trajectories creating a possible locus of interference. By contrast, paths without crossings are less unpredictable and conform to a more “natural scanning pattern” (Parmentier & Andres, 2006, p1873) than would a crossed sequence. It is also therefore of note that simultaneous presentation of items would allow for benefits of volitional encoding: if locations of a simultaneous spatial array are processed sequentially due to view traversing the information, self generated eye movements would allow for a representation to be built up in accordance with participants’ expectations of an array structure. It should be noted, however, that regression analyses of previously described experimental data (Parmentier et al., 2005, Experiment 3) revealed that the effects of path length and path crossing are not fully accounted for by frequency of left-right directional changes or by angles created within a path.

The findings of Parmentier and colleagues (2005; 2006) place an emphasis on recall of a sequence of locations as memory for transitional information rather than as discrete locations. That is, the trajectory between points presented is proposed to be internally represented such that manipulation of this information – for example, path crossing, path length, angle of trajectory – can affect performance. While presentation of locations to be recalled was of single successive dots (after Jones et al., 1995) these results complement the previously described effects of sequence structure (e.g., Bor et al., 2003; Kemps, 2001) which manipulated path created between locations in an array. The temporal factor highlighted by Tremblay and Saint-Aubin (2009) is also consistent with a conception of memory which ties memory for a location to the locations preceding and succeeding it.

Number of items effects on sequence encoding.

Boduroglu and Shah (2006), in a study in which participants were required to reproduce a series of individually presented locations (at list lengths of three, four, five and seven) report evidence suggesting short and long sequences of locations are represented differently. Reproduced locations were compared to presentation stimuli

to establish both distance and angle error of the reproduction; participants' distance errors were subsequently fed into a computer simulation that calculated corresponding estimates of angle error which would occur if no other information but absolute presentation location had influenced reproduction (see Boduroglu & Shah, 2006 for details). For sequences of three and four items participants were found to produce angular error which differed from the computed data, indicating that their representations of the locations had incorporated the relative location of preceding and succeeding presentations. A subsequent experiment implied that presence of crosses in presented paths removed effects of relative encoding.

In contrast to Boduroglu and Shah (2006) another positional reconstruction study (Dent & Smyth, 2006) emphasised the relative lack of configural information informing representation of small numbers of sequentially presented locations. Configural information was, however, evident in both longer sequences and simultaneously presented arrays. Dent and Smyth (2006) assessed the distance error between presented and reconstructed locations of dots for both sequences and patterns consisting of three, six, eight and ten locations. It was revealed that mean displacement distance error in simultaneous presentation was related to number of items to remember, increasing from three to six, but reaching a plateau from six to ten, while sequential presentation error continued to increase with increasing number of items. These results are in accordance with data reported by Igel and Harvey (1991). Dent and Smyth (2006), however, demonstrated through a series of further analyses that such measurement representation (as adopted by Igel & Harvey, 1991) falsely characterises output – especially for that of sequential presentation.

Dent and Smyth (2006) calculated the amount of error relative to when each item was reproduced (first response provided, second response provided and so on); it was determined that in both simultaneous and sequential presentation, the most accurate items were recalled first and accuracy decreased with subsequent responses. These response slopes (plotted as a function of error over response position) were found to be steeper for recall of three items than for recall of eight or ten items, while the steepness of response slopes for six, eight or ten items did not differ. This demonstrates, specifically, that after a memory load of six items, further addition of items does not affect how much error is produced in successive responses. This was true for both simultaneous and sequentially presented stimuli, though sequential presentation produced steeper response slopes overall. Steeper response slopes in sequential presentation were determined to reflect the protracted nature of sequential

presentation, exacerbated by the free recall procedure (see Dent & Smyth, 2006 for details); the steep increase in error with successive responses thus created lower overall error means (e.g. as in Igel & Harvey, 1991) with longer sequences despite not reflecting an effect of memory load. For both simultaneous and sequential presentation analysis of accuracy of the first position reproduced (and, additionally accuracy mean over the first six positions reproduced for longer sequences) did not differ on account of how many items were to be retained in a sequence past six items. The contrast between three and six items did, however, reveal an effect for both presentations of increased memory load on first position accuracy. Further analysis of the distance error between items produced revealed that, overall, items were produced as closer together than initial presentation had been. This is considered (Dent & Smyth, 2006) as an indication of configural representation. Configural representation was evident in all simultaneous presentation reproductions and sequential reproductions for six or more locations, however, was significantly less evident in sequential reproductions for presentations of three locations. Dent and Smyth (2006) thus suggest that six or more locations, regardless of presentation format, are represented in a configural manner and this form of encoding is not subject to tight capacity limits. In contrast, three items when sequentially presented are independently encoded- the basis of which is subject to capacity limits and therefore representations suffer with each additional encoded location - with virtually no configural information. Simultaneous presentation of three items induces both individual and configural encoding.

Mechanisms of visuo-spatial rehearsal.

Response based rehearsal system.

Smyth and Scholey (1992; 1994b) sought to assess the possibility of a “response-based rehearsal system” (Smyth & Scholey, 1992, p482) in the visuo-spatial domain in light of contemporary theories (for a review see e.g. Baddeley, 2007, 2003a) relating subvocal rehearsal to maintenance in the verbal domain. Specifically, Smyth and Scholey investigated the possibility that movement time – the time taken to carry out a movement between two target items – was related to CBT performance; evidence of a relationship could indicate a potential mechanism of rehearsal. Smyth and Scholey (1992, Experiment 1) had participants perform computer touch-screen based CBT in two conditions in which the presented array comprised small or large blocks to be

tapped, while distance between centre-points of each block remained consistent between small and large conditions. As anticipated by experimental design (larger blocks allowing for less precise targeted movement), time taken to make movements to recall successive items in the larger array condition was shorter than that in the smaller array condition. Span performance did not, however, differ between array conditions despite the difference in movement time. Performance was also assessed on speeded tapping between two and between four target items, as was speeded eye movement between two target items. Simple correlation, regression and factor analysis thoroughly revealed there was no relationship between any of the measures of movement time and span performance. Smyth and Scholey (1994b, Experiment 1) repeated the small and large array comparison and movement time analysis with an additional condition in which a small block array also used smaller distances between centre-points of blocks; the distance between blocks was half that of the larger array. Movement time was found to differ between conditions for every set size tested, however, recall performance did not differ between the conditions. A maintenance period introduced in a second experiment – employed to maximise chances and effects of rehearsal - found an unfilled delay of 12 seconds led to poorer recall overall, however, recall performance did not differ between array conditions. The results of Smyth and Scholey (1992, 1994b) would indicate that neither distance between locations to be recalled nor movement time feature in any possible rehearsal mechanism for visuo-spatial storage. Further support for this indication could be found in results which were the converse of those expected by a visuo-spatial movement time or distance related basis of rehearsal (Kemps, 1999, Experiment 2). It was observed that blocks positioned closer together produced poorer recall, despite the reduced distance between target items. However, due to manipulations for the variable of interest in the study – complexity of array – the number of items present in the shorter distance array was greater than in the longer distance array. Therefore, the strongest conclusion that could be drawn is that if there *was* a beneficial effect of distance or movement time on recall performance, it was not large enough to counteract the detrimental effect of greater complexity that was demonstrated throughout the study (Kemps, 1999).

Parmentier et al. (2006) point out, however, the use of span measures rather than assessment of performance at each serial position may not be sensitive enough to reveal the effects of distance on recall. Parmentier et al. (2006) found distance between items effected performance such that longer path lengths reduced recall; with

their use of the dots task (Jones et al., 2005) distance between stimuli comprising the array was equal. This manipulation was employed to protect against any possible effect of density – that is, the occurrence of items closer together - which could otherwise occur with the scaling down of a larger array. Furthermore, Logie and Vecchi (2006) point to the computer screen based equipment of Smyth and Scholey (1992, 1994b) as restricted in the distance available for manipulation; it was suggested that a small (though significant) difference in movement time due to this limitation may not produce a discernable effect on recall performance while a larger difference could. Logie and Vecchi (2006) employed a more traditional CBT based procedure which used wooden blocks, tapped by the experimenter and to be reproduced in sequence by the participant. Two displays were used for comparison of distance differences: a small array, in which smaller blocks were presented in an overall smaller area, and a large array in which larger blocks were presented in an overall larger area. Sequences for use in each array were created so that for each set size larger array sequences traversed near double the distance of those used in the smaller array (inter-item distance was also fixed to be both steady and to adhere to this proportional difference between arrays) . Small array recall performance was shown to be slightly better than that of larger array recall (significance reported as marginal) whereas small array movement time was considerably faster than that in the larger array. Further relationships between the variables were revealed through correlation analysis: while both recall and movement time were shown to correlate across small and large conditions, within a condition recall and movement time did not correlate. A second experiment in which a 10 second delay was introduced between presentation and recall - which should emphasise any rehearsal effects - replicated this finding; it was again observed that movement time and recall performance within an array condition were not correlated (Logie & Vecchi, 2006, Experiment 2).

In sum, the above recounted manipulations of distance created between blocks in an array or between items in a sequence provide, at best, modest evidence for an effect on recall ability (Parmentier et al., 2006; Logie & Vecchi, 2006; see also, Guérard & Tremblay, 2009; Parmentier et al., 2005, for discussion) yet demonstrate an effect on movement time taken in reproducing items for recall (Smyth and Scholey, 1992, 1994; Logie & Vecchi, 2006). The lack of correlation between measures of movement time and recall performance, however, indicate that serial visuo-spatial information is not maintained through a movement based rehearsal mechanism. Evidence obtained from interference studies, in contrast, has suggested a link between the visuo-spatial system

supporting recall and planning and control of movement –for example, in the previously described study of Logie and Vecchi (2006, Experiment 2) introduction of a tapping task in a 10 second maintenance delay impairs recall performance (for both array conditions, equally). Tapping in this manner has repeatedly been shown to have a detrimental effect on serial recall for location information (e.g. Della Sala et al., 1999; Parmentier & Andres, 2006; Jones et al., 1995; Zimmer et al., 2003; Logie & Marchetti, 1991; Smyth & Scholey, 1994a). Smyth and Pendleton (1989) found an interference effect on CBT performance of spatial tapping to four unseen locations in a regulated sequence, when interference was carried out throughout presentation of stimuli; in contrast a task which required only motor control (executing and releasing grip control on a squeezable tube) rather than targeted movement did not impair performance. Moreover, movements of hands to positions on the participant's body (Smyth et al., 1988) did not cause impairment when carried out throughout CBT presentation, while tapping between four locations in a square arrangement did. These findings suggest that observed impairment is not due to the presence or operation of movement itself, rather targeted and controlled movement is key to disruption of spatial memory. This echoes studies (Quinn & Ralston, 1986, Quinn, 1994) which outlined minimum parameters for disruptive movement effects on the generation of spatial images from verbal instruction (Brooks Matrix Task, Brooks, 1968). While uncontrolled movement – in the form of the experimenter moving a participant's arm – produced interference with the generation of an image charting serial progression through cells of a matrix (Quinn & Ralston, 1986), to be disruptive this movement had to incorporate predictable movements and known target locations (Quinn, 1994).

A disruptive effect on generation of a path through an image in this same task (Brooks, 1968) has been reported with tracking a moving stimulus – both through visual guidance (Baddeley, Grant, Wight & Thompson, 1975) and on the basis of auditory feedback (Baddeley & Lieberman, 1980). The latter study included participants performing the tracking task while blindfolded, indicating that not only visually guided targeted movements were disruptive to imaging a sequence of steps through a matrix. A series of experiments (first reported in Baddeley 1986, subsequently detailed in Postle et al. 2006) also indicate that changing visual input (a background in which irrelevant stimuli are stationary or move) while participants fixate at a certain stationary point is not as disruptive to this version of the Brooks Matrix Task as when participants have to track a moving stimulus amongst irrelevant items (whether these irrelevant items are stationary or moving). Moreover, Postle et al.

found no disruptive effect of artificially induced eye movements - created by spinning participants in an electric motor powered chair – to this task. Together, these findings could be taken to suggest that eye movement planning or control, rather than any resulting visual input change or movement may be the level at which interference occurs and thus could suggest eye movement or control supports creation and rehearsal of a visuo-spatial image (Baddeley, 1986). Baddeley (1986) advocated a role for processes used in programming or controlling eye movement as a mechanism by which visuo-spatial information to be retained could be rehearsed, however, an alternative interpretation was also considered, whereby covert attention shifts were used to rehearse information and that interference could also have occurred at this level.

Attention based rehearsal.

Smyth and Scholey (1994a) investigated susceptibility of the maintenance period in a computerised CBT task to interference from both visual and auditory location distraction tasks. It was found that processes engaged in maintenance periods – considered as rehearsal processes – were disrupted by identifying visually presented squares as appearing on the left or the right of the computer presentation screen and by identifying tones presented as emanating from either the right or the left of the computer. Disruption was found to be equal between these presentations and between the manner in which participants had to respond – by pointing to locations or verbally stating left/right. While it initially appeared that even just hearing tones from two different locations could interfere with recall of CBT like sequences (Smyth & Scholey, 1994a) this effect of passive interference was later (Smyth, 1996, Experiment 2; Klauer & Stegmaier, 1997) indicated as an artefact of within subjects design; when subjects were only required to listen to tones emanating from two locations, without ever having to have located them in a previous experiment, no impairment to recall of sequences was found. Repeating words from two different locations (Experiment 3) did not produce comparable disruption to pointing to or categorising location of tones, emphasising that attending to the spatial property of tones resulted in impairment of CBT recall (though see Klauer & Stegmaier, 1997, discussed further below). Smyth and Scholey (1994a), in displaying interference from spatial localisation tasks in which no eye movement to targets was required (auditory presentation) and in which no manual response was required (verbal categorisation), advanced the idea that covert shifts of

attention to localise information produced disruption to CBT maintenance. This was further supported by a follow-up experiment (Smyth, 1996) in which verbal response categorisation of left or right to presentation of tones impaired CBT recall, when carried out during maintenance, even when eye movement was prevented through central fixation (and eye movement monitoring). Moreover, the requirement to centrally fixate (Smyth, 1996) was found not to affect CBT recall in comparison to when this requirement was not enforced (Smyth & Scholey, 1994a). Free eye movement as compared to central fixation has not been found to produce better recall (Pearson & Sahraie, 2003), though there have been reports that rehearsal via eye movements occurs when locations are present - and therefore could support rehearsal - throughout retention intervals (Tremblay, Saint-Aubin & Jalbert, 2006; Tremblay & Saint-Aubin, 2009). Moreover, Tremblay and Saint-Aubin (2009) found that amount of eye movement rehearsal throughout a ten second array-supported retention interval was predictive of recall performance. It has been suggested that any eye movements observed during rehearsal could be a result of covert attention shifts (Tremblay, Saint-Aubin & Jalbert, 2006) and lack of effect of enforced fixation reveals overt eye movements are not necessary to support maintenance of location information. Oculomotor suppression, however, significantly impairs recall (Tremblay, Saint-Aubin & Jalbert, 2006; Guérard, Tremblay & Saint-Aubin, 2009) – that is, when participants are required to alternate fixation between two dictated points. The results of oculomotor suppression studies corroborate the previous findings that enforced eye or spatial attention movements disrupt the rehearsal of serial location information.

Lawrence, Myerson, Oonk, and Abrams (2001) found that, for serial recall of locations sequentially presented in a matrix, the extent of interference produced by all types of movement investigated was similar: eye movement to a presented flash (reflexive saccade) impaired serial location memory in comparison to constant central fixation. Eye movement to a directed location (pro-saccade) and in the opposite direction to a flashed stimuli (anti-saccade) produced equal disruption - notably, so did moving a hand to one of two directed points while maintaining central fixation of the eyes. The indication of these studies - that limb and eye movements produce comparable disruption to serial location memory - suggested that the common factor to all interference tasks was spatial attention. As found previously (Smyth & Scholey, 1994; Smyth, 1996), requiring shifts of attention affected maintenance of locations - further supporting rehearsal of locations as represented at the level of shifts of spatial attention.

Awh and Jonides (2001) detail further evidence for common mechanisms underlying spatial selective attention and maintenance in memory when reviewing neuroimaging findings: similar frontal and parietal regions were found to be involved in both tasks. Spatial attention as a mechanism of rehearsal has found further support with studies demonstrating that effects linked to attending to a location are also evident when a location is held in memory. Facilitated processing - as exhibited by, for example, faster responses - is known to occur at attended locations (Posner, 1980). Awh, Jonides and Reuter-Lorenz (1998) found faster responses for identification of items presented in a maintenance period when these items were presented in the same location as memory stimuli, compared to presentation elsewhere on the screen. Throughout the task, participants carried out continual central fixation, and the memory task required either maintaining the identity or the location of a single item; the benefit of faster location-match responses was only evident when location, as opposed to identity, was being held throughout the retention delay. In a subsequent experiment (Awh et al., 1998), identification of a presented colour was shown to be more accurate when the colour patch encompassed a location held in memory than when presented at a different location; moreover, recall of the location held in memory was more accurate when the stimuli of the colour identification task involved the location memory compared to when identification required a shift of attention to be carried out. An account of rehearsal in spatial working memory as based on directing attention to to-be-remembered locations has therefore garnered much support (for a review see e.g. Awh, Vogel & Oh, 2006).

Eye movement control and rehearsal.

In contrast to an attention based rehearsal theory, Lawrence, Myerson and Abrams (2004) found that eye movements to distracters produced greater impairment in recall than did shifting attention while centrally fixating; shifting attention was also found to impair performance relative to baseline requirements of only central fixation. Responses to distracters were required in all shifting conditions, and were presented and responded to at central fixation as baseline comparison, in order to successfully ascertain that attention had been shifted. These results suggest a role in rehearsal for processes related to eye movements. In both studies by Lawrence and colleagues (2001; 2004), however, eye and attention shifting was carried out during presentation of items - that is, a shift was required after presentation of each item. This is noted as

unusual in typical investigation of retention in short term memory which is more cleanly investigated via interference in a delay period (Pearson & Sahraie, 2003). In a study with interference conducted during the delay period of a computerised CBT task, Pearson and Sahraie (2003) demonstrated that the magnitude of impairment caused to recall by attention shifts and eye movement was not equal. Comparison of overt and covert tracking of a continually moving target found eye movements produced greater interference than did attending to the target, presented at the top of the display screen, while centrally fixating. Both conditions did produce interference as compared to when performing the memory task while centrally fixating only (Experiment 1). Additionally, verification of complying with attention requirements was monitored (Experiment 2) via production of manual response to colour changes in attended stimuli. Similar results were found for saccades to appearance of targets as compared to central fixation with shifts of attention to targets; while both tasks were disruptive to recall, eye movements produced greater impairment. Inclusion of a motor task, where participants had to move their hand between two locations while centrally fixating, also proved detrimental to recall. Hand movement, however, was disruptive to an extent equal to that of shifting attention, but not to that of target acquiring saccades. Consistently, across experiments, the presence of overt eye movement produced a greater decline in recall than any of the other tasks which involved only shifting of attention or arm movement. This was also found for self generated eye movements, carried out when eyes were shut. A case is therefore made for involvement of oculomotor control processes in recall of a series of visually presented locations; an account of maintenance of stimuli through attention based rehearsal would not predict the additional disruptive effect of eye movements.

Pearson (2007; Pearson & Sahraie, 2003) has suggested that a premotor theory of attention (Rizzolati, Riggio, Dascola & Umiltà, 1987) could be incorporated into explaining retention of sequences of locations in working memory. The premotor theory of attention conceptualises orienting of spatial attention as resultant of intended motor action. While covert attention shifts can take place in absence of overt eye movements, it is indicated that the same processes may be involved in both actions to differing degrees (e.g. Beauchamp, Petit, Ellmore, Ingeholm & Haxby, 2001, though see Awh, Armstrong & Moore, 2006). Recent investigations employing retention of a single location have argued for attention as closely linked with coding preparation for action and the control of eye movement programming (Theeuwes, Belopolsky & Olivers, 2009; see also Postle, 2010).

Importantly, it has been noted (e.g. Lawrence et al., 2004; Theeuwes, et al., 2009; Tremblay et al., 2006) that the emphasis on memory for *sequences* of locations in behavioural literature is not reflected in much of the neuroimaging and spatial attention studies (e.g. see Awh & Jonides, 2001; Awh et al., 2006; Theeuwes et al., 2009); it is possible the systems involved in maintenance of a single location may not be the same, or work in the same way, as those involved in maintenance of a series of locations. Additionally, the conceptualisation of pre-oculomotor maintenance of location information (e.g. Pearson & Sahraie, 2003; Theeuwes et al., 2009) has not investigated memory for numerous simultaneously presented locations. The influence of factors identified in affecting encoding and retention of location information – for example, reference frames (Avons & Trew, 2006; Avons, 2007), visual array and sequence characteristics (e.g. Kemps, 1999; 2001) have also yet to be considered.

The role of executive resources.

Studies investigating recall of visually presented location information which require only retention (without manipulation or transformation) have traditionally focused on domain specific encoding, storage and rehearsal processes. A recent emphasis has emerged, however, on a possible role of central executive involvement. This recent emphasis has led some to question whether storage and executive processes operate with as clear a distinction for visuo-spatial materials as that demonstrated in the phonological system (e.g. Klauer & Stegmaier, 1997; Vecchi & Richardson, 2001; Fisk & Sharp 2003; Vandierendonck et al., 2004; Hamilton, Coates & Heffernan, 2003; Rudkin, et al., 2007; Pearson 2007; Quinn, 2008). Much of the evidence influencing this view stems from a particular literature which will be addressed in the next chapter.

Tasks which involve serial location memory or sequentially presented items have particularly been questioned as to central executive involvement. Smyth and Pelky (1992) reported a small but significant effect of backward counting during a maintenance period for recall of a series of three items in Corsi blocks array. There was, however, a notably greater disruption to recall when counting was performed during both encoding and maintenance. Klauer and Stegmaier (1997) demonstrated interference during the retention interval of a computerised CBT procedure which questioned the results of Smyth & Scholey (1994a) as attention based disruption; sequence retention was impaired by concurrent binary pitch (high or low) and

loudness (soft or loud) judgements to the same extent as when replicating the left or right localisation judgements of Smyth and Scholey (1994a). Moreover, the effects of pitch and loudness judgements (the vocal responses of which are stressed as without spatial connotations in the language of testing) were consistent when the tones judged emanated from a central location rather than two different positions. Of note, interference effects were evident both at span level and at each list length tested (four to seven items, Experiments 2-4).

Klauer and Stegmaier (1997) suggest the requirement to make a decision is the underlying cause of interference observed in their own study and that of Smyth and Scholey (1994a), rather than any spatial element of the task. They therefore point out it is possible to interpret these results as indicating that executive resources provide the rehearsal of serial, visually presented location information. Through studies with a number of recall materials Szmalec, Vandierendonck and Kemps (2005) determined that choice reaction decisions (as evidenced through high or low frequency judgements) are a function of the central executive. With respect to recall of location information, the effect of decisions carried out during encoding of forward and backward recall of computerised corsi sequences was different to that of matrix tapping; while choice decisions affected forward and backward recall equally, matrix tapping had a greater effect in backward compared to forward recall. Szmalec et al. concluded effect of response selection on sequence encoding occurred at executive *rather* than at the level of the slave systems. Consequently the results of Klauer and Stegmaier (1997) may indicate executive resources were impaired in a filled retention interval, and therefore had been otherwise engaged in an unfilled interval, but it does not necessarily follow that executive resources were used in place of domain specific rehearsal process. Moreover, the results indicating detrimental effects of attention and eye movement shifting (e.g. Lawrence et al., 2001; 2004; Pearson & Sahraie, 2003), and of facilitation at attended locations (e.g. Awh et al., 1998), still provide support for a rehearsal system which is linked to shifts in attention or to the oculomotor system.

A disruptive effect of verbal fluency (see e.g. Baddeley, 1996) when carried out during the retention interval of a location recognition task has been reported for both children (aged 6-9 years) and adults (Hamilton et al., 2003). Participants were presented with a sequential build up of dots (i.e. once it appeared, a dot remained visible throughout presentation) within a number of possible locations situated within a cartoon figure. At recognition, all dots were either presented in the same order or the order of two dots was swapped; while this methodology differs slightly from the

majority of location presentation tasks reviewed – placing the emphasis on order rather than location in particular – the effect of verbal fluency does indicate executive resources were used to maintain order of location information. A simultaneous presentation of dots task, in which a combination of colour and location information memory was required, also proved susceptible to verbal fluency interference. Interference conditions were administered at list lengths corresponding to 75% of individual span and spatial tapping was also found to disrupt both tasks. Of note, the magnitude of verbal fluency interference increased between the two age groups for the ordered location task, while the relative effect of spatial tapping decreased. The finding that adults were employing maintenance processes which involved executive resources more than did the children suggests the locus of executive interference at maintenance may be in complex strategy. It is therefore suggested that the results of Hamilton et al. (2003) should not be taken to imply an incompatibility between carrying out simple rehearsal or maintenance and executive tasks.

A stronger case can be made for more extensive executive resource involvement in *encoding* of a series of locations. Rudkin et al. (2007), for example, revealed executive resource use in sequentially presented- serially recalled tasks. Moreover, Rudkin et al. demonstrated little evidence of executive resources in tasks which used simultaneous presentation. Span level for participants on CBT and a matrix pattern reproduction task (akin to VPT) was determined. Span was then used as the level at which interference task random number generation (RNG) was administered. RNG requires participants to continuously generate a random string of digits using only the numbers one to nine, without repetition or any discernable structure (e.g. reciting even numbers or multiples of two in sequence would be non-random); sustained production of randomness is considered a role of the central executive (Baddeley, 1986). RNG was performed as an interference task both throughout presentation and immediate recall. Random number generation (RNG) was shown as disruptive to matrix pattern recall and to CBT performance, with significantly more disruption caused to CBT performance. The overall disruptive effect - that found in matrix reproduction and a portion of the disruption to CBT - was considered to be of the level expected for dual task coordination cost. The disparity in effect, however, was considered to reflect RNG interruption of executive involvement in CB performance. Interference to CBT performance was also found by Vecchi and Richardson (2001) where RNG, when carried out throughout immediate recall performance, significantly reduced CBT span.

In a second experiment Rudkin et al. (2007, Experiment 2) employed the same apparatus for a simultaneous presentation as for a sequential, serial order, task in order to focus on presentation differences while minimising array, formation and response differences. Apparatus consisted of a light-button box with a five by five grid of buttons which could light up either all at once, or one after the other, to display the to-be-remembered locations. At recall participants had to reproduce the simultaneous pattern by typing in the boxes and these boxes remained lit for the rest of recall. This was also the case for sequential recall, however, the order in which the buttons were reproduced was to be matched to that of presentation. Consecutive RNG throughout presentation and recall, on trial lengths at each individual's span, was shown to disrupt serial recall performance but not simultaneous recall performance. As previously recounted, the findings of Rossi-Arnaud et al. (2006, Experiment 3) also show significantly lower memory span for sequences of locations in a uniform matrix when performed under an executively demanding task (verbal trails) compared to when performed alone.

Demonstration of executive resource involvement in a serial recall task through an interference task which may require maintenance of previously stated items (in order to produce non-replicated or non-consecutive items) has a possible confound of memory or serial order resource based interference (Baddeley, 1986; Vandierendonck, De Vooght & Van der Goten, 1998a). Though dual task methodology has proved fruitful in a number of studies there is a potential limit to this methodology when attempting to discern involvement of the central executive in a primary task, especially when using 'typical' central executive demanding secondary tasks such as Random Number Generation (RNG) and n-back tasks (Hegarty, Shah & Miyake, 2000). Hegarty et al. expose the lack of clarity as to location of interference when looking for performance decrement from tasks which require frequent, attention demanding responses; these are properties of many tasks designed to tax the central executive and could precipitate response bottleneck and strategic trade-off respectively.

While Rudkin et al. (2007, Experiments 1 & 2) measured RNG task performance - when performed alone, then in secondary task capacity - and found no evidence of a strategic trade off, a third experiment adopted an alternative interference task to address the concerns listed above. Using the same primary task set up as that of the second experiment, an interference task of random interval repetition (RIR, after Vandierendonck, De Vooght & Van der Goten, 1998b) was employed. RIR required participants to listen for, and detect, tones which were presented at unpredictable

intervals –participants were thus required to remain vigilant for the duration of the task. A fixed interval duration condition - where tones were presented at a known pace - was utilised as a control; tones presented at fixed duration would be expected to require less vigilance and executive resources therefore resulting in a lesser predicted impact. It was revealed that simultaneous performance was not affected by either interference task, while sequential interference was significantly disrupted by both. Surprisingly, fixed and random interference tasks did not significantly differ in their impact on sequential recall. This was interpreted (Rudkin et al., 2007) as due to the slow pace used for fixed interval repetition. It was suggested that slow presentation meant fixed timing was not easily discerned, and consequently not easily predicted, by participants - this would therefore negate the premise of reduced executive involvement in fixed as compared to random interval tone presentation. This series of results (Rudkin et al., 2007) thus suggests that the involvement of executive resources in encoding and recalling sequentially presented, serial recall visuo-spatial tasks is much greater than that in encoding and recall for simultaneously presented information. Vandierendonck and colleagues (2004) revealed that employment of executive resources in encoding sequenced location information may only be for intermediate and longer lengths of sequences. When participants were required to generate random intervals - via pressing of a single key at non-repeated or systematic times (Vandierendonck et al., 1998a) - throughout presentation of a computerised Corsi block task, span performance was significantly lower than when performed alone. Analysis of random interval generation (RIG) effects at each of the sequence lengths administered revealed sequences of three to five items were not affected, while sequences of five to six (Experiment 1) and seven to eight (Experiment 2) items were. In comparison the detrimental effect of spatial tapping (repeatedly tapping round four pegs in a clockwise manner) was greater, and was evident at all sequence lengths, while no effects of articulatory suppression or fixed interval generation (pressing a single key at fixed pace) were found. These results indicate the domain specific resources involved in encoding sequences are required regardless of sequence length, while executive resources are only involved when encoding of sequences exceeds capacity of the domain specific system. Detrimental effects of random letter generation (letter variant of RNG) when carried out during presentation of sequences of four items in length (presented and recalled within a computer displayed five by five grid) have, however, also been reported (Fisk & Sharp, 2003).

Rudkin et al. (2007; see also Hamilton et al., 2003) point out that, given the indication of higher executive resource use in sequential encoding, it is possible to interpret the developmental trajectories observed for VPT and CBT performance (e.g. Logie & Pearson, 1997; Pickering et al., 2001) as reflecting differences in executive abilities. For example, if CBT requires more executive involvement (e.g. on the basis of encoding strategy) than does VPT then a shallower CBT performance developmental trajectory could be explained as linked to the lengthy development of executive abilities (e.g. De Luca et al., 2003; Jurado & Rosseli, 2007; Anderson, Anderson, Northam, Jacobs & Catroppa, 2001). The lack of correlation observed at specific age groups between VPT and CBT performance in the children tested by Logie and Pearson (1997), combined with the results of Rudkin et al. (2007) could potentially argue for no executive resource involvement in VPT performance. The results of Hamilton et al. (2003) suggest evidence to the contrary, at least for the retention of VPT information. Logie et al. (1990) report small yet significant effects of concurrent arithmetic on recall of statically presented matrices. Moreover Phillips and Hamilton (2001) recount evidence of the course of performance in simultaneous presentation matrix recall throughout the lifespan; increase in recall capabilities from childhood to adulthood followed by decline in older adulthood is likened to that found for executive abilities. It is suggested, (Hamilton et al., 2003; Phillips & Hamilton, 2001) that simultaneous presentation matrix recall tasks may also engage strategy use which involve executive resources, though not necessarily in the same way or to the same extent as do sequentially presented tasks.

Summary

There is a distinct line of research indicating that visuo-spatial working memory comprises dissociable subsystems (e.g. Della Sala et al., 1999; Krikorian, et al., 1996; Logie & Pearson, 1997; Pickering et al., 2001; Zoelch & Schumann-Hengsteler, 2006). The nature of this dissociation, however, is somewhat ambiguous, and varied interpretations of VSWM organisation reflect this (e.g. Logie, 1995; Pearson, 2001; Cornoldi & Vecchi, 2003; Repovs & Baddeley, 2006; Quinn, 2008). For example, some posit separable but interlinked (Logie, 1995) subsystems, while others suggest a certain combination of presentation and materials will employ separate resources when little attentional control is required in a task, but these divisions be less well

defined when tasks engage more active control (Cornoldi & Vecchi, 2003). Others take the dissociation further, suggesting two sets of rehearsal and storage mechanisms support performance (Repovs & Baddeley, 2006) or that storage of information of presented images is held separately from a spatial rehearsal mechanism except from when in the form of a conscious visual image (Pearson, 2001).

A number of studies suggest presentation affects the way in which information is represented in memory such that information presented as one simultaneous image is supported by a different sub-system than that which deals with sequentially or dynamically presented information (e.g. Pickering et al., 2001; Mammarella, Pazzaglia et al., 2008; Lafranchi et al., 2009; Mammarella et al., 2003; Mammarella et al., 2006; Mammarella et al., 2009). There has also been further indication that different means of encoding are available for information which is simultaneously presented and that which is sequentially presented (e.g. Lecerf & de Ribaupierre, 2005). Additionally, evidence suggests sequentially presented locations are not necessarily encoded as absolute locations in memory, as they are shown to be affected by reference frame adopted (e.g. Avons & Trew, 2006; Avons, 2007).

Studies exploring factors which could enhance and limit sequential recall have identified array complexity (e.g. Kemps, 1999) as influencing performance and have shown that sequences can incorporate array complexity, exhibiting hierarchical organisation (e.g. De Lillo, 2004; De Lillo & Lesk, 2010; Parmentier et al. 2006). Incorporation of provided temporal features into sequence representation has also been demonstrated (Parmentier et al., 2006; Bor et al., 2003). Moreover, experiments which show that recall of a path created by a presented sequence is limited by complexity have also revealed a role of concepts of redundancy and possible long term memory contributions to performance (e.g. Kemps, 2001; Imbo et al., in press; Tremblay & Saint-Aubin, 2009). These beneficial effects of path structure may reflect automatic processes (Rossi-Arnaud et al., 2006) in place of, or in addition to, a possible form of executive contribution (Bor et al., 2003; 2006). Studies have also demonstrated transitional information between locations is important in sequential presentation and certain properties of a sequence – for example, path crossing – may externally dictate how a sequence can be processed (Parmentier et al. 2005). Additionally, the ability to relate sequentially presented items to one another is possibly increased (Dent & Smyth, 2006) or limited (Boduroglu & Shah, 2006) by increasing number of items to be recalled.

Investigation of a rehearsal system through manipulation of distance has provided mixed results (e.g. Parmentier et al., 2005; Logie & Vecchi, 2006) and lack of an association between accuracy in recall and movement time suggests a movement based rehearsal mechanism is unlikely (e.g. Smyth and Scholey, 1992; 1994b). Interference studies, however, indicate a role for targeted or controlled movement. Eye movement control (e.g. Pearson & Sahraie, 2003; Postle et al., 2006), spatial attention (e.g. Smyth & Scholey, 1994a) and general amodal attention (e.g. Awh et al., 2001) have all received support as the basis of a rehearsal mechanism, however, each account is also limited. There is mounting evidence that executive resources can be involved in the *encoding* of sequences and that this may be to a greater extent than any possible involvement in tasks with simultaneous presentation (e.g. Rudkin et al., 2007). Executive involvement in encoding sequences may only be for intermediate and long (e.g. Vandierendonck et al., 2004; Rudkin et al., 2007; Vecchi & Richardson, 2001; Rossi-Arnaud et al., 2006), or also at shorter (e.g. Smyth & Pelky, 1992; Fisk & Sharp, 2003), list lengths. The evidence for executive involvement in *rehearsal* of sequences, however, is somewhat more ambiguous (e.g. Smyth & Pelky, 1992; Klauer & Stegmaier, 1997; Hamilton et al., 2003) and, if present, may not negate the need to account for domain specific rehearsal mechanisms (Szmalec et al., 2005).

The nature of the visuo-spatial working memory system is investigated in the present thesis for evidence of dissociable resources underlying performance on memory tasks employing simultaneous and sequential presentation.

In Experiments 1 and 2, an interference paradigm is described which was employed to assess whether passive interference during a retention interval can impair memory for short sequences or their simultaneous presentation counterparts. It was of particular interest whether interference of two different formats would produce differential effects on the basis of memory task presentation condition – that is, whether there would be evidence of memory for locations being retained differently on the basis of presentation. Experiment 3 presents the development and use of a novel, active interference paradigm created to target stored visual information. A comparison is made between the effect of this new interference task and that of spatial tapping task for simultaneous and sequential location memory. A subsequent experiment makes use of a comparison between memory and imagery tasks in order to further verify the conclusions from Experiment 3 and to assess the utility of the newly developed interference task. Experiments 5 to 7 assessed memory for longer sequences and their

simultaneous counterparts when using a uniform array and under manipulation of this array whereby temporal factors are emphasised in sequential presentation.

The following chapter provides a review of a particular approach to working memory which has had an increasing impact on the visuo-spatial literature. This approach informs the methodology of the final experiment which investigated evidence for resources common or unique to memory for simultaneous and sequential presentation (Experiment 8).

Chapter Two

Working memory span: shared resources, controlled attention and recall measurement

Working memory capacity (WMC) tasks have been employed for nearly thirty years as a way in which to ensure, as much as possible, that the working memory system functions of processing and storage are engaged to their maximum capabilities. On the basis of this purported all-encompassing nature, WMC tasks are thought to reflect the natural operations of the system as it functions in everyday tasks. Working memory (WM), primarily measured through WMC tasks, has been a core concept used in the examination of individual differences in intelligence, varied mental abilities and development (for a review see e.g. Conway et al., 2008).

Capacity tasks were formulated (Daneman & Carpenter, 1980) on the basis of early WM conceptualisation whereby processing and storage rely on shared resources – that is, a storage element was attributed to the central executive (Baddeley & Hitch, 1974). Thus, in WMC tasks resources were considered as theoretically traded-off as difficulty in performance in one aspect of the task would lead to recruitment of more resources and subsequent reduction in available resources for the other portion of the task. Revisions and expansions of the Baddeley and Hitch (1974) model have, however, included a modification emphasizing central executive resources as independent of those used by storage mechanisms (Baddeley & Logie, 1999). Consideration of the issue of shared resources between executive and storage functions in particular has more recently become central to debate in the individual differences literature, not only as a question of the structure of working memory but, increasingly, as the intimately linked question of what the widely used WMC task measures actually represent.

The Daneman and Carpenter (1980) reading span task required that, within a trial, sentences be read aloud and the last word of each sentence recalled after all sentences had been read. Recall of final words was required in the order of sentence presentation. Performance of a storage task whilst concurrently performing a processing task fulfils the principle requirement for a task to engage the working memory system beyond the proposed slave systems or sustained short-term activation of items to be retained in memory. Performed at increasing levels of difficulty from two

to six sentences (and consequently two to six words to be recalled), Daneman and Carpenter showed reading span correlated with measures of comprehension and verbal scholastic aptitude test (SAT) scores whereas traditional short term memory tasks (digit recall and word span) did not. 'Span' was determined by the last level at which a participant correctly recalled all words in a given trial, two out of the three times that the task was performed at that level. Under the conceptualisation of working memory as a single pool of shared resources, span performance, as measured through recall, was thought to reflect the functioning of the whole system with regard to the verbal material with which it was dealing.

In this particular case of a resource sharing view, Daneman and Carpenter (1980) also advocated domain specificity. High and low WMC performers were thought to have equal potential WM 'capacity', but that their skills for a specific task – here, reading – determined how much of that capacity was available for storage functions after processing functions were accounted for. That is, recall was considered as determined by how much of the limited capacity system was not being consumed by the processing task; predictive power of the reading span task for reading comprehension was therefore thought to lie in common reflection of participants' verbal abilities or skills. This reasoning would mean that a participant's performance on a WMC task which did not measure similar processing abilities need not yield a similar correlation with reading comprehension. If, however, the processing was similar to reading abilities, the resulting correlation would be similar.

Subsequently developed alternative WMC tasks also demonstrated correlations with measures of comprehension, including the counting span (Case, Kurland & Goldberg, 1982), which comprises the processing requirement of counting and the storage task of maintaining consecutive counts in a sequence, and operation span (Turner & Engle, 1989). Turner and Engle (1989) compared a reading span task with three similarly structured tasks, requiring storage of information while completing processing. These four tasks required sentence processing (verification of information in the sentence) combined with memory for either digit or word recall, and math processing (verification of an arithmetic equation) with memory for either digit or word recall. Importantly, despite the different requirements of processing component, word storage based WMC tasks, as measured by total number of items correctly recalled over all trials, equally predicted reading comprehension while simple word recall performance again did not. Moreover, the correlation of a word storage-operation processing (arithmetic verification) WMC task with reading comprehension

remained significant when a measure of covariance between 'quantitative skills' and verbal abilities was controlled. Predictive utility of both reading and arithmetic processing based WMC or 'complex' (processing plus storage) span measures over that of simple span was confirmed in a meta-analysis by Daneman and Merikle (1996). The meta-analysis demonstrated that the predictive value of WMC tasks had, in the years since its inception, been extended to use with numerous measures of comprehension.

Engle, Tuholski, Laughlin and Conway (1999) undertook an investigation aiming to establish whether various WMC tasks measure a common construct and to determine the relationship of this single proposed WM construct to a simple short term memory (STM) construct. Recognised measures (Raven's Standard Progressive Matrices and Cattell's Culture Fair Test) of general fluid intelligence (Gf) were taken with a view to exploring the relationship of a derived latent variable to each proposed WM and STM construct. Factor analysis and structural equation modelling found that two separate latent variables derived from three measures of WMC (reading span, counting span and operation span) and three measures of short term memory (forward recall of rhyming words, forward recall of dissimilar words and backward recall) to be a better representation of the data than a single variable representing all tasks. The two constructs were, however, highly related. Furthermore, structural equation modelling revealed that when variance common to both the WM and the STM latent variables was removed, the WM construct was strongly correlated with Gf; STM was not significantly correlated with Gf once variance shared with working memory was removed.

The aforementioned study furthered contributed to the development of a leading theory of WMC performance - the 'controlled attention' view (Engle, Kane & Tuholski, 1999); this view posits that WM can be defined as STM plus controlled attention. As can be interpreted from the results of Engle, Tuholski et al. (1999), controlled attention is the proposed link between working memory (as measured in WMC tasks) and higher cognitive abilities. It is emphasised (Engle, Kane et al., 1999; Engle, Tuholski, et al., 1999), however, that no task is 'process pure' and STM or simple storage requires controlled processing - only to a smaller degree than WM tasks. Likewise working memory tasks require short term storage, however, this storage represents a smaller contribution to WMC or complex task performance than it would to simple recall performance.

The controlled attention view was later re-termed the executive attention view in order to emphasise similarities to other theories concerning executive function and control (Kane, Poole, Tuholski & Engle, 2006). The role of executive or controlled

attention in WM functioning is summarised as applying activation to memory representations, maintaining information, inhibiting irrelevant information and suppressing unnecessary or detrimental response tendencies (Heitz, Unsworth & Engle, 2005). It has been likened (Engle, Kane & Tuholski, 1999) to the Focus of Attention (Cowan, 1995) and the central executive (Baddeley & Hitch, 1974) in other prominent models of working memory, and is inherently domain free, flexibly deployed and capacity limited. The content of STM is considered to be LTM representations activated above a certain threshold, in a manner again akin to the model of Cowan (1995, 2005). Activity of representations can be lost due to both decay over time and interference resulting from information similarity, or gained due to allocation of controlled attention.

The central and essential role of controlled attention in WM is stressed when capacity of the system as a whole is defined: “{capacity} is not really about storage or memory per se, but about the *capacity for controlled, sustained attention in the face of interference or distraction*” (Engle, Kane & Tuholski, 1999, p104). A number of studies conducted by Engle and colleagues have shown a link between WMC performance and measures of controlled attention. Conway, Cowan and Bunting (2001) demonstrated with individuals categorised as either high or low WMC performers that individuals of ‘high’ ability were more adept at blocking non target information in a dichotic-listening task than individuals of ‘low’ ability. Kane and Engle (2003) revealed that high and low span participants differed significantly on their accuracy in performing a colour-word Stroop task and Kane, Bleckley, Conway and Engle (2001) found low span individuals performed poorly in an anti-saccade task in comparison to high span individuals. Kane et al. (2001) point out poorer goal maintenance in low span individuals was evident through both the frequency and the speed of error trials, in comparison to performance of high span participants.

Miyake (2001) states this organisation need not align itself with a resource-sharing view, however, it is clear that recall measurement in complex span is accepted as an appropriate reflection of the capabilities of the system - capabilities which are largely determined by controlled attention. Skills and strategies tied to the format and domain of information that is being maintained *are* acknowledged to impact on complex span performance (Heitz, Unsworth & Engle, 2005). For example, Engle, Kane and Tuholski (1999) point out a child performing a task requiring encoding and rehearsal of digits will likely require more executive attention than an adult. Again, however, this impact of maintenance is considered minimal in capacity task

measurement; in contrast simple span measurements are considered to use executive attention for coding and rehearsal but do not suffer from switching of attention between performing task components, or from the competing demands of maintaining multiple task goals and blocking interfering information.

In a change of direction, Unsworth and Engle (2007a) recently re-evaluated the most prominent evidence that STM and WM are separable constructs. Three approaches to this evaluation were employed: reported patterns of experimentally manipulated or observed effects were assessed for commonalities between simple and complex spans, a meta-analysis of studies adhering to specific inclusion criteria was conducted, and a re-analysis of data from often cited evidence for dissociable constructs was undertaken. When looking at experimental effects, it was observed that complex and simple spans differ in the patterns of recall errors that they tend to exhibit – it was concluded from this that these tasks may differ as to the processes that operate at recall. However, similarity of experimental effects between the two tasks was observed in list length effects (decrease in proportion of words recalled as list length increases though total recall increases), transposition gradients (indicating some similar processes occur at recall), word frequency effects, word length effects, phonological similarity effects, and articulatory suppression effects (see e.g. Baddeley 2007 for review of effects in simple span performance). It was consistently observed (Unsworth & Engle, 2007a) that all these effects were larger in simple than in complex span performance; interpretation of the meaning of these effects can be illustrated with the observation that under articulatory suppression – a task designed to prevent rehearsal – simple span performance (initially performed producing higher recall than complex) was reduced at a greater magnitude than complex span, bringing performance of the two tasks to equal levels when rehearsal is reduced or abolished. It is suggested that rehearsal processes operate to a greater degree in simple than in complex spans, however, the process is common to both versions – that is, it is indicated that the two tasks rely on similar systems.

While investigating list lengths Unsworth and Engle (2006) found that though complex span correlations with higher cognition remained stable across list lengths, correlations of simple span with higher cognition increased as list length increased until a point at which they were found to be similar to those of complex span. Unsworth and Engle (2007a) address this issue by examining scoring methods used in the literature. The previous prevalence of ‘absolute scoring’ (ABS) method, whereby scores reflect only lists in which all items were correctly recalled, was determined as inferior

to 'proportion correct' scoring (PCS) whereby all items correctly recalled (in serial order position) within a trial are calculated as a proportion of the possible total; performance is then represented by the mean proportion correct throughout all trials – that is, across all set sizes/list lengths (after Friedman & Miyake, 2005). While Friedman and Miyake (2005) focus on the correlational benefits of proportion correct due to increased variability, such as increased sensitivity, Unsworth and Engle (2007a) also point to the potential ability of this method to represent performance reflecting "individual differences in the ability to effectively retrieve items from supraspan lists" (Unsworth & Engle, 2007a, p1047).

Unsworth and Engle (2007a) undertook a meta-analysis of previously published studies in the literature addressing predictive value of simple and complex spans; 22 studies were included under a strict list of inclusion criteria (see Unsworth and Engle, 2007a, p1047-1048), and these studies were classified as to the scoring method they had employed. Surprisingly, with adherence to strict inclusion criteria, simple and complex span tasks displayed comparable correlations with measures of higher order cognition. Differences in correlation as determined by scoring method were not, however, observed.

To further investigate the issue of scoring, Unsworth and Engle (2007a) rescored the data from their influential Engle, Tuholski et al. (1999) study, changing scoring procedures from ABS to PCS, and reanalysed the resulting values using the same method of factor analysis and structural equation modelling. An increased correlation between Gf and a latent variable derived from re-scored STM measures was observed, relative to the Engle, Tuholski et al. (1999) finding. There was not, however, an increase in correlation between Gf and a latent variable, derived from re-scored working memory measures relative to the Engle, Tuholski et al. (1999) finding. Of particular importance is the change in structural equation modelling outcome relative to the Engle, Tuholski et al. (1999) model; WM and STM latent variables were again highly correlated, however, when variance common to the two tasks was partialled out, neither measure significantly contributed to variance in Gf - that is, WM and STM were equally predictive of Gf and it was the variance common to the two tasks that held this value. It was concluded that WM and STM are one construct.

The recent nature of the above described study means the full impact of the findings is not yet known. The explanatory potential of a recent view proposed by Unsworth and Engle (2006, 2007b), however, has already been applied to the findings. This view proposes a framework which comprises two components: one which

represents items currently in a state of activation, in this framework termed primary memory (PM), and one in which items are of various lesser states of activation (Secondary memory, SM). Representations in SM to be brought to higher activation or recall must be retrieved through a 'cue dependent search process'. It is proposed that PM is highly limited in capacity (after Cowan, 2005 and Broadbent, 1975) and incoming items will displace information already there into SM. It is also noted that removal of attention will displace items from PM. Thus during complex span, processing is proposed to displace memory items and in simple span incoming items in a list displace items already represented. Recall of items from PM is thought to be an easy 'unloading' of information while retrieval from SM is a much tougher process requiring discrimination of appropriate retrieval cues among competitors. Each form of task measure is thought to primarily reflect the processing of each component : a higher representation of PM in simple span tasks, with increasing representation of SM when longer lists are used and a high representation of SM in complex span tasks with likely all items to be recalled having been displaced. One important point of divergence of this view from previous views of controlled attention is the focus on cue dependent retrieval and the rejection of decay based explanations of forgetting (Unsworth & Engle, 2007b). As pointed out in Kane, Conway, Hambrick and Engle (2008) a build up of proactive interference over trials leads to a reduction in ability to discriminate retrieval cues; active maintenance of representations in PM is, however, challenged by processing tasks and so, therefore, is the encoding of representation. Active maintenance and retrieval discrimination processes are thought to be the primary limiting factors which are represented in individual differences such as participants with low WMC compared to participants with high WMC.

A recent study by Healey and Miyake (2009) focused on further exploring the Unsworth and Engle (2007a) view that active maintenance and long term retrieval are behind the 'storage' performance portion of WMC tasks. Participants were required to execute secondary tasks, designed at easy and hard levels of difficulty, while performing recall of both a standard WMC task (operation span task) and a modified task. The modified task required all processing components to be performed before the storage portion of the task begins (therefore the storage aspect of the task is essentially a simple span task). Dividing attention at recall via secondary task performance was shown to affect accuracy and initiation of recall time to a much greater degree in the operation span task than in the 'modified' (simple) task. It was theorised that complex span storage measures may extensively reflect the involvement of attention and forms

of executive resources which are required for long term retrieval. Healy and Miyake (2009) suggested that there are many levels of activity at which a representation may lie and when active maintenance is prevented (e.g. due to executive attention being used to complete processing requirements, or because number of items exceeds active maintenance capabilities) activity of a representation declines due to either decay or interference. They state that 'long term memory representation' retrieval is necessary for representations at a very low level of activity. A number of executive resources relevant to long term retrieval are suggested, such as generation and elaboration of cues, search for cue matching representations, and blocking of irrelevant information; the recall requirements of WMC tasks are thus proposed to require more effortful processing than previously understood. Healey and Miyake (2009) pronounce the suggestion that active maintenance and long term memory retrieval contribute to complex span performance (Unsworth & Engle, 2007a, 2007b) an 'emerging view' in the literature (see also Unsworth, Brewer & Spillers, 2009).

Processing measures in complex span performance: Evidence for independent resources

Though much of the more prominent literature on WMC has drawn conclusions on the functioning of the system as a whole solely through measuring recall performance, the significance of the processing component of the task has become increasingly apparent. In what has, until relatively recently, remained a somewhat separate line of inquiry, a number of studies have established the importance of measuring the processing component of a complex span. Recognition of these findings necessitates consideration of complex span performance as supported by separable resources.

Waters and Caplan (1996) demonstrated that, when assessing performance on verification of sentences read during a verbal complex span task (after Baddeley, Logie, Nimmo-Smith & Brereton 1985²) to derive a measure of processing, there is a lack of evidence to support the idea of a single pool of resources underlying performance. They proposed that if a single pool of resources were used to perform WMC tasks, then positive correlations would be expected between processing and storage measures when a task is performed below span level; however, negative correlations should

² Baddeley et al. (1985) employed sentence verification requirements but did not analyse performance in relation to recall.

emerge when tasks are performed at or above span since resources are theoretically given to one task or another and are not able to provide for both. The data did not show this, rather low to moderate positive correlations between processing and storage measures were found at all list lengths which followed no fixed pattern and also varied in reaching significance.

Duff and Logie (1999) further demonstrated performance on complex span tasks does not fit predictions which should follow from a shared resources view. In a study which employed visuo-spatial information in a complex span design, participants were required to memorise the appearance of a series of items while concurrently performing a processing task which involved tracking a series of locations. A series of squares were presented in unpredictable locations on a computer screen and participants had to click on these as they appeared; items to be memorised were line forms (of varied orientation and curvature) and each item appeared embedded within the squares presented for tracking. At the end of a given trial participants reproduced, in order, each line form presented. Measurement of participants' accuracy in tracking as well as accuracy in recall performance was taken. Performance was also measured on each task – recall of line forms, tracking of a box target - when performed individually at set levels of difficulty. Difficulty was manipulated by increasing number of items to be recalled (from two to nine) and by reducing the on-screen time of tracking items. Combining the set levels of difficulty in these tasks within the complex span task was complementary – as the number of items to be remembered increased, maximum time on-screen decreased (determined by proportion of a given time available to be allocated to each presented square/item combination). Recall performance was not significantly different when completed alone and when completed as part of a complex span. Increasing length of list to be recalled negatively affected both single and complex span performance. This effect interacted with task type, however, this was identified as due to poorer performance in complex recall than single for the shorter list length conditions. It was thus established that even at levels of high difficulty equivalent recall performance is obtained in single and complex conditions. Tracking accuracy comparisons yielded a small yet significant difference between single and complex conditions; this difference was statistically consistent across presentation durations, and both versions of the task produced lower tracking accuracy at shorter display durations. The observed drop in tracking accuracy from single to complex performance, however, is of note, with an average difference of not even three percent of performance. Such a preserved processing ability in a complex

span task, in addition to comparable memory performance between conditions, directly conflicts with an account of task performance which does not allow for independent resources dedicated to processing and to storage performance. A second experiment in which articulatory suppression was employed throughout the complex span task obtained similar results, indicating the maintained high performance levels in recall and processing could not be attributed to use of supplementary verbal coding.

Duff and Logie (2001) again demonstrated – using verbal stimuli - that processing and storage components of a complex task showed only a relatively small decrement in performance compared to when executed alone. Participants were required to complete a sentence span task in which a verification response for each statement was recorded, as was accuracy in recall of the final words for a series of sentences; each of the sentence verification and memory tasks were initially completed separately. In the verification task participants were required to respond to an increasing number of sentences in a given ten second time limit; as the number of sentences to respond to increased the time allowed for each decreased in proportion and thus difficulty in processing increased. This procedure continued until participants could no longer correctly verify sentences for two out of three trials at a difficulty level; span was taken as a mean of the last three sentence lists correctly verified. In the single memory task participants recalled a series of words in the order in which they were presented; list lengths of words to be recalled progressed from two to a maximum of eight, terminating at the last level at which participants were able to correctly recall all items in two out of the three administered trials. A measure of span was taken as a mean of the last three correctly recalled sequences. When these tasks were combined to produce a complex span participants were therefore required to process sentences with progressively less time allocated to each, as well as recall more items, as list lengths increased. Performance in this case was terminated when both components of the task were no longer correctly performed at two out of three repetitions – that is, if one task component was performed poorly, the task continued until this was also the case for the other component. Measure of span for each component of the task was then calculated in the same way as for single span.

Comparison of single and complex performance revealed that while there was a small, significant drop in performance, each task was still performed considerably well – with performance for each component remaining at, on average, around seventy percent of respective single task performance. This pattern of results was replicated in a second experiment in which an operation like task (verification of sums, and memory

for unrelated words presented simultaneously with said sums) performed to span level leads to a significant yet small drop in performance on processing and storage measures in comparison to single task performance. An average of eighty percent of single task performance was maintained in memory storage, while complex span sum verification was not significantly different from single sum verification task performance. Similar findings were again demonstrated (Logie & Duff, 2007) when, in a parallel experimental set up, the processing task to be completed was arithmetic verification and the items to be recalled were the two digit items given at the end of the arithmetic sum (item to which 'true' or 'false' judgement is given). Recall was shown to improve (Experiment 1) or stay the same (Experiment 2) when performed in complex compared to single task conditions, while verification performance showed a slight fall in accuracy. Overall performance was shown – via a combined average of percentage change exhibited in processing and in storage – to remain in dual task conditions at a level of 94% (Experiment 1) and 98% (Experiment 2) that of single task performance.

Waters and Caplan (1996) strongly argued for use of measures of complex span performance in addition to that of recall. As previously noted, Waters and Caplan (1996) demonstrated the informative nature of the correlation pattern found between storage and processing performances. The same study further revealed the separability of storage and processing resources, highlighted the potential contribution of reaction time data in understanding complex span task performance, and challenged the widely held belief that recall measures hold the most value in predicting comprehension skill.

The recorded reaction time responses to sentence judgement did *not* show a corresponding linear increase to increasing list length of sentences to be processed and items to be recalled. This measure of reaction time was termed 'processing efficiency' and the observation that processing efficiency need not steadily decline when task difficulty is increasing, though recall accuracy is declining, emphasises the limitation in using recall data to interpret complex span performance. Such a point was further stressed by revealing the range of reaction times present when participants are performing at span; with a range of 2.2 to 11.5 seconds there is the distinct possibility that the same task is being performed in different ways.

Waters and Caplan (1996) assessed correlations between reading comprehension ability (as measured through Nelson-Denny reading test comprehension scores) and both recall measures of sentence span and a measure of processing ability - a z-score measure comprising processing reaction time data and

error performance in sentence span judgements. Furthermore a composite score was created which represented recall, reaction time, and error performance. It was observed that a (dual determined) processing measure and the composite score correlated highly with reading comprehension, both of these correlations were at a level of nearly double that found between recall and comprehension.

Within the Waters and Caplan (1996) study a number of additional working memory measures were taken, including digit span, number generation, novel shape generation tasks and reading span performance (measured via recall score). Together with a z-score measure of recall from sentence span performance and the aforementioned sentence processing (dual) measure, these measures were all subjected to factor analysis; four factors emerged which represented numerical, shape, processing and (complex span) recall performance. That sentence processing and complex span recall loaded on different factors further indicates the separability of the measures. The differential predictive value of each of the measures of interest for reading comprehension ability was evaluated with a series of regression analyses. Using the four scores derived from the factor analysis and, in addition, a Nelson-Denny vocabulary score, preliminary multiple regression indicated that only the vocabulary, processing and recall factors emerged as significant predictors of reading comprehension. Three subsequent stepwise regression analyses followed, in which each of these three measures were in turn forced in as initial predictor. This method established that the sentence processing factor accounted for a further 42% of variance in reading comprehension score after an initial 11% was accounted for by the recall measure. A direct comparison in which recall performance was added directly after sentence processing is not available, however, a regression with predictors in the order of 'processing, vocabulary, recall' found that each measure accounted for 42%, 18% and 4% respectively. It is therefore evident that while much research has focused on the predictive value of the recall measure of a complex span task (e.g. Engle, Tuholski et al., 1999; Daneman & Merikle, 1996) the predictive value of a sentence span processing measure for reading comprehension appears to be notable. Moreover, in the above described study, processing predictive value was considerably larger than that of the corresponding recall measure.

A study by Bayliss, Jarrold, Gunn and Baddeley (2003) provided further evidence against a single pool of resources underlying both processing and storage components of complex span performance. Bayliss et al. tested children (average age eight years) on four different versions of a complex span task. These WMC tasks were

the product of combining two different (verbal and visuo-spatial) processing requirements with two different (verbal and visuo-spatial) storage components. Storage and processing tasks were also performed in single task conditions. Verbal processing required matching coloured squares from a grid to a given word (representing an item that would possess a specific colour), while verbal memory was for individual digits presented after each processing item – to be recalled in order. visuo-spatial processing required the subject to view a display and find a target (a circle among circles identified by a distinctive form characteristic), visuo-spatial memory required remembering the location of each target in the processing task it was paired with – specifically, the location of a circle in visuo-spatial target detection or the location of the appropriate colour square from the verbal matching task. Simple visuo-spatial memory required remembering sequence of locations highlighted within the display otherwise used in the target-detection task. Processing efficiency in single task performance (finding colour or finding target) was indexed by reaction time data, and storage performance was measured by span performance (until no longer successfully recalling two out of three trials at a given length). From complex span performance, only a recall measure was taken.

Performance in processing and storage tasks when performed alone was assessed for predictive merit with respect to complex span recall. In a series of hierarchical regression analyses each of the four complex span performances were used, in turn, as the dependent variable. As possible predictors, reaction times from *both* processing performances and only 'relevant' storage measures were entered - that is, the visuo-spatial single storage measure was entered when the complex performance to be measured was visuo-spatial storage based. Analogously, when the complex spans were verbal storage based the relevant regressions utilised a single verbal storage measure of performance in addition to the processing efficiency data. For each complex span a subsequent hierarchical regression was performed, in which the order of entry of predictors was inverted, to assess possibility of independent variance accounted for by each separate measure. It was found for all complex span performances that (domain specific) simple storage performance accounted for variance over and above that accounted for by processing measures. For verbal processing based complex spans, processing was also found to account for variance in addition to that accounted for by simple storage; for visuo-spatial processing based complex spans, there was no significant contribution of processing efficiency following variance accounted for by simple storage measures.

Bayliss et al. (2003) also evaluated the determinants of complex span performance through factor analysis. It was observed that three factors emerge to represent the data – a processing factor – on which reaction time data and verbal processing based complex spans (as measured through recall) load, a verbal storage factor (featuring loadings of simple verbal and complex verbal-storage based recall measures) and a visuo-spatial storage factor (simple spatial and complex spatial-storage based recall measures). The results of regression and factor analysis led Bayliss et al. (2003) to conclude span performance is determined by both domain specific storage and domain general processing efficiency. When complex span measures featured visuo-spatial processing, the basis for this conclusion appears to be less secure; however, this was attributed to the possibility that a less demanding visuo-spatial processing task (in comparison to the verbal processing task) had been used. The study also assessed the relationship of the residuals obtained from the regression analyses to measures of higher order cognition (as indexed by Ravens coloured progressive matrices, mathematics and reading tasks). It was observed that residuals from complex span performance which was verbal storage based were correlated with mathematic and reading performance, however, visuo-spatial storage based complex span performance residuals did not correlate with measures of higher order cognition. The authors interpreted the residuals as representing the ability to coordinate performing processing and storage functions at once - that is, as the third conceptualised component to a complex task performance. The apparent influence of storage domain on this measure led Bayliss et al. (2003) to emphasise that the nature of storage domain is reflected in the predictive utility of complex span task performance.

Bayliss et al., (2003) replicated the above study with adult participants, using ability appropriate versions of the same tasks and with the amendment of increasing the difficulty of identifying a target in the visuo-spatial processing. The results from this group in factor analysis again produced three factors – visuo-spatial storage (simple and visuo-spatial storage based complex), processing, and verbal storage (simple and verbal storage based complex) loadings respectively. Regression analyses with this group (as performed in Experiment 1) revealed that, for adults, verbal processing/verbal storage complex span recall was predicted both by processing and by storage independently of any variance shared between the two measures; processing and storage were both found to contribute individual variance to prediction of verbal processing/visuo-spatial storage complex span and visuo-spatial

processing/verbal storage span was predicted by both processing and storage measures when entered together. Visuo-spatial processing/visuo-spatial storage complex span does not appear to be predicted either independently by a processing measure or by variance shared between processing and storage; only storage performance is shown to predict complex span performance. With respect to visuo-spatial processing based complex span tasks the authors again suggest the contribution of processing ability to performance may depend on the difficulty of the task. Correlations of measures of higher order cognition (Raven's progressive matrices, and age appropriate mathematic and reading assessment) with residuals from these regressions indicated no strong, reliable relationships. Bayliss et al. (2003) did note, however, that for adults, there appears a closer relationship between residuals from all complex span regressions and Raven's performance which they held indicated that a measure from complex span, independent from storage or processing efficiency, was related to fluid intelligence.

Another study by the same authors (Bayliss, Jarrold, Baddeley & Gunn, 2005) further investigated the apparent finding that domain general processing and domain specific storage contribute to complex span performance. In particular the study sought to address the possibility that the predictive utility of residuals was storage domain dependent. Moreover, a related experimental confound was amended; the tasks of Bayliss et al. (2003) differed in composition between the domains - verbal information to be remembered was not a part of the information which was to be processed, while visuo-spatial recall information was integrated within the processing tasks. In a study with children (average age of eight) the general structure of the first experiment by Bayliss et al. (2003) was replicated with the exception of ensuring that visuo-spatial recall information was also separate from that which is processed (memory task requirement was changed to a series of locations within an array, each location presented after each processing episode). The study was not replicated in an adult population.

A factor analysis akin to that of Bayliss et al. (2003) was not performed by Bayliss et al. (2005), however, an examination of correlations between all the measures taken in the study revealed that recall in all four complex spans showed correlations with the three measures of higher order cognition; these correlations were of the same magnitude as those found between simple spans and the three measures of ability. The regression analyses differed slightly from those of Bayliss et al. (2003) as reaction time data ('processing efficiency') entered in to each analysis was from the task-relevant

single processing measure (e.g. only visuo-spatial processing reaction times were used to predict visuo-spatial processing based complex span performance). The series of hierarchical regressions, and subsequent reverse forced entry regressions, enabled assessment of independent predictive variance; for all regression analyses task relevant storage independently predicted span performance whereas reaction time did not significantly contribute. Residuals derived from these regression analyses showed correlations between verbal storage based span tasks and all three measures of higher order cognition; residuals from visuo-spatial based complex span regressions did not significantly correlate with any of the measures. Thus, as was suggested in the earlier studies (Bayliss et al., 2003), it appeared that the domain of storage component of the complex span task influences the predictive nature of the residual variance. That this domain specificity exists prevents the authors from interpreting the residual measure as reflecting a coordination of performance, rather Bayliss et al. (2005) suggest a general executive resource account of the data. It was argued that executive resource contribution is removed from complex span recall performance when visuo-spatial storage variance is removed and therefore is not present in any resulting residual.

A recent comprehensive study (Unsworth, Redick, Heitz, Broadway & Engle, 2009) has adopted and further extended the approach of Waters and Caplan (1996), and Bayliss and colleagues (2003; 2005) by undertaking a latent variable approach (using multiple complex span tasks) based on measures of processing accuracy, reaction time and recall data. The relationship of these various measures of complex span to each other and their shared or independent relationships to higher order cognition (HOC) were assessed. Three complex span measures from three different domains were employed in the study: numerical, verbal and visuo-spatial. Each task was performed to a certain level by all participants and three times at each level. An operation span (Turner & Engle, 1989) task required verification of sums combined with memory for a series of letters, a modified reading span task (Daneman & Carpenter, 1980) required 'sense' judgements of statements combined with memory for a series of letters, and a symmetry span task (Kane, et al., 2004) required judgment as to the symmetry present or not in half filled matrices, combined with memory for a series of locations presented in matrices (locations to be recalled were in a different matrix and of a different colour than processing information). Measures of recall were computed through a total score method (number of correct items in correct position over the course of the whole task), measures of processing accuracy through proportion of items correctly responded to over the whole task, and processing time

was the mean time of each participant over the course of each task. In this study all processing accuracy, reaction time data and recall measures were taken from complex span performance rather than obtaining processing or storage measures from a component task performed by itself (as was the case in studies by Bayliss et al., 2003; 2005). A number of different measures - covering numerical, verbal and spatial domains - were taken to index higher order cognition (see Unsworth et al., 2009, for details) and taken together the resulting latent variable using these measures was believed to represent general fluid intelligence (Gf).

Correlation data of Unsworth et al. (2009) revealed processing accuracy and storage measures were highly related and this relationship was comparable across domains. Processing time correlated negatively with both recall and accuracy measures; processing time correlations were equivalent across domains. Confirmatory factor analysis found a three factor model representing recall, accuracy and processing time was the best representation of the data. Alternative models - including those with factors arranged around domain specificity, a model representing only a single factor for all measures and a model with measures divided into processing and storage factors - were significantly less accurate in portraying the data. The latent variables of recall, accuracy and processing time in the best-fit model were each shown to correlate highly with the Gf variable; this was taken as further evidence that each measure of complex span performance represents "slightly different processes" (Unsworth et al., 2009, p646).

Mediation analyses using SEM revealed that both processing measures (reaction time and accuracy) mediate the relationship between recall performance and Gf, however, they show that a partial mediation model is a better fit of the data than a full mediation model. The dual indication of independent and shared variance between the measures was further investigated; Variance partitioning analyses were conducted in order to identify the relative magnitude of independent and shared contributions to explained variance of Gf. It was established that processing accuracy, reaction time and recall measures each made independent contributions to explaining the variance found in the latent variable representing Gf. There was also shared predictive variance between all three of these measures - 16% of the 69% total explained variance. While this shared variance was the largest single section of the explained variance, Unsworth et al. (2009) still identify it as a rather small proportion of total explained variance. Shared variance between every combination of any two of the three measures was also revealed, however, these shared variances were small. Moreover, while storage

performance was shown to account for a lot of Gf variance (42%), removing the variance shared between storage performance and processing accuracy or between storage and reaction time led to a considerable drop in this predictive value. The finding that all three recorded measures of complex span performance possess predictive utility for higher order cognition, through a number of shared variance combinations and – especially - independently, is of notable consequence. As Unsworth et al. (2009) point out, there is currently no theoretical account of complex span performance which would adequately predict all the revealed relationships between complex span measures and their relation to measures of cognitive ability.

Multiple component model interpretations of complex span performance

Duff and Logie (2001; Logie & Duff, 2007) proposed that complex span task performance, specifically the mounting evidence of separable resources underlying performance, is best explained by the multiple component model (Baddeley & Logie, 1999). The given interpretation of the verbal complex span findings of Duff and Logie (2001) held that the central executive was responsible for performing the processing aspect of the span task and the phonological slave system supported maintenance of final words for recall, employing subvocal rehearsal. Duff and Logie (2001) interpreted the *slight* drop in performance found when combining a processing and a storage component, both performed at span level, as the cost of a working memory system coordinating performance on two tasks. This coordination ability is attributed to the central executive, however, they posited that this cost of coordination could manifest both in processing and also in storage performance, due to the possible requirement of executive processes in encoding or retrieval of the stored information.

Further evidence against a domain general model of resources is also found in the previously described study of Duff and Logie (1999). Requirement to undertake articulatory suppression (Experiment 2) in addition to performing a visuo-spatial complex span did not lead to appreciable decrement in performance; this is not compatible with a domain general model of shared resources, as a domain general model would suggest that articulatory suppression is a third cognitive load (in addition to processing and storage) to compete for finite resources. The multiple component model accounts for the observed finding by assigning the role of supporting articulatory suppression performance to the phonological loop whose resources are distinct from those of the visuo-spatial system. The multiple component model would

thus make the accurate prediction that visuo-spatial complex span performance should not be affected by a verbal task.

Such an assertion is in line with the previously recounted recent findings that recall measures of complex and simple span tasks are equally predictive of higher order cognition (Unsworth & Engle, 2007a), share a number of experimental manipulation effects indicating a common rehearsal and storage mechanism (La Pointe & Engle, 1990; Unsworth & Engle, 2007a), and the conclusion from latent variable analyses these two recall measures reflect one rather than separate constructs (Unsworth & Engle, 2007a). It is also compatible with the above evidence that the separate measures of complex span tasks – processing time, accuracy and recall – hold independent predictive utility for higher order cognition, suggesting dissociable resources (Bayliss et al., 2003, 2005; Unsworth et al., 2009). The complex pattern of shared predictive value between accuracy, reaction time and recall (Unsworth et al., 2009), however, has not yet been addressed explicitly by the multiple component model interpretation of complex span performance.

Bayliss et al. (2003) concluded their findings were compatible with the model of Baddeley and Logie (1999), and asserted an analogous interpretation of complex span performance to that recounted by Duff and Logie (1999; 2001), such that storage would be provided by slave systems and processing would recruit domain-general resources. The residual variance, however, found after removing variance shared with processing efficiency and simple storage, initially interpreted as ‘coordinating ability’ (Bayliss et al., 2003) and later as executive resources (Bayliss et al., 2005) required for verbal complex but not simple storage performance (recruited in both simple and complex visuo-spatial), necessitates an explanation of processing impact on recall performance. Moreover, though simple and complex span recall measures were equally predictive of cognitive abilities, the residual variance in complex span recall once variance shared with simple span was removed was still predictive of higher order cognition. This was found even though the complex task storage items were not a part of the processing information and were thus presented for recall in a manner more akin to that of a simple storage task. The authors asserted that the presence of independent predictive value of complex span recall indicates simple and complex tasks may use a common storage system, yet are performed somewhat differently – that is, storage operations may constitute less of the variance evident in complex span performance than they do in simple span performance.

A dissenting view within the multiple component tradition is that of Baddeley (2001, 2003a, 2003b; Repovs & Baddeley, 2006) who has stated that a multiple component model without the presence of the episodic buffer component (Baddeley, 2000) cannot account for performance of a complex span task. The basis of this assertion appears to be that, for example, in the reading span task (Daneman & Carpenter, 1980) the verbal storage system would be overloaded by the volume of information to be both processed and stored (Baddeley, Hitch & Allen, 2009). This is essentially a variant of a critical view of the multiple component model explanation of complex task performance which claims performance of the verbal processing task would impede storage and rehearsal of words for recall - that is, a verbal processing task would produce articulatory suppression (Kane et al., 2008). The episodic buffer is posited as a multimodal store, however, and earlier studies have suggested the involvement of the phonological loop and a phonological code in complex span recall. Loblely, Gathercole and Baddeley (2005), for example, show that complex span recall performance (using an auditory version of sentence span) and simple recall performance demonstrate common experimental effects. Use of a common code in simple and complex tasks has previously been argued against (Tehan, Hendry & Kocinski, 2001), due to an apparent lack of phonological similarity effect (poorer recall of phonologically similar words) in complex recall. Loblely et al. (2005), however, replicated an experiment conducted by Tehan et al. (2001) with improved methodology - use of phonologically similar or dissimilar words without a previous confound of rhyme, and list lengths increasing to span length rather than at a set level of four sentences. Loblely et al. demonstrated better recall of phonologically dissimilar words in complex span tasks. The presence of a phonological similarity effect suggests the phonological loop, specifically indexed by the phonological store and a phonological code, supports recall in a verbal (auditory) complex span. The possibility of interference with memory of words for recall, resulting from a verbal processing task, is, however, acknowledged. While Loblely et al. (2005) provide no reference to the episodic buffer as comparative explanation for these results, elsewhere the episodic buffer has been suggested to interact with and be supported by the phonological loop (Baddeley et al., 2009). The possible role of the episodic buffer in complex span performance is currently underspecified.

Complex span performance

Turner and Engle (1989; see also La Pointe & Engle, 1990) suggested the predictive value of complex span recall for reading comprehension (compared to apparently poorer simple recall predictive value, e.g. Daneman & Carpenter, 1980; Turner & Engle, 1989, Experiment 1) was due to restriction of rehearsal- or any other strategy for the recall of words –because of ongoing processing. This claim was strengthened by the finding that increasing the difficulty of the processing task in a sentence span task (by addition of phrases and changing of voice from active to passive) and in operation span (by increasing number of steps in arithmetic) affected the correlation of the respective to-be-remembered word and digit recall performance with the comprehension measure (Turner & Engle, 1989 Experiment 2). Increased difficulty (from easy to medium difficulty) increased the correlation found between the recall and comprehension measures. It was posited that increased difficulty lessened the likelihood of rehearsal and when rehearsal was limited a truer measure of the ability of an individual's system to maintain items in the face of processing was obtained. This ability was proposed as the link between complex span performance and higher order cognition.

Towse, Hitch and Hutton (1998) demonstrated that recall performance on three complex span tasks (counting span, operation span, and reading span) could be reduced by altering the length of processing task components. This was shown, in a study with children (aged between 6 and 11), by manipulation of the order in which processing information was to be carried out; despite the given manipulation, the same recall information and the same overall task time was required in all instances. Three different lengths of processing episodes (long, medium and short) were created for each of the span tasks; these lengths were not specifically defined times, rather they corresponded to amount of information to be processed - for example, in counting span a long processing episode would consist of counting a large number of items and would therefore take longer to process than when less items were to be counted. When, in a complex span of four processing and storage episodes (list length four), a longer processing episode was performed first followed by two medium and finally a shorter processing sequence, this required that recall information (resulting from the end of each processing episode) had to be held over a shorter duration than when order of completion was short, medium, medium, long. Where short processing was performed first, time over which information had to be held contained longer processing periods

and therefore required storage items to be maintained for a longer time. This result was replicated in an adult population (Towse, Hitch & Hutton, 2000) where the same experimental set up showed that longer retention time (taken from the first point at which storage begins) negatively affects sentence and operation span performance. Towse et al., (1998, 2000, 2002) propose a task switching performance underlies complex span completion whereby maintenance of items is not performed during completion of processing tasks – that is, only one of the task components is performed at once. Therefore, longer time taken for processing leads to a longer task time over which information has to be held and this increases the chance of time based decay of the recall information. Time over which information cannot be rehearsed due to completion of processing tasks is time in which information will decay; performance of a long processing section last entails having to hold all accrued storage items over the longest processing period (as compared to when long processing was performed first and no memory items were being held). Such an explanation of processing time could also be applied to the results of Turner and Engle (1989). That is, decrease found in span performance apparently resulting from increased difficulty could be reinterpreted as due to longer processing time; difficulty increase had involved an increase in number of presented pieces of information to be processed. This interpretation of complex span performance leads to, as Miyake (2001) points out, a proposed '*indirect relationship*' between separable processing and storage components of a complex span task whereby processing performance is reflected in recall measures.

Turley-Ames and Whitfield (2003; see also McNamara & Scott, 2001) demonstrated that strategies such as rehearsal of to-be-recalled items between completing processing episodes can be deployed (in this study, under instruction) in complex span tasks and that use of strategy increases span performance. It was also shown that uniform strategy use among participants increases the correlation with higher order cognition (as measured by reading ability). It was therefore offered that a varied use of strategies by participants in many complex span tasks may limit the information contained in any correlation otherwise found between span performance and cognitive ability measures; rather than span recall scores reflecting system performance in the way proposed by Turner and Engle (1989) and La Pointe and Engle (1990), performance could be contaminated by differences in the way in which the task is performed. Friedman and Miyake (2004) examined the differences brought about by using two versions of a self paced reading span; processing episodes were either terminated by the experimenter (experimenter terminated) as soon as a sentence had

been read aloud, or were terminated by participants themselves (participant terminated) when they had finished reading. It was found that correlations with reading comprehension and verbal SAT are higher for experimenter terminated span performance. Participant terminated performance did produce higher span scores and significantly longer processing times and, furthermore, within the participant terminated group, slower processing time produced higher span scores. Friedman and Miyake (2004) suggested that this indicates extra time was taken in PT performance in order to increase recall and this led to reduced correlations with comprehension. However, a series of regression analyses showed that, overall, processing time itself was not responsible for the relationship between recall and comprehension. This relative lack of consequence of processing time to span and comprehension correlations was highlighted as evidence against the theory (Towse et al., 1998, 2000) in which recall performance is determined by amount of processing time.

In a recent study (Saito & Miyake, 2004), the task switching and decay based theory of Towse et al. (1998, 2000) was investigated following the observation that Towse et al. confounded amount of processing to be completed with time over which this processing was to be carried out. Saito and Miyake (2004; Experiment 2) manipulated the methodology of Towse et al. (1998) by adopting computer administered presentation of segments within a processing episode (e.g. sentences to be processed presented word by word). This allowed control of time spent on segments of a processing episode and, consequently, on each whole processing episode. In agreement with the findings of Towse et al. (1998;2000) slower presentation, and thus processing, in the final processing episode of a trial (when more items are to be maintained) resulted in poorer recall than did faster presentation at the end of a trial. The suggestion of Towse et al. (1998, 2000) of task performance and related decay over time was challenged, however, in a third experiment where time of presentation was equalled for a given processing episode, but amount of information to be processed was varied. This was accomplished by varying the amount of processing – a large amount or a small amount – to be done in a given time; three segments per processing episode were used, and each contained a more (large) or less (small) information to be processed in set time onscreen. An effect of the order of completion (that is, worse performance when larger processing is undertaken last) was still found despite equivalence of presentation time. A fourth experiment was administered where amount of items to be processed was held constant and time was varied. Short duration sentences comprised three large segments and long duration sentences comprised six

small segments, timing of *every segment* across conditions was equal. Overall therefore, sentences had the same amount of verbal information to be processed but differed in the pacing and overall presentation time. In this fourth experiment there was no finding of recall differences when the final processing episode of a trial was of short or long duration. Saito and Miyake (2004) summarise that the results negate the proposal (Towse et al., 1998, 2000) that duration of retention determines effect of processing on recall and therefore question the proposal of a decay of memory over time as determining span performance. Saito and Miyake propose, however, that a task switching theory of performance can still hold if a representation based interference account is adopted rather than that of decay over time; greater amounts of processing (as shown in Experiment 3) will prove more detrimental to recall, whereas a constant amount of processing over a variety of different times (Experiment 4) does not produce differential disruption to recall. Representation based interference would, however, be somewhat difficult to reconcile with the previously recounted experimental findings which have shown that the presence of a processing task proves to have little effect on recall performance -even when processing and storage are of the same domain (Duff & Logie, 2001) – unless representation based interference effects are predicted to be very small. Even if representation effects were small this would not account for the finding of constant differences between complex and simple recall performance (Duff & Logie, 1999, 2001), as at longer list lengths more processing is carried out than at shorter list lengths.

A further conceptualisation of task performance proceeded to produce a theory of working memory composition. Barrouillet and Camos (2001) assessed (in a study with children aged 8-11) the processing time and associated decay theory proposed by Towse et al. (1998). Barrouillet and Camos tested children on a counting span (Case et al. 1982) which required them to count out loud the number of items in a processing episode, subsequent to each processing episode a letter was presented and these letters were to be recalled at the end of a trial. Timing for counting each card in the counting span task was recorded and used in a corresponding 'complex' task where processing comprised only articulatory suppression. Participants' timing from the counting task was used to dictate how long each participant was to articulate the word 'baba'; recall was for letters presented at the same point in time at which they had occurred in the counting span task. No difference in recall of items between these two tasks was found. In older children (9 years and 11 years) a similar experiment, in which operation span was substituted for counting span, showed that operation span recall

was poorer than a time matched articulatory suppression condition. These findings were suggested as evidence for both time based decay – that is, recall is subject to disruption from *any* processing episode (after Towse et al., 1998) - and also evidence of a trade off in resources whereby a more difficult processing task produces a bigger decrease in recall (notably, however, operation recall performance was observed to be a relatively small 20% less than corresponding baba recall). It was proposed that a model which considers both decay and shared resources was needed to account for the data.

Barrouillet, Bernardin and Camos (2004) proposed a time-based resource-sharing (TBRS) model in which attention is proposed to underlie both processing and storage; when attention is engaged in a processing task it is unable to sustain memory representations which will otherwise decay over time. Equally, when attention is given to refreshing memory items, processing cannot be supported. It is believed that, rather than *complexity* of a processing task, the limiting effect of a processing task on attentional refreshing is in the form of opportunities within a given processing episode to quickly switch attention to memory representations before resuming the processing task. In a series of experiments in which internal pace within processing components on a number of complex span tasks were varied – that is, number of processing operations to be carried out in relation to any given time for a processing episode – pace was shown to determine recall performance. This effect was termed cognitive load (CL) and the authors thus hold that even a simple task, completed at a fast pace, will result in a high cognitive load and poor recall.

Lewandowsky, Oberauer and Brown (2009a) argue against a decay based explanation of loss in serial memory recall and highlight that a single processing item following memory items can produce disruptive effects that are not increased by increasing the number of items and resulting time of processing (Oberauer & Lewandowsky, 2008). Lewandowsky et al. (2009a) also reveal that data which has previously been interpreted as decay due to a number of difficult processing episodes occupying attention (Portrat, Barrouillet & Camos, 2008) can, when re-analysed, show poor recall as attributed to post-error monitoring on difficult stimuli reducing the amount of time given to refreshing the items for recall (that is, rather than poorer recall resulting from decay results can be explained by insufficient refreshment). Furthermore, Lewandowsky, Oberauer and Brown (2009b) point out that the TBRS is unable to account for phonological similarity effects, or predict some basic findings in serial recall tasks such as serial position curves.

The most recent version of the TBRS (Camos, Lagner and Barrouillet, 2009) proposes both a code specific rehearsal mechanism and a central attention mechanism (not code restricted) which serves to refresh information to be maintained; these rehearsal and refreshing mechanisms work together to support maintenance of to-be-recalled information. Camos et al. (2009) note that, throughout the literature, when articulatory suppression is employed there still remains a residual number of items which can be recalled; Camos et al. propose that it is the attentional refreshing mechanism which allows this continued maintenance, by reactivating representations through allocation of attention. As in previous models of the TBRS, this attention – when engaged in a processing task – is not available to preserve activation of items for maintenance. This version of the model is illustrated with a series of experiments which sought to establish the independence of attentional refreshing and rehearsal mechanisms. In an complex span set up in which processing requires either completion or reading aloud of simple arithmetic equations (and recall of letters presented following these operations) attentional demand is defined as lower for reading while higher for completion; a factor of the task which was considered to affect rehearsal was kept constant between these conditions – the number of words articulated was equal in both attentional variations. Pace of presentation was determined by presentation of items and not by participant response (this factor was manipulated, however does not contribute to information here). Completion of sums was found to produce worse complex span recall performance than did reading, indicating an effect of attention on maintenance. In a second experiment attentional load was kept constant while articulatory suppression factors were manipulated; judgments to a series of digits (each series presented within one processing episode, each item in a series requiring a response) were responded to by either button pressing (low articulatory suppression condition) or by voicing a one word judgment (high articulatory suppression condition). Span performance was revealed as poorer in the high articulatory suppression condition. It was also noted that speed of responses to presentations indicated that processing performance was near constant, which suggests rehearsal was – in the low articulatory suppression condition – performed at the same time as processing, again indicating separability of the rehearsal and attention mechanisms.

A further experiment (Camos et al., 2009, Experiment 4) varied both attentional demand and articulatory suppression variables within the same experiment. Attentional demand was considered low in the processing task by requiring identification of a number in sequentially presented numbers or high by requiring what

was essentially performance of two sum verifications per processing episode (items presented sequentially). Articulatory suppression was manipulated by requiring participants, while responding to the processing task by key press, to either voice aloud the task they were performing (high suppression condition) or read the task silently (low suppression condition). Additionally pace was manipulated by slow or fast presentation of items. Results showed that each factor had an effect on recall performance in the manner indicated by the first two experiments and, additionally, faster pace resulted in poorer recall - reinforcing the idea that time pressured attention processing results in a poorer recall (Camos et al., 2009). The authors further note that the lack of an interaction between attention and suppression effects establishes the independence of these mechanisms. It appears, however, that there is also a lack of an interaction between attention manipulation and pace with the details of effects revealing that an effect of attention task is found in a slow pace condition while no effect of attention task is found at a fast pace. While this latter finding could indicate that under time pressured conditions participants are already continually using attention - as an effect of attention demand was previously found at fast pace (Experiment 1) this is a somewhat strange result and it is not specifically addressed by the authors.

Camos et al. (2009) concluded that attention and rehearsal, while independent mechanisms, "*work jointly on the same memory traces*" (Camos et al., 2009, p467) as the effects of both manipulations were additive; there was a larger decrement in performance when both attention and rehearsal were prevented from maintaining memory representations (Experiment 4). It was therefore asserted that format of information representation is multimodal (including phonological features), and consequently that the TBRS is not compatible with a multiple component model (Baddeley & Logie, 1999) in which a storage system is code specific (the phonological loop) and does not involve domain general attention (the central executive) in maintenance. It is proposed that the addition of the episodic buffer (Baddeley, 2000), which allows for a multimodal store and executive involvement in maintenance, is a more congruent conceptualisation. A problem in the form of crosstalk between - and dual representations in - the phonological loop and the episodic buffer would, however, produce a level of complexity that is not addressed by the TBRS (Camos et al., 2009). While the latest version of the TBRS makes moves to address some of the earlier criticism of a purely attention and decay based model (Oberauer & Lewandowsky, 2008; Lewandowsky et al., 2009ab) some predictions resulting from a TBRS model in

which attention is allocated both to processing and to maintenance appear irreconcilable with data such as that of Duff and Logie (1999, 2001; Logie & Duff, 2007) in which participants perform processing and recall tasks at their individual maximum ability. Participants are found to achieve complex span recall at a level only slightly below that of simple span recall while performing processing tasks presented at speed equal to that of their maximum performance in a single processing task condition (Duff & Logie, 1999, 2001; Logie & Duff, 2007). Moreover, participants' reaction times were shown to decrease (Duff & Logie, 1999, 2001) or stay stable (Logie & Duff, 2007) across list lengths in complex conditions. These studies, in which it is evident that participants are performing tasks at their maximum capability, potentially provide a more secure measure of the effects of processing demand or speed as compared to conditions in Camos et al. (2009) which are defined a priori as representing 'slow' or 'fast' pace and 'high' or 'low' demand.

Of specific interest: Complex span and visuo-spatial resources

Domain specificity in resources underlying both storage and processing components of complex span tasks was indicated by Shah and Miyake (1996) in an investigation of spatial span composition. A letter rotation task was developed as a visuo-spatial analogue to the reading span task; a series of letters were presented in a variety of orientations and for each letter participants were to respond whether the letter was presented in a normal or a mirror image format – at the end of each trial participants recalled the location of where the top of each letter had been rotated to, in the order in which these locations had occurred. Performance on this task, and on all other memory tasks that they used, was measured by recall span performance and this was determined by the last level at which three out of five trials were correctly performed. Additional marks were added if participants obtained two out of five items correctly at the level above this³. In the first of two experiments participants completed two WM tasks (reading span, letter rotation), three tests to index spatial ability and a task measuring perceptual speed; verbal SAT scores (scores from academic testing) were reported by participants and included in the analysis. A simple visuo-spatial span was also employed in which a sequence of centrally presented arrows, each of a different orientation, was shown to participants and at the end of a

³ A total number of items correctly recalled score was also obtained, but not reported as it was "highly correlated with the span measure ... and yielded essentially the same correlational results" (Shah & Miyake, 1996, p9).

trial of a given list length participants were required to indicate, on a response grid, the orientation of each arrow in the order in which they had occurred. While each memory score was represented by span performance, scores from the spatial ability tests were transformed into z scores and combined to produce a single measure. Spatial WM span was found to correlate significantly with this spatial ability measure ($r=.66$), as did the simple visuo-spatial span ($r=.62$). However, neither of these memory tasks correlated with the verbal ability measure (SAT scores). Conversely, reading span correlated significantly with verbal ability ($r=.45$), but not with spatial ability. Furthermore, spatial span and reading span produced only a low, non-significant correlation. Spatial WM and simple span were significantly correlated ($r=.52$) and it was further shown through partial correlations that both of these tasks were still correlated with the spatial ability measure when variance shared with the other was controlled (spatial WM $r=.50$; simple $r=.43$). This last result, together with reports from participants, led Shah and Miyake (1996) to propose that strategy use was employed in simple span in order to deal with large amounts of information. This option was not available in WM task performance due to processing demands, thus different processes were brought into play for completion of simple or complex tasks. Simple visuo-spatial span was also shown to correlate with perceptual speed while neither of the WM spans did. Subsequent factor analysis revealed two factors – each loading on only spatial or verbal measures respectively (while perceptual speed represented low loadings on each factor), indicating domain specificity in resources used to complete simple span, complex span and ability tasks.

Shah and Miyake (1996; Experiment 2) further demonstrated domain specificity in resources underlying both processing and storage completion through manipulation of the combination of processing and storage tasks used within a complex span measure. Four combinations of complex span were created by pairing visuo-spatial processing with visuo-spatial storage and verbal storage, and verbal processing with both verbal storage and visuo-spatial storage. A judgement requirement (true or false) was added to the reading span processing task (to equal the format judgment required in letter rotation). Furthermore, in order to manipulate processing and storage, for combination purposes, to-be-recalled information and information for processing used separate (non-integrated) stimuli. Visuo-spatial storage therefore involved presentation of arrows, of varied orientation, after each processing episode; verbal storage involved presentation of single words after each processing episode. Simple span versions of the verbal and visuo-spatial storage tasks were also

administered. These six measures were performed along with two spatial ability tasks and a reading comprehension measure, with verbal SAT scores again being utilised. The spatial ability measures were combined (as z scores) to create a single, composite spatial score and the same procedure was used for the verbal measures to create a composite verbal score. Processing accuracy was obtained from the processing task of the complex spans. However, this measure was used to confirm there was not a strategic trade off in performance; no assessment of processing performance relationship to ability measures was made. Correlations between target measures again revealed a relationship highly influenced by storage domain: letter rotation-arrow performance correlated with spatial ability ($r=.68$), as did sentence-arrow ($r=.65$) and simple arrow ($r=.63$), while no verbal storage based tasks produced a significant correlation with spatial ability. Verbal ability, however, was shown to correlate with sentence-word ($r=.55$) and simple word performance ($r=.44$) but not with the spatial storage based tasks. While span measures failed to show letter rotation-word performance as correlated with verbal ability this correlation was revealed with total score measurement of complex span performance ($r=.40$). This influence of storage domain was again demonstrated through factor analysis which produced two factors that could be labelled verbal and visuo-spatial, with ability measures loading on the factors corresponding to their domain of information, and with all (simple and complex) task loadings determined on the basis of storage domain.

Domain specificity in resources supporting completion of processing tasks in complex span was revealed through a series of partial correlation analyses using the recall measures of span performance only. The correlation between sentence-word and verbal ability remained significant when controlling for variance shared with both of the other word storage measures ($r=.45$). However, neither simple word span nor rotation-word span performance was significantly related to verbal ability when removing variance shared with sentence-word performance. Rotation-word performance was also not significantly related to verbal ability when controlling for simple word span performance. Spatial (arrow) based storage tasks showed that sentence-arrow performance was no longer correlated with spatial ability once variance shared with rotation-arrow or simple arrow span was removed, however, rotation -arrow was still related to spatial ability when sentence-arrow or simple arrow span performance was partialled out ($r=.39$ and $r=.55$ respectively). As in the first experiment, simple arrow span was still significantly related to spatial ability when rotation-arrow performance was partialled out ($r=.49$). These analyses indicate

firstly, that processing performance has an influence on storage performance and, furthermore, that the effect of processing on storage is domain specific, such that same domain processing and storage combination performance contains additional predictive variance where cross domain and, in the case of verbal stimuli, simple performance does not. Examination of task performance on the basis of the specific processing and storage task combinations was carried out using three measures: processing performance, processing reaction time and recall accuracy. Processing performance revealed no interaction between processing and storage domains - that is, there was no significant difference in either sentence or rotation processing performance when carried out with verbal or with visuo-spatial storage. Processing reaction time, however, did reveal an interaction: while verbal processing time was equal between recall conditions, spatial processing performance was impaired more by concurrent visuo-spatial storage than by verbal storage. Analysis of recall scores provided clear evidence of an interaction: visuo-spatial storage was poorer in the visuo-spatial processing condition than the verbal processing condition, and verbal storage was poorer in the verbal processing condition than in the visuo-spatial processing condition.

The findings of Shah and Miyake (1996) appear to contradict both the claim that, when complexity of the verbal processing task is limited, processing or sentence comprehension does not require use of an immediate memory system (see e.g. Caplan & Waters, 1990; Caplan & Waters 1999 for discussion) and the independence of these tasks as demonstrated in the verbal domain by Duff and Logie (2001; Logie & Duff, 2007; see Loblely et al., 2005). Rather, results appear to give support to positions that information to-be-processed can displace stored information (Engle, Kane et al., 1999; Kane et al., 2008). Alternatively, it could be that hypothesised dual tasking costs (Duff & Logie, 1999, 2001; Logie & Duff, 2007) evident in recall are particularly high for same domain information - that is, that more executive resources are required to carry out two tasks at once when the information in both tasks pertains to the same domain than when the two tasks correspond to different domains.

The work of Shah and Miyake (1996) has been influential, especially in the study of VSWM, however, caution should be taken in interpreting these results. For instance, a practical point of the data analysis is rather unusual; in the second experiment - in which processing domain is examined - recall performance was scored as correct regardless of accuracy in recall of order (although the requirement of order was still present in instructions). This left open the possibility that aspects of recall

could be affected and missed in the analysis. If, for example, maintenance of order is domain general (Jones et al., 1995; Depoorter & Vandierendonck, 2009) - or recruits domain general resources - then serial order or rehearsal could be susceptible to interference regardless of domain of processing, while recall of items without order may reveal largely domain specific disruption due to feature or representation based interference. It is also a possibility that detrimental effects of dual tasking requirements manifest more in serial order than item recall, if - for example - dual tasking affects executive involvement in encoding strategies that are particularly geared to, or based around, maintenance of order. Kane et al. (2004) further critique the methodology and findings of Shah and Miyake (1996) and suggest that the results overestimate the influence of domain specificity in performance. It is noted that participants in the study of Shah and Miyake (1996) are obtained from a single (prestigious) university undergraduate population and are thus likely to be of high general intelligence and ability; Kane et al. (2004) adhere to the belief that controlled or executive attention is, if not synonymous with Gf or general ability, a highly related construct and that this property of an individual's abilities largely determines their performance on WMC tasks (Engle, Kane, et al., 1999). Kane et al. (2004) therefore make the point that a limited or restricted range of Gf in participants will lead to over representation of other factors - such as domain specific storage or processing - which could otherwise contribute minimally to span performance. Miyake and Shah (1999) themselves suggest their earlier study overemphasised domain specificity. Furthermore, Miyake and Shah (1999) point to admission by Engle, Kane et al. (1999) of possible domain specificity as evidence that a general consensus of neither complete domain specificity nor domain generality in the working memory system is held. However, the stance of Engle, Kane et al. (1999) maintained "the specific factors correspond primarily to the domain of to-be-stored information, but the general factor transcends the domain of processing" (Engle, Kane, et al., 1999, p125). The vehemence of argument for domain specific *processing* resources - of any magnitude - in the individual differences literature is therefore small; the possibility of inflation of domain specific effects reduces the impact of the findings of Shah and Miyake (1996), however, the correlation, factor analysis and interference data do appear to identify domain specific effects in processing tasks.

Targeting their investigation of resource allocation to specifically within the visuo-spatial domain, Miyake, Friedman, Rettinger, Shah and Hegarty (2001) examined the relationship of STM to WM and the relationship of each to executive functions. Two

tasks were used to investigate each of VS-STM, VS-WM, and executive functions. Executive functions were measured using a version of the Towers of Hanoi (that is, to be performed with the dictated strategy of goal recursion, see Simon, 1975) and using RNG; these tasks require maintenance of - and navigation through - task goals or strategies, prevention of the intrusion of irrelevant information and inhibition of pre-potent responses (see Miyake et al., 2001, p626). STM was indexed by computerised CBT and a recall task in which participants had to reproduce the location of dots which had appeared within a matrix grid - presentation of items to be recalled in this Dot Memory task (Ichikawa, 1983) was simultaneous in all trials. Two complex span tasks were used to tap VSWM - Letter rotation (Shah & Miyake, 1996, Experiment 1) and Dot Matrix (Law, Morrin, & Pellegrino, 1995) tasks, the latter of which requires verifying a 'visual equation' and recalling a storage item presented subsequent to each processing episode. Visual verification required participants to view, within a single processing episode, two visual displays in which a line appears amongst an array of dots - each line joining two dots together; in a third visual display the presented item is either a correct combination of the two prior displays, or an alteration has been made - participants must judge true or false to this presented combination. Storage within the Dot Matrix task requires recalling a series of dots - which have each been presented within a grid, with one item appearing after every processing episode. All STM and WM tasks were performed to a predetermined list-length level, with participants completing each level five times, and scores were calculated for each task as a total count of all items correctly recalled over the course of the task. The method of scoring thus fulfils recent recommendations for best statistical practice (Friedman & Miyake, 2005), and concerns of theoretically representing supra-span retrieval abilities in simple span are therefore also met (Unsworth & Engle, 2007a).

Miyake et al. (2001) established through confirmatory factor analysis that while a three factor representation of STM, WM and executive functions task performance is an adequate portrayal of the data, the STM and WM factors were also shown to be highly correlated ($r=.86$) and, furthermore, both the STM and WM factors showed statistically equal correlations with the factor representing executive functions. A two factor model, in which the tasks previously labelled STM and WM loaded on the same factor - an STM-WM factor - and the second factor represented executive functions, was found to be as equally representative of the data as the three factor model. In light of the statistical equivalence of the two and three factor models Miyake et al. (2001) recommend a two factor representation of the data in the name of parsimony.

However, this choice has subsequently been questioned, with the proposition that increased power would have led to the detection of non-equivalence between WM and STM, and thus the three factor model would be preferable (Kane et al., 2004). The variance shared in the three factor model by the STM and by the WM factors with that of the executive functions factor ($r=.56$, $r=.55$ respectively), and in the two factor model by the STM-WM factor with that of the executive functions factor ($r=.59$), could suggest an important role for executive resources in STM and WM recall.

Miyake et al. (2001) utilised the parsimonious two factor model of the data for further structural equation modelling (SEM) in which the relationship of STM-WM and executive functions to spatial ability was ascertained. Two tasks were used to tap each of one of three spatial abilities – spatial visualisation, spatial relation and visuo-spatial perceptual speed, and these were represented by three separate factors. SEM revealed the STM-WM latent variable was only related to one of the measured spatial abilities - perceptual speed, to which it shows a small contribution (.38) – when variance shared with executive functions is controlled for. The executive functions variable, however, was still strongly related to all three spatial ability factors when controlling for STM-WM, contributing especially highly to Spatial Visualisation (.91) and Spatial relations (.83), while less so to Perceptual speed (.43). However, the correlation between executive functions and STM-WM was found to be high (.71) and so further analysis, in which shared variance was not controlled for, was conducted. This approach reveals implied correlations between VS STM-WM and Spatial visualisation (.63), spatial relations (.54) and Perceptual speed (.69). Comparison of the relationships indicated by these two analyses shows the difference in magnitude as a result of removing variance shared with executive functions; it was thus suggested that, while VS STM-WM may support spatial abilities, this is largely due to resources linked with executive functions resources.

Importantly for both the interpretation by Miyake et al. (2001) of the results of the study, and for the subsequent impact in spatial STM, spatial WM and complex span literature, the nature of the visuo-spatial STM and WM performance relationship is emphasised as different to that found elsewhere in the verbal domain (Engle, Tuholski et al., 1999); the analysis presented by Engle, Tuholski and colleagues (1999) established that verbal STM and WM were better represented by separate factors, while here visuo-spatial STM and WM shared enough variance to warrant representation as a single variable. Moreover, shared variance between verbal STM and WM performance has been previously attributed to common storage resources (Engle,

Tuholski et al., 1999), here, however, the extent of the executive resource relationship to the joint visuo-spatial STM-WM factor indicates the shared variance between visuo-spatial STM and WM is not limited to storage. Miyake et al. (2001) submit that, for visuo-spatial material, maintenance alone may employ executive resources, however, it is also proposed that the involvement of executive resources in STM tasks includes strategy deployment such as constructing a path between items in the Corsi blocks task and creating a pattern out of the Dot Memory items. Such strategies were reported by participants, and the novelty of the visuo-spatial STM tasks and resulting strategies is suggested to heighten the requirement of executive resources, thus making them “*more than just simple storage tasks*” (Miyake et al., 2001, p632-633). The apparent inequality between the domains in STM-WM relation, and extent of executive involvement in storage tasks, has been taken as evidence of differential architecture between proposed slave systems. While this study does give insight into the relationship of visuo-spatial storage processes to executive resources, the assumption of non-analogous ‘slave’ systems or storage mechanisms between domains based on comparison with results in the verbal domain found elsewhere - namely Engle, Tuholski et al. (1999) - is misleading; Miyake et al. (2001) draw conclusions about the visuo-spatial system based on a total score measure, while Engle, Tuholski et al. (1999) draw conclusions about the verbal system based on span measures - indeed, as previously recounted, re-analysis (Unsworth & Engle, 2007a) of the Engle, Tuholski et al. (1999) data with a PCS method establishes a single factor representation of verbal STM and WM performance.

Kane et al. (2004) assessed STM and WMC performance in the both the verbal and spatial domains for unique and common variance - that is, common variance across domains and across tasks. STM in each domain was measured using the same items as those used in the storage task of a corresponding complex span so that apart from the concurrent processing requirement - and necessary resulting performance adaptations - the recall tasks were as similar as possible in STM and WMC. Verbal STM measurement comprised three span tasks: serial recall of words, letters, and digits. Verbal WMC was measured using operation span, reading span and counting span, which required processing tasks of verifying math equations, verifying sentences and counting targets amongst distracters respectively; recall items in complex span performance consisted of words presented alongside equations in operation span, letters presented alongside sentences in reading span, and count totals of targets in counting span processing episodes. Spatial STM recall included three tasks - arrow span, matrix span and ball span; arrow span required remembering the orientation

(each possible 45 degree angle in a 2D plane) and length (short or long) of a series of arrows, and matrix span required recalling a series of cells which appeared in red in a four by four matrix grid. Ball span consisted of participants viewing, and then recalling, a series of appearances (out of a possible eight locations) and subsequent movements (horizontal, vertical or diagonal) of a ball stimulus. Spatial WMC tasks employed were rotation span, symmetry span and navigation span; rotation span utilised the rotated letters of Shah and Miyake (1996), which required a normal/mirror judgment for processing, however, recall items in this version of the task were non-integrated arrows – corresponding to the simple arrow span – each of which was presented after a letter processing episode. Symmetry span processing involved presentation of complex, half filled matrices (black and white) which participants were to judge the vertical symmetry of – each of these complex matrices episodes were followed by the four by four matrix of the simple matrix span, in which filled squares-to-be-recalled appeared in red. Navigation span processing episodes required participants to view a letter presented on screen (either capital E or capital H) and to follow a route around the whole letter from a given point of origin (both origin and route indicated by a single arrow) and, in doing so, to voice whether the corners they were covering en route were in the centre of the screen or either of the top or bottom of the screen ('no' indicated centre, 'yes' indicated either top or bottom). Recall in navigation span consisted of the simple ball span task items, with the stimuli interpolated between processing episodes (one ball presentation and trajectory presented after one processing episode). While all STM and WMC tasks are consistently referred to as 'span' tasks, this term is used here to indicate the completion of tasks at a variety of set sizes; all tasks were presented three times at a given set size and all participants performed the task until the same level – that is, with the same maximum number of items in a set (maximum number of items within a set was specific to each task and order of completion of trials was pseudo-random rather than incremental). Such administration allowed for a proportion correct scoring method.

Using performance from all WMC and STM tasks Kane et al. (2004) revealed through confirmatory factor analysis that a four factor model was the best representation of the data with tasks labelled verbal STM, spatial STM, verbal WMC and spatial WMC loading on factors corresponding to these four concepts. This model was statistically better than a representation of the data as a single factor, as a two factor model (factors corresponding to WMC and STM), a model comprising a single WMC factor and two (domain specific) STM factors, or as a three factor model whereby a

single factor represented spatial performance (encompassing all spatial WMC and STM measures) while verbal performance was represented by two separate factors for WMC and STM performance respectively. Within the selected four factor best fit model WMC factors shared around 70% of their variance. A comparison of variance shared between STM factors reveals a smaller relationship between domains (around 40% shared variance); Kane et al. (2004) emphasise the greater relationship between WMC factors compared to that found between STM factors, stressing the indication of domain general resources underlying WMC performance whereas evident domain specific resources (that is, variance not shared across domains) appear to account for a larger proportion of STM performance. Of particular importance is the between domains comparison of variance shared by STM and WMC factors. Verbal STM and WMC variables revealed a relationship comparable to that found between spatial STM and WMC ($r=.79$ and $r=.89$ respectively); when the four factor model with the stated correlations was tested against a model in which verbal STM/WMC correlation was set to be equal to that of the spatial STM/WMC correlation, there was no statistical difference in fit of the models. Kane et al. (2004) point out that this equivalence of STM to WMC relationship between the domains is despite the higher similarity of tasks in the spatial domain than in the verbal domain – in particular, recall items in counting span were integrated within the processing task and were also thus a slightly different range of numbers than those used in digit span recall. Furthermore, in the verbal complex span tasks (reading span and operation span) recall items were presented alongside processing items, while in all spatial WMC tasks recall items were non-integrated, were presented separately, and were the same items used in simple span recall therefore ensuring that in the spatial domain simple and complex storage tasks were superficially more similar than those in the verbal domain.

Executive involvement in visuo-spatial STM and WM was investigated by Lecerf and Roulin (2006) through examining differences and similarities of visuo-spatial STM and WM tasks – the location span task (LST) and the direction span task (DST) respectively (Lecerf, Ghisletta & Jouffray, 2004) - under a series of experimental manipulations. The LST required participants to view a five by five matrix within which a series of arrows appeared, and the cells occupied – the location of the arrows - were to be recalled in serial order. In the DST participants viewed the same matrix and series of arrows, however participants were to recall the cells at which these arrows *pointed* (rather than the cells in which they appeared). The DST therefore required processing of information, in the form of following the direction of the presented item,

and recall of a separate storage item which was the cell indicated by the arrow. While 'storage' and 'processing plus storage' have previously been equated with STM and WM respectively Lecerf and Roulin (2006) hold that even slight differences in task structure can make the tasks more equivalent measures.

While LST recall is consistently found, across a series of experiments, to be better than DST recall, Lecerf and Roulin (2006) further assess performance by success of recall across different list lengths. The authors relate this approach to Neo-Piagetian views through which they consider WM performance to be limited by a maximum capacity, while STM should be less burdened and allow for use of strategies which enables beneficial organisation of information. The theory following from this belief holds that WM performance should be constant (that is, at capacity) across all list lengths while STM performance, with no such restriction, should exhibit variance across list lengths. Stability and variability in performance across list lengths, in the standard DST and LST respectively, was in fact observed (Experiment 1). An increase in encoding time (from one second per item to three seconds per item) produced better performance in the DST but not the LST (Experiments 2 and 4 as compared to shorter encoding time, Experiment 1), and variability in performance over different list lengths in the DST emerged at this longer encoding time. These observations were interpreted as encoding time allowing strategies to develop in the DST - the results of this manipulation was therefore subsequently interpreted as the DST being performed as more of an STM task than a WM task.

In a final experiment, Lecerf and Roulin (2006) assessed the relation of the standard LST and DST, as STM and WM visuo-spatial tasks, to Gf (as measured through Raven's matrices performance). Despite initially equivalent zero order correlations for LST and DST with Gf ($r=.44$ and $r=.52$ respectively) further partial correlation analyses revealed that LST no longer correlated with Gf once variance shared with DST was controlled for while a correlation between DST and Gf still remained when variance shared with LST was controlled for. This pattern was corroborated through further regression analyses; the study thus appeared to reveal a difference in the predictive utility of visuo-spatial STM and WM tasks for general intelligence measures. It is important to note that this difference is revealed using a total item count - that is, all correctly recalled cells in correct serial order tallied up over course of experiment and represented as a percentage correct measure - in keeping with the previous research and recommendations (Friedman & Miyake, 2005; Unsworth and Engle, 2007a) which advocate total score as a more accurate representation of performance. The

observation of predictive WM variance over and above that of the variance shared with STM difference is in contrast to the absence of such an additional predictive value demonstrated both in the previously described study of Unsworth and Engle (2007a) and comprehensively in Colom, Rebollo, Abad and Shih (2006). Colom et al. (2006), through reanalysis of the data of previously published studies, used SEM to reveal that in studies in which proportion correct or total score was used, for each cognitive ability being predicted there was no predictive variance exclusive to complex span performance once variance shared with simple span performance was removed. While no specific comparison between verbal and visuo-spatial tasks was made the studies included for reanalysis included both verbal and visuo-spatial STM and WMC tasks. For example, SEM using the data of Kane et al. (2004)⁴ - the verbal and spatial STM and WMC task data as described above as well as simultaneously obtained data measuring Gf - established that the shared variance between all simple and all complex span recall performance was found to be the best predictor of Gf, while the complex span recall performance held no predictive value beyond this (this analysis was also subsequently replicated by Unsworth and Engle, 2007a). Lecerf and Roulin (2006), however, administered tasks not at an individual span level but at predetermined list lengths, terminating testing at list length of six items/locations; participants' ability at longer list lengths on STM tasks is therefore not included in the analyses and this could have resulted in underestimating participants ability and variation in performance (Unsworth and Engle, 2007a).

Ang and Lee (2008) made use of both complex and simple span comparisons and interference methodology to investigate executive resources in VSWM and STM. In a study with children, random number generation (RNG) was employed as an executively demanding secondary task to be performed throughout completion of a computerised CBT procedure and a letter rotation complex span task (Shah & Miyake, 1996). Span measures of CBT and letter rotation recall were both found to be significantly lower when performed concurrently with RNG compared to when each task was performed alone (Experiments 1 & 2). This pattern of decrement was equivalent in children aged eight years old and children aged eleven years old,

⁴ Kane et al. (2004) reported an analysis (not described in the present review) which represented variance shared across *all* simple and complex tasks (across domains) as a single latent variable in SEM and residual variance shared between simple and complex tasks *in a given domain* was represented as a domain specific storage latent variable. Complex span latent variable was found to be a reliable predictor of Gf while storage was not. Reanalysis represents shared variance across *all* simple and complex tasks as a single latent variable, and all shared variance remaining in complex performance *across domains*.

however, the older group of children consistently performed better than the younger children in every condition. Ang and Lee (2008) had hypothesised that older children would not only perform the CBT better than younger children but would be less susceptible to executive interference, due to increased ability and familiarity afforded by development; however, older children more frequently reported using strategies in the CBT – that is, specific encoding techniques. The authors therefore proposed that, despite a probable increase in ability, older participants were susceptible to RNG effects through use of executive resources in encoding and subsequent encoding determined maintenance. A contrast between recall tasks did emerge in a third experiment which employed articulatory suppression as an interference task; articulatory suppression impaired letter rotation performance relative to when performed alone, however, CBT performance was not found to be impaired. Correspondingly, complex span performance was otherwise accompanied by reports of verbal strategies (e.g. attaching verbal labels to the placement of letters); as presentation times were set at five seconds an item and participant terminated - in order to be age appropriate –verbal label allocation was quite possible. Such strategy deployment could help explain the observed interference effects. A comparison between experiments (Experiments 2 & 3) revealed that RNG affected letter rotation performance significantly more than did articulatory suppression. While Ang and Lee (2008) point to the common effect of RNG in CBT and WM as indication that the two tasks are not dissociable it should be noted that the precise nature of this executive involvement in each task was not confirmed. Effects of RNG could potentially, for example, manifest in letter rotation recall through one or a combination of any of the following – impacting on processing efficiency, encoding of stimuli location or order, recall of stimuli location or order, or indeed the ability to simultaneously perform, or switch between, processing and storage tasks. Similarly, RNG effects on CBT performance were not indisputably localised to encoding, maintenance or recall. Therefore, while the use of executive resources is again indicated in both visuo-spatial STM and WM recall, these resources may not support performance in the same way in both tasks.

Complex span and visuo-spatial fractionation

In a recent study complex span and individual differences methodology has been applied to the issue of fractionation within VSWM. Vergauwe, Barrouillet and Camos (2009) sought to contrast one of the theories emerging principally from

complex span performance – the TBRS (Camos et al., 2009) – against the multiple component view (e.g. Baddeley, 1986; Baddeley & Logie, 1999). In doing so, Vergauwe et al. (2009) aimed to both address the divide between complex span and experimental literature, and to address domain generality or specificity at what they term the ‘central level’, that is, Vergauwe et al. (2009) intended to establish whether or not visual and spatial tasks share attention-based resources. From the perspective of the TBRS model, information maintained in the storage system requires attentional refreshing otherwise it is subject to decay. This refreshing is challenged by any other attention demanding task – the frequency of which in a given time period determines the cognitive load (CL) of the distracting task and the subsequent extent of performance impairment in the storage task. Information in the storage systems is also considered subject to representation based interference; Vergauwe et al. propose that previous fractionations in the visuo-spatial system, as demonstrated through interference, have been at the level they term ‘peripheral’ – that is, limited to storage system, and due to representation based interference. It was claimed that possible centrally based interference has not been established or duly considered. If information pertaining to two different domains (proposed sub-domains within the visuo-spatial domain) recruits the same attentional resources, competition for these resources should produce a detriment in performance of any task requiring them, regardless of domain. Manipulating complex span methodology, Vergauwe et al. (2009) varied processing and storage combinations in order to assess whether same domain (visual or spatial) processing tasks produce a greater decrement in (visual or spatial) storage performance, or whether storage performance was consistent across processing tasks which would indicate a domain general central attentional resource. Vergauwe et al. also manipulated the cognitive load (CL) of processing tasks utilised in order to test the premise of the TBRS that CL determines extent of impairment from interference.

Four combinations of processing and storage complex span were created from a visual storage, a spatial storage, a visual processing, and two different spatial processing tasks. Spatial processing was created with two alternative tasks to avoid similarity between items used for visual storage and spatial processing; visual storage required viewing a series of half filled matrices (dimension 2 x 3 cells) – that is, each matrix to be remembered in a task was presented after each processing episode and at recall participants were to reproduce the series of viewed matrices. Spatial processing when combined with visual storage required responding with a judgment as to whether a presented line would fit within two presented points, situated below the line

(numerous lengths and distances were utilised throughout the task). Spatial storage required memory for a series of ball locations and resulting movements as used in a previously described study (Kane et al., 2004), with one location and associated movement per storage 'item'. Spatial processing when combined with this spatial storage consisted of participants providing responses as to the presence or absence of symmetry along the vertical axis of half filled (6 cell x 6 cell) matrices. Visual processing, regardless of coupled storage task, required judgement as to the properties of a colour presented on screen: whether a colour presented was more blue or red in its composition. CL was manipulated by altering the number of processing segments presented, and to be completed, within a given processing period; participants were required to either respond to three, five or seven processing requirements per processing episode, and all processing episodes were of a fixed time limit (8,500 ms).

Only one of each combination of processing, storage and CL was performed by a participant – specifically, all manipulations were between subjects manipulations. Only storage performance was analysed with respect to manipulations of the study. Analysis on storage based performance measures was thus on the basis of CL (number of operations in a given time), rather than on the basis of 'difficulty' of task, as the TBRS model proposes CL to be the determinant of extent of interference (Barrouillet, Bernardin and Camos, 2004; Barrouillet & Camos, 2007). Participants performed the assigned complex span task to a given level (proceeding from list length two, on until list length six, with each level performed three times) and the scoring procedure employed was that of proportion correct representation (Friedman & Miyake, 2005; Conway et al., 2005). Analysis of storage performance revealed no difference between visual recall when performed with a visual processing task or with a spatial processing task and spatial recall performance was not significantly different between concurrent visual or concurrent spatial processing tasks. While single recall task performance was not recorded as a control against which to ascertain effect of *presence* of a processing task – that is, to establish that the lack of difference found between domain of processing tasks was not due to a lack of any effect of processing on storage - a significant effect of manipulation of CL in both visual and in spatial storage performance revealed that higher CL resulted in poorer recall performance, therefore demonstrating an effect of processing on recall. An analysis of the time taken up by 'active' processing during a processing episode was carried out for participants in each CL condition; time taken to respond to presented processing items was added up to create a total 'time occupied' score for each processing episode and then a mean of this

across all list lengths and across all participants in one of the 12 given conditions (four complex span combinations, three CL divisions). The mean time for each group was then divided by the time allocated to a processing episode (8,500ms), in order to create a specific measure of CL – that is, time taken up actually carrying out processing tasks in a given processing period. Regression revealed that recall performance was predicted by this time based representation of CL, in each of the four combinations of complex span with variance in recall performance explained by time based measure of CL ranging from 89 to 99 %. It was thus argued that processing affects storage performance and that degree of CL of concurrent processing task determines degree of interference observed in recall performance in a complex span task. Furthermore, the effect of processing and CL is domain general, thus visual and spatial memory were shown to share resources at a ‘central’ level.

Vergauwe et al. (2009) argue that an effect of processing on storage, and the domain generality of central resources means the findings are in contrast to multiple component model views of visual and spatial performance; domain generality of ‘central’ resources is patently not, however, incompatible with most conceptualisations of central executive resources in this framework (e.g. Baddeley, 1986; Baddeley & Logie, 1999; Logie, 1995; 2003). Moreover, while Vergauwe et al. (2009) aimed to ascertain the generality or specificity of resources beyond a peripheral level a number of limitations in experimental design, described below, prevent even a conclusion that information pertaining to the visual and spatial domain utilises general resources. Furthermore, these same aspects of task design also result in the above described experiment, in practice, revealing the effect of frequency of processing operations completed in a given time on recall performance rather than providing a demonstration of a requirement for processing or attention resources in storage or maintenance processes.

Vergauwe et al. (2009) describe the visual storage task used as an adapted version of the VPT, however, the adaptation undertaken changes more than one property of the task rendering it an entirely different task that could be expected to tap different resources. Rather than increasing memory load by manipulating complexity- each stage of difficulty created by addition of one filled and one unfilled cell - as in the VPT, increase in load here (Vergauwe et al., 2009) is by addition of another matrix for recall so that a longer list length is achieved. Serial memory is not associated with the VPT and memory for a sequence of matrix patterns was shown by Phillips and Christie (1977a; 1977b) to be limited to a recency effect of one item - that is, participants

essentially only remember the last matrix presented (though see e.g. Avons, 1998); the requirement for locations within matrices combined with seriality includes properties that could be considered more spatial than visual, or even to involve some executive resources for encoding a spatial sequence (see e.g. Logie, 1995; Della Sala et al., 1997; Logie & Pearson, 1997; Rudkin et al., 2007; Mammarella et al., 2006; Pickering, et al., 2001). A further concern with the study's visual task is that matrices composed of two by three cells were used; due to the limited number of locations involved, this leaves open a possibility of verbal coding and no articulatory suppression was employed to prevent this. The limited combinations possible in the (2 cell x 3 cell) matrix, and the resultant shapes created by such an arrangement, could encourage this strategy. Such verbal labelling would especially be a possibility due to a lengthy practice session involving completion of, at minimum, 98 processing tasks⁵ which would create familiarity with the stimuli and could enable verbal labelling. The pronouncement of the serial matrix memory task as visual is therefore questionable and demonstration of any resources in use of completion of the task could be attributed to possible spatial involvement or to verbal coding and associated encoding strategy – the latter of which would elevate the level at which resources could be causing interference. Following this line of argument, the apparent demonstration of an increase in CL (processing items completed in a given time frame) as producing greater interference could equally be the result of allowing less time to verbally code items in this task – a process which could theoretically continue throughout a processing episode were it an unfilled delay, or a delay that allowed any time for consciously employing a strategy. This possibility undermines the conclusion that central resources are required in storage or maintenance performance. Further issues with task choice and experimental design can be raised: while the authors utilised a processing task (matrix symmetry judgment) and storage task (ball span) present in a previous study (Kane et al., 2004), the appropriateness of these tasks for this interference task investigation is arguable. Kane et al. (2004) undertook a latent variable analysis and made use of a number of different tasks to index spatial resources – additionally, the visuo-spatial system was indexed as a whole: the validity of each component of the tasks Kane et al. employed was not

⁵ Participants in CL of 3 items per processing task completed an initial 33 trials, participants in CL of 5 items per trial completed an initial 20 trials and participants in CL of 7 items completed an initial 14 trials. If performance fell below a criterion of 80% achievement, this phase was repeated; if performance of 80% was achieved after the first or second phase, participants completed further training in which storage and processing performance were completed together (four trials of which entails a further 15, 25 and 35 processing items for CLs of 3 items, 5 items and 7 items respectively) before continuing on to experimental trials.

verified as specific to either visual or spatial resources as this was not of particular importance to the study.

While Vergauwe et al. (2009, p1014) acknowledge that matrix symmetry may appear to some extent a visual (requiring consideration of property of shape) rather than a spatial task, they counter this with the assurance that the complexity of the matrices requires attention to individual locations and associations between these locations, rendering the task a spatial one. However, this is not thoroughly established and is counter to the current indications and interpretations of memory for simultaneously presented complex visual patterns as more visual than spatial in nature (e.g. Logie, 1995; Della Sala et al., 1997; Logie & Pearson, 1997; Rudkin et al., 2007; Hamilton et al., 2003; Mammarella et al., 2006; Pickering, et al., 2001).

Concerns can also be raised regarding the use of the spatial storage task of Kane et al. (2004) with interference task methodology; the limited locations and predictable trajectory of the items used in the ball span, combined with lack of articulatory suppression, leaves performance of the chosen storage task again open to the allegation of supplementary verbal coding and the subsequent ambiguity of effect of CL in a similar manner to that previously detailed regarding the matrix storage task. While the use of a latent variable approach by Kane et al. (2004) reduces the impact of these discrepancies, due to use of multiple tasks, the specific resources drawn on by tasks is of much greater consequence for interference studies where claims are made on the basis of these tasks alone. It can therefore be concluded that the study of Vergauwe et al. (2009) does not unequivocally establish the requirement of domain general resources to support visual or spatial storage.

Thompson et al. (2006) investigated executive resource involvement in performance on the VPT and CBT using two visuo-spatial WMC tasks. WMC was measured by two complex span measures, the first of which was an adaptation of the letter rotation task of Shah and Miyake (1996). This involved presenting two rotated letters and asking the participant to judge whether the letter on the right was of the same format (normal or mirror image) as that on the left; storage requirements involved recalling the sequence of orientations of each letter that occurred on the right hand of the screen. The second WMC task employed the same methodology and requirements but used 3D block stimuli in place of letters. VPT and CBT performance

measurement was termed as 'span'⁶, while WM performance was described as including an addition to span (defined as three out of five trials correct at a given level) whereby successful trials at the level above span were "integrated into span score" (Thompson et al., 2006, p441). A relationship was revealed between VPT and CBT performance ($r=.44$). A factor representing performance in both WMC recall measures revealed correlations with VPT ($r=.37$) and with CBT ($r=.27$). A fifth measure – size just noticeable difference (Size JND) was also employed. Size JND required participants to maintain an accurate representation of a visual image (a square) over a given period of time (here, four seconds) so that a recognition phase involved judgment of whether the re-presented item is of exactly the same size as initial presentation (progression through trials reduced the size differences between presentation and test items in non-matching trials). It is believed Size JND assesses visual memory with minimal involvement of executive resources (Phillips & Hamilton, 2001 though see e.g. Dent, 2010); observed correlations indicated size JND was related to only VPT ($r=-.30$; negative relationship due to smaller scores representing better performance in size JND). Thompson et al. (2006) interpret these correlations as indicating both CBT and VPT are related to executive resources due to the stated relations to WMC; lack of size JND – WMC correlation was taken as further evidence of the purely visual nature of size JND. Hierarchical regression revealed the contribution of visual (5.8%) and of apparent executive resources (10%) to VPT performance, however, CBT performance was not included in the regression. A second study (Thompson et al., 2006) investigating the performance of patients with bipolar disorder utilised different measures of executive resources (backwards digit span and a Self Ordered Pointing Task, Petrides & Milner, 1982) and found deficits in patient groups on CBT performance were attributable to impaired executive resources. This executive resource impairment, however, did not impact on VPT performance, which was still equal to that of a control group.

Subsequently, the results of Thompson et al. (2006) have been interpreted (e.g. Quinn, 2008) as evidence that both the VPT and the CBT employ executive resources, with the CBT involving these resources to a greater extent. Furthermore, these results have contributed to suggestions (e.g. Thompson et al., 2006; Holmes, Gathercole &

⁶ No specific details are given (see Thompson et al., 2006, p440-441), only reference to original Visual Patterns Test (Della Sala et al., 1997) and Corsi Block paper (Milner, 1971), neither of which provided definitive scoring procedures for non-patient data. Della Sala et al. (1997) recommend a score of the mean performance from last three successfully recalled patterns for research study, however, patient scores are represented as the highest level at which *a single pattern* is successfully recalled. Thompson et al. (2006) report CBT performance for patient data is scored as the last level at which a single trial is completed without error.

Dunning, 2009) that a previously proposed analogy to the verbal system (Logie, 1986; 1995) is not an appropriate depiction of visuo-spatial working memory architecture. However, the ready interpretation of the predictive value of WMC recall for VPT performance as 'executive' is questionable given the close relationship between simple span and complex span recall (e.g. Unsworth and Engle, 2007a) and the indication, through stability under executive demands, that recall in complex span performance is similar to that in simple span (Duff & Logie, 1999, 2001; Logie & Duff, 2007). Inclusion of CBT performance in hierarchical regression prior to WMC inclusion would have maximised the chances of tapping any executive resources specific to WMC recall, and enabled better assessment of executive resources in VPT performance. The presence of correlation between VPT and WMC recall is therefore not surprising given known correlations between VPT and a spatial simple span measure (CBT; e.g. Della Sala et al., 1999) and, rather than indicate executive resource involvement, could again reveal a relationship between traditionally termed visual and spatial tasks with the implication of shared resources. Furthermore, the possibility of performance representation beyond span level leaves open the possibility that any executive resource variance present in VPT or CBT scores could be due to the same factors as that indicated in verbal simple span when supra-span performance is represented (Unsworth & Engle, 2007a). The suggestion that these results can be taken as indicating that visuo-spatial information is maintained via executive resources *rather* than by any specific visuo-spatial processes or resources (Holmes et al., 2009, pF13) is therefore extreme. Equally, while the presence of a VPT-Size JND correlation in contrast to the lack of a CBT-Size JND correlation might indicate there are resources specific to visual maintenance (Thompson et al., 2006; Quinn, 2008) it is misleading to extrapolate from this finding and - for reasons detailed above - from VPT or CBT correlations with WMC recall, that "CBT shows only an executive component" (Quinn, 2008, p38).

Summary

There is evidence for independence of resources supporting processing and storage (Duff & Logie, 1999; 2001; Logie & Duff, 2007), and for the case that multiple resources underlie completion of complex span tasks (Waters and Caplan, 1996; Bayliss et al., 2003; Bayliss et al., 2005; Unsworth et al., 2009). There is also an indication of executive resource involvement in recall performance (Kane et al., 2004;

Miyake et al., 2001; Shah & Miyake, 1996; Bayliss et al., 2005) that suggests executive resources could supplement those resources reserved for storage (Ang & Lee, 2008). Initially, complex span tasks were thought to prevent maintenance strategies (e.g. Turner & Engle, 1989; La Pointe & Engle, 1990) seen in simple span performance. However, it has subsequently been demonstrated that strategies (e.g. subvocal rehearsal) can be, and frequently are, applied (Turley-Ames & Whitfield, 2003; Friedman & Miyake, 2004; McNamara & Scott, 2001) though likely (Unsworth & Engle, 2007a) operating in a reduced form. In addition to strategy use, evidence of the presence of executive resources in *complex span performance* has previously been variously suggested as due to support of active maintenance in the presence of proactive interference, prevention of intrusion of irrelevant information, suppression of habitual responses (Engle, Kane et al., 1999; Heitz, Unsworth & Engle, 2005; Kane et al., 2008) and retrieval of information displaced into LTM from STM by processing of information (Healy & Miyake, 2009; Unsworth & Engle, 2007b). All of these proposed explanations would expect that executive resource involvement would be evident even at short list lengths. Executive resources use is also proposed to underlie the coordination required for dual tasking of processing and storage (Duff & Logie, 1999, 2001; Logie & Duff, 2007), the effects of which can result in slightly reduced recall performance.

Executive variance in *simple span performance*, previously thought minimal (e.g. Engle, Kane et al., 1999; Duff & Logie, 1999, 2001; Logie & Duff, 2007), appears to be evident in measures representing long list length performance. Executive resource involvement in verbal and spatial simple span storage performance at longer list lengths has been determined as equivalent (Kane et al., 2004), however, specific evidence of use in visuo-spatial domain architecture has provided interest in executive resource use in spatial recall in particular (Miyake et al., 2001; Ang & Lee, 2008; Bayliss et al., 2005). The possible nature of executive resource involvement in recall has not been unequivocally determined, however, encoding strategies (Ang & Lee, 2008; Kane et al., 2004; Miyake et al., 2001), retrieval from LTM and efficiency of encoding information for LTM retrieval (Unsworth & Engle, 2007b, Healey & Miyake, 2009; Mogel, Lovett, Stawski & Sliwinski, 2008; Unsworth, Brewer et al., 2009) are primary potential candidates. Previous indications of asymmetric executive employment between the verbal (e.g. Engle, Tuholski et al., 1999) and spatial (e.g. Miyake et al., 2001) domains could be reconciled with current indications by suggesting a requirement for executive resources in strategies to deal with quantities of information

that exceed storage capacity. Commonly practiced verbal strategies (e.g. rehearsal and chunking) would require little executive involvement until information exceeds these simple strategies. For example, novel or unsuccessful (when not well practiced) strategies might be deployed for supra-span items, and/or executive resources might be utilised to retrieve these supra-span items. The use of uncommon strategies for spatial information would demonstrate one or more possible components of this pattern earlier – that is, with shorter list lengths.

The endeavour to connect the experimental and individual differences literature in the visuo-spatial domain is a necessary step; the disconnection between the two literatures within working memory as a whole – with a few notable exceptions – is perplexing. As evident in the recent study of Vergauwe et al. (2009), however, the way in which complex span methodology has been employed previously, and fruitfully, in the verbal domain is largely unsuitable for investigating visuo-spatial fractionation. Due to the inherently serial nature of complex span presentation (a single storage item presented after each processing episode) investigation into the possibility of fractionation on the basis of presentation or seriality, for example, is likely unworkable in the traditional complex span approaches. These traditional methods involve pitting two storage mechanisms against each other in complex span form, manipulating processing and storage combinations and properties, or assessing predictive value of complex span performance for higher order cognition. Information regarding performance on simultaneous tasks is currently limited to presence or absence of simple correlations (e.g. correlation of VPT with CBT but not with LST, Lecerf et al., 2004) or to the satisfactory fit of a task included within latent variables representing STM or joint STM-WM performance (Miyake et al., 2001). As detailed above, however, acknowledgement of complex span literature findings leads to further consideration of clearly pertinent issues including, but not limited to: resource allocation, performance strategies, whole system performance, and possible interaction between subsystems – for example, presence and limitations of executive resource participation in storage and recall performance. Information gained through this literature on the resources underlying complex span performance, can, furthermore, be used to further illuminate the processes underlying simple span performance.

Chapter Three

Experiment 1

As noted in Chapter 1 there is evidence to suggest performance in a serial location recall task (CBT) and memory for statically presented matrix patterns (e.g. VPT) are supported by dissociable subsystems in visuo-spatial working memory (e.g. Della Sala et al., 1999; Krikorian, et al., 1996; Logie & Pearson, 1997; Pickering et al., 2001; Zoelch & Schumann-Hengsteler, 2006). There is growing belief that the manner in which information is presented contributes to this dissociation in performance (e.g. Cornoldi & Vecchi, 2003; Lecerf & de Ribaupierre, 2005; Logie, 1995; Pickering et al., 2001; Mammarella, et al., 2008). A recent emphasis in the literature concerned with a possible greater involvement of executive resources in tasks which make use of sequential presentation, however, undermines this dissociation and questions the fractionation of the visuo-spatial system into components supporting performance on these tasks (e.g. Holmes et al., 2009; Quinn, 2008; Thompson et al., 2006). The main evidence for this executive resource view stems from results which may relate largely to differences occurring at encoding (e.g. Rudkin et al., 2007; Vandierendonck et al., 2004). It is therefore of interest whether differences can be found in the maintenance of simultaneously and sequentially presented information.

In the experiments detailed in the present chapter a recognition paradigm was employed to test memory for the location of three dots. These dots were either simultaneously or sequentially presented within a template array. Within a presentation condition, initial and test presentation formats were the same - participants had only to determine whether one of the three presented dots had moved location. Therefore, the sequentially presented dots of the sequential presentation condition were always in the same order at presentation and at test - there was no requirement to maintain order in either the simultaneous or the sequential condition; participants were made aware of this. All aspects of the primary task apart from presentation format were designed to be equal between the two conditions in order to test specifically whether there was any evidence that different means of maintenance were employed when memory is required for items which are simultaneously or sequentially presented.

Della Sala et al. (1999) provided evidence that passive viewing of irrelevant abstract images interferes with retention in the VPT more than does spatial tapping;

conversely, spatial tapping interferes with CBT performance more than does viewing of irrelevant images. From the line of studies assessing dissociable resources for appearance versus location (or multiple locations) memory, Logie and Marchetti (1991) found that viewing of irrelevant black and white line drawings interfered more with memory for colour hues than did spatial tapping while spatial tapping interfered more with memory for a sequence of presented blocks than did viewing irrelevant images. In addition to these two influential studies which demonstrate largely selective interference, effects of spatial tapping on memory for a series of blocks (CBT or similar) have been extensively reported (e.g. Smyth et al., 1988; Smyth & Scholey 1994a; Pickering et al., 2001; Pearson & Sahraie, 2003; Vandierendonck et al., 2004; Logie & Vecchi 2006; Alloway et al., 2010). There is also evidence that controlled eye movement and shifts of attention disrupt memory for a series of locations (see e.g. Pearson & Sahraie, 2003). Moreover, Smyth and Scholey (1994a; Experiment 2) and Klauer and Stegmaier (1997; Experiment 1) both found an effect of passive viewing of irrelevant location information (two possible locations appearing six times throughout delay period) on computerised Corsi block recall at short and long list lengths.

A spatial tapping task could be considered to require more active control than passively viewing irrelevant images; this would mean a potential confound of unequal attentional demand if spatial tapping and viewing images were used as interference tasks. Given the current concern over executive resource involvement in serial or sequential tasks, a selective effect of spatial tapping on sequential performance could potentially be interpreted as due to how active the interference task was rather than on spatial or visual properties of the tasks. Cornoldi and Vecchi (2003; Mammarella, et al., 2008) posit that separable resources for a task will be most evident when little active control is involved. The use of passive interference tasks was therefore employed (after Della Sala et al., 1999; Logie & Marchetti, 1991; Smyth & Scholey, 1994a; Klauer & Stegmaier, 1997) to assess possible differences in maintenance processes on the basis of presentation. In the current experiment each presentation version of the recognition task was performed in an unfilled delay condition and a condition in which interference was presented during the retention interval. This allowed for a comparison between maintenance for simultaneously or sequentially presented items to determine if one presentation condition led to maintenance which is more susceptible to interference than the other. Moreover, two formats of interference were employed: a static presentation of dots or a series of dots which appeared one after the other. These tasks were derived from distilling the most salient feature of tasks shown to selectively

interfere with recall of simultaneously presented information and tasks shown to interfere with serial or sequential recall of locations (e.g. Della Sala et al., 1999; Logie & Marchetti, 1991) – that is, presentation of an irrelevant image and of a series of irrelevant locations. On the basis of experiments reported above it could be expected that presentation of an irrelevant static image would interfere more with simultaneously presented dots than would a series of irrelevant interference dots while a series of irrelevant dots could be expected to interfere more with memory for sequentially presented dots than would viewing a single irrelevant image.

Past studies have shown that memory for serial recall of three locations is, despite being below span level, susceptible to interference effects (Smyth & Scholey, 1994a; Smyth & Pelky, 1992); moreover, studies of single item appearance and single item location have shown that memory for even one item is susceptible to interference (e.g. Tresch et al., 1993; Klauer & Zhao, 2004). Three locations were chosen for use in the current study both on the basis of piloting studies and in order to minimise presentation effects which could occur in the sequential condition – for example, path crossing or multiple directional changes (Parmentier et al., 2005). Additionally, previous studies have suggested that differences may exist between encoding in memory for simultaneous and sequentially presented locations at a level of three items (Dent & Smyth, 2006), however, differences in maintenance processes at this level have not been assessed.

All stimuli were presented at a distance from the participant so that all stimuli were viewable within foveal vision. This precaution was employed in order to minimise the possibility that a sequential condition may suffer from a viewing disadvantage of imposed order. For example, if a presentation array was close to a participant and locations appeared at opposite ends of the screen, then eye movements to locations may be slower - resulting in less time to encode locations - than in a simultaneous condition. An immediate recognition condition (500ms delay) was employed in order to ensure that locations, and location changes, could be detected at this distance. A complex template array and only small location changes in 'different' trials were employed to minimise the possibility that participants may additionally verbally encode a location. Brief presentation times for locations (matched across presentation conditions) were also used for this reason.

Method.

Participants.

Thirty-four undergraduate students from the University of Edinburgh were recruited through a University careers website advertisement for a one off testing session of one hour. Participants were provided with a single payment of £5.05 for taking part. Of a total 34 participants tested eight were excluded due to poor performance (as detailed in results). The data of a further two participants were not included due to computer faults which occurred during testing. The data of 24 participants (7 males, mean age 21.5 years, SD 0.67, median 22, range 18-25) were included in analysis. All participants were right handed, and fulfilled the inclusion criteria of normal or corrected-to normal vision with no known problems with colour blindness.

Design.

A (2 x 2 x 3) mixed design was employed: presentation format of stimuli was manipulated (simultaneous or sequential) as a between participants factor, as was format of interference task (simultaneous or sequential). All participants performed the primary recognition task in three conditions: immediate (500ms) recognition, recognition after an unfilled delay (15000ms) and recognition after an interference filled delay (15000ms). There were therefore four comparable groups (simultaneous presentation, simultaneous interference; simultaneous presentation, sequential interference; sequential presentation, simultaneous interference; sequential presentation, sequential interference). Each group comprised six participants, with performance recorded for each in immediate, delayed and interference filled delay conditions.

Apparatus.

Presentation of stimuli was by computer and involved an LCD screen of size 43cm diagonal (33.8 x 27cm). Screen resolution of the monitor (CTX S700A), which used an Intel (R) 82865G Graphics Controller, was set at 1024 x 768 pixels at the highest colour quality (32 bit) with a refresh rate of 75 Hertz. Stimuli were presented and responses were recorded using E-prime (Version 1.1) software which was run using an RM innovator Pentium 4 @processor PC.

Presentation of images throughout the entirety of the task was designed to fall within participants' foveal vision. For this reason, participants were situated at a minimum distance of 172cm from the testing computer screen; the front of the chair in which participants were seated was positioned at a distance of 180cm from the computer screen and the edge of the table on which the response keyboard was positioned marked the distance of 172cm (see Figure 1 diagram of testing setup). Participants were not permitted, and never attempted, to lean forward past this distance marker. All images used were presented in the centre of the computer screen and were of dimensions 6cm in width (3cm either side of central point), and 4.5cm in height (2.25cm either vertical side of central point). Such dimensions and presentation distance was employed so that images were presented within two degrees of the visual angle (one degree radius of central point). All images were presented against a completely black background which served to fill the surrounding screen area consistently throughout all trials and conditions.

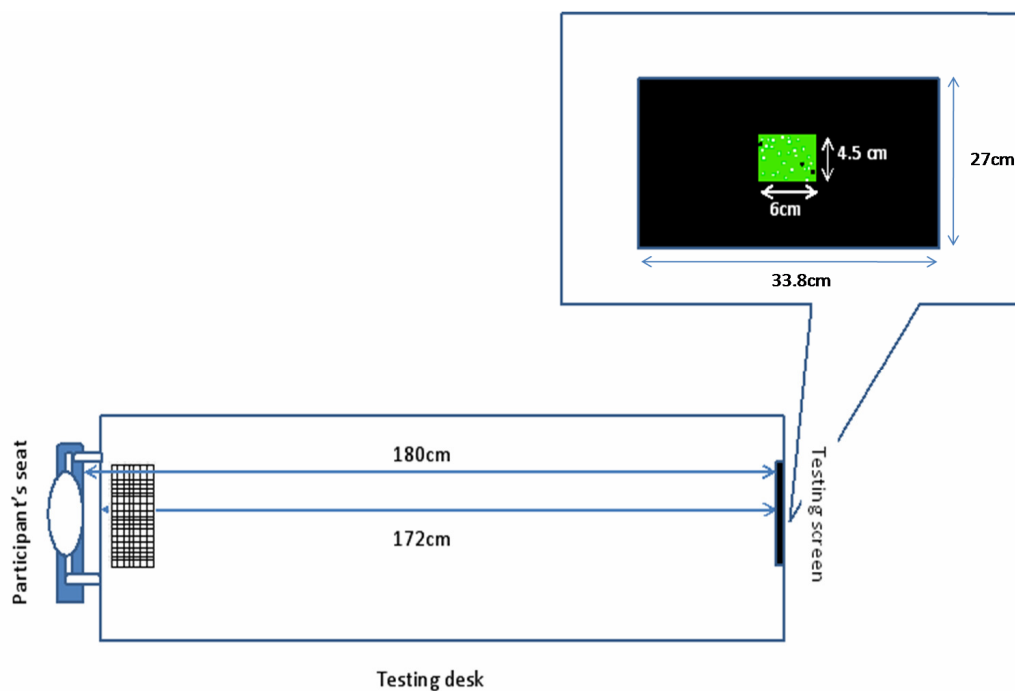


Figure 1: Physical set up of Experiments 1 through 3.

Materials and Stimuli.

Lists of stimuli comprised items in a fixed random order. This allowed the creation of two different versions of each list which differed only in simultaneous or sequential presentation format. These lists determined the locations in which each of three dots appeared in a given trial. Three lists of stimuli were therefore created and counterbalanced for use across presentation and interference formats, and partially across condition, using a Latin square design. This ensured the same locations were used for every participant, only in a different presentation format, in a different condition or with different interference stimuli.

Lists were created to correspond to a template of 30 white squares based on an array used by Darling et al. (2009); location of these squares was randomly generated and then fixed for use as an array in all presentation and recognition displays. Squares in the template served as potential locations in which stimuli to be remembered could be located. In order to create lists for locations to feature in each trial, these squares were labelled one to 30 (see Figure 2 below) and an online random number generator programme⁷ was used to generate sequences of three numbers; the triplets generated dictated the location of the three dots whose location was to be memorised per trial. Duplicated triplets, or sequences containing duplicated numbers within the triplet, were removed and replaced with more randomly generated sequences of three. This method was used to create three lists of twenty four triplets.

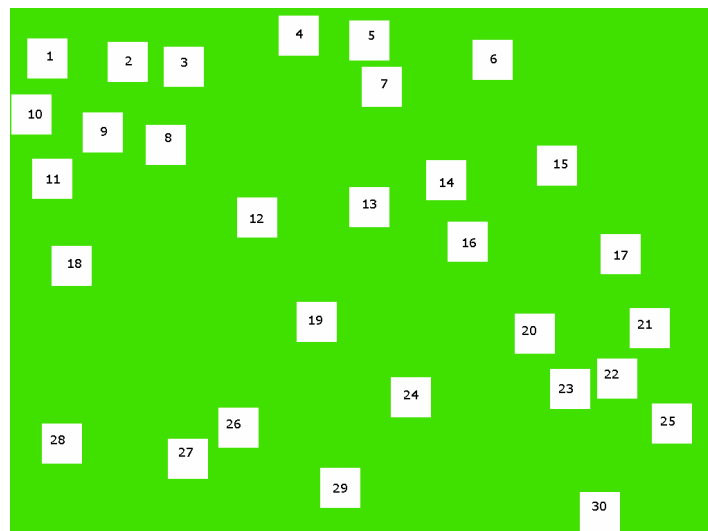


Figure 2: Presentation array used throughout experiment, shown with location identification numbers superimposed. Based on Darling et al. (2009).

⁷ Sequences were generated via the website www.random.org (specifically <http://www.random.org/integers/>)

Experimental aims required dot stimuli would not appear at the same locations in presentation and re-presentation for test displays for all trials. Therefore for half the trials in each list a change was made to one of the dot locations in the re-presentation for test segment of the trial. This change was carried out by systematically taking the last 12 in the lists of 24 triplets and changing one dot location out of the three. Which location to change was not chosen subjectively – rather in the order of ‘first, second, third, first, second, third...’ and so on. There was therefore no bias in choosing, for example, more or less isolated dots within a display. Likewise, to minimise bias in choosing a distractor, the location to which an ‘incorrectly located’ dot should be moved was selected adhering to the following rule: the dot may be moved to a nearby square in any direction (above, below, left, right or diagonal) under the constraint that there could not be a white square in between old and new locations. This avoided large and obvious shifts of location that might also have encouraged verbal encoding – for example, remembering that a dot occupies the lower left hand side of the screen rather than encoding its specific location. Alternative locations were thus created for 50% of all trials used in a condition: for all trials there was a 50% chance that locations to be remembered would be different at test as compared to presentation. Images were made, according to the above constraints, for each triplet in each list. Bitmap images corresponding to each presentation triplet (a single bitmap image for simultaneous presentation, three bitmap images for sequential presentation), and to each corresponding test presentation of triplets, were created whereby black to-be-remembered dots were shown within the white location squares.

Interference tasks.

Interference employed either simultaneously or sequentially presented stimuli (see Figure 3). Interference of a simultaneous format condition entailed the appearance of a static array of 14 red dots presented upon a black background which remained onscreen continuously throughout the delay. All possible locations of interference items corresponded to primary task presentation locations – that is, the 30 locations which were previously occupied by the white squares. The locations used for interference dot stimuli were, for each trial, randomly chosen from these 30 locations; for sequential interference this was achieved through a feature available in the E-prime software supporting task presentation. Simultaneous interference presentation

necessitated generating a random 14 locations for each interference trial, from the available 30, outside of E-prime software. This task was performed using function available in Microsoft Excel and locations were inserted into E-Prime prior to starting the experiment.

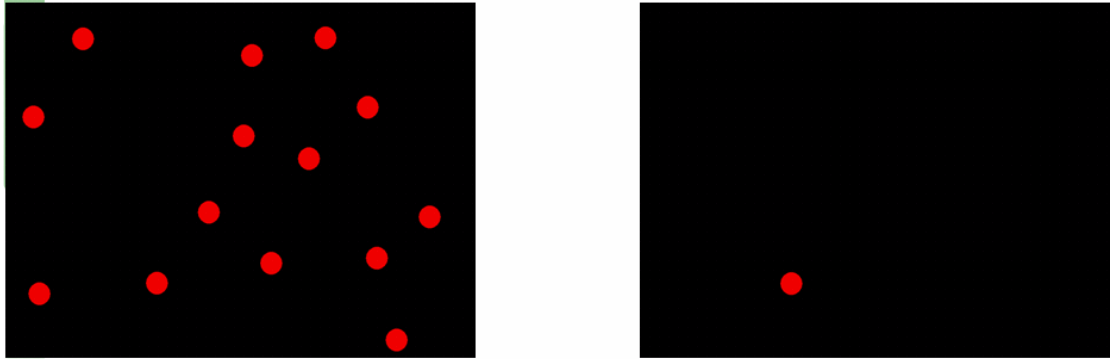


Figure 3: Interference arrays: *left* is an example of a simultaneous interference that would be presented continuously throughout a filled delay, *right* is an example of the first screen of 14 in sequential interference which would run throughout a filled delay.

As interference stimuli adhered to presentation locations, array dimensions of interference stimuli were thus also limited to the 6cm x 4.5cm presentation area of the primary task. Sequential format interference involved 14 successive presentations of a single red dot, each appearing against a black background. After one dot would disappear another would appear in a different location; locations used were again randomly chosen from the 30 possible template locations, within the constraint that a single location not be used as an interference location twice within the same trial.

Procedure.

For all participants the experiment consisted of performing the primary memory task of remembering the location of three black dots 24 times in each of three conditions: an immediate (500ms), an unfilled delayed (15000ms) and a filled delayed (15000ms) recognition condition. Half of the participants tested completed the recognition task with presentation and test screens in a simultaneous format and half the participants tested completed the task with screens in a sequential format. In each of these groups half of the participants completed the experiment with the filled condition consisting of simultaneously presented interference and half of the

participants completed the experiment with the filled condition consisting of sequentially presented interference. Performance of a condition was blocked and the order in which conditions were completed was fully counterbalanced across participants for each presentation-interference combination.

Participants were familiarised with a colour coding practice employed within the experiment during instructions: presentation array screens consisted of a green background, test array screens consisted of a red background and a completely blue screen was used to signal the time frame in which a response should be provided by the participant. Colour coded screens, as demonstrated in Figure 4, aided identification of each stage of a trial and removed the need for verbal or picture-stimuli prompts (e.g. indicating response screen). Practice trials were undertaken before beginning each condition (six trials for each condition) to ensure participants' grasp of task structure and demands.

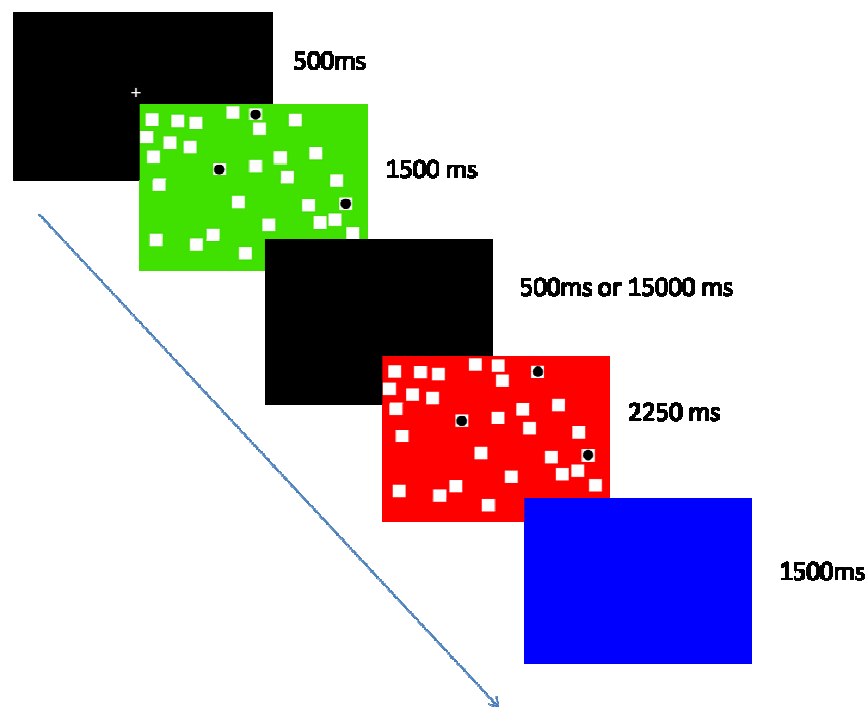


Figure 4: Example of experimental set up: simultaneous presentation with immediate/unfilled delay. Red recognition screen shows example of a 'changed' trial whereby one target location differs from presentation. Black screen area surrounding all images has been removed for clarity.

Participants were required to initiate each trial by pressing a spacebar. Trials were participant initiated in order to avoid fatigue and possible eye strain due to the distance employed in stimuli presentation; total time duration for a session was consequently variable. Completion of a trial, however, was determined by the predetermined timing of each screen presentation and was therefore consistent across participants. Following the instigation of a trial, a centrally presented fixation cross (white plus sign, courier new, point size 24) would appear for 500ms. In all conditions participants were instructed to look straight ahead at the screen in front of them, focusing on the fixation cross when it appeared. They were further instructed to continue attending to this central area throughout the trial, to avoid closing their eyes and to prevent their eyes from moving outside of the area determined by presentation arrays.

Presentation screens followed the fixation cross; in the simultaneous presentation condition a single green template with three location dots appeared for 1500ms while in the sequential presentation condition three successive green template screens appeared with a single location dot each (500ms each screen). Participants were required to view their respective presentation screens and to remember the location of the three dots shown. Instructions informed participants they would be required to make a decision as to whether the three dots shown changed location between presentation and test. It was further disclosed that only a single dot could change location in any given trial and that there was a 50% chance that a trial would contain a change. The possible change within a trial was described as a dot having moved a single (white box defined) location in any direction. Participants in the sequential presentation condition were informed that order of presentation would remain consistent between presentation and test and that only a single location may change. The possibility of a change equalled between the first, second and third dot presented was also pointed out. Within a condition, for each participant, the use of memory triplets was randomised and the occurrence of unchanged and changed trials followed no order.

Immediately following presentation screens a blank black screen appeared. In the immediate recognition condition this appeared for 500ms followed by the appearance of red recognition screens (as shown in Figure 4). In the unfilled delay condition this blank screen lasted for 15000ms before recognition test screens appeared; throughout the unfilled delay participants were required to attend to the central area. Fifty percent of the time recognition screens that appeared contained the

initial simultaneous (2250ms) or sequential screens (750ms each) respectively, presented with the red template background. Fifty percent of the time recognition screens contained a location change. Participants were required to view these recognition test screens and to mentally form a decision as to whether there had been a change made from presentation.

At the appearance of the blue screen participants were required to indicate, as quickly as possible, their decision as to whether a trial contained a single location change. A key press was required to indicate this decision: participants were to press a key labelled 's' for same/unchanged trials and a key labelled 'd' for different/changed trials (keys used and labelled were the s and k keys of a standard keyboard). Participants were informed the blue response screen was time limited (1500ms) and were made familiar with this timing in practice trials; it was therefore emphasised that responses should be made quickly, that reaction times were logged and that responses should be formulated in the recognition screens phase in preparation for immediate response at the appearance of the blue screen. While information occurring in a simultaneous format allowed for decisions to be made immediately upon presentation, a consequence of sequential presentation was that information necessary for a decision to be made was available at a variety of times depending on which trial was being performed; a decision could be made, for example, within 750ms in the instance of a changed condition in the first position or within 2250 in the case of unchanged trials or trials changed in the third position. Use of a response screen helped to reduce the potential of artificial differences in reaction times between simultaneous and sequential presentations at test. The blue response screen which followed recognition test screens was presented for 1500ms in every trial – that is, the screen remained even after a response would have been made. Decisions and reaction times for all participants were logged when the blue screen was presented; participants were recommended to press their response key more than once if unsure whether the response had been registered (for example, premature responses in the red recognition screens were to be repeated in the blue screen period). At the end of a trial, a blank black screen followed the blue response screen; participants were required to press the spacebar of the keyboard to fully end the trial. This final black screen did not allow for late answers to be recorded.

Interference conditions required participants to perform the recognition task as described above. Participants were additionally informed prior to beginning the condition as to the array which would appear in front of them during the retention

period following a 1000ms delay - a static array of dots for 14000ms or a dot which 'jumped' from location to location (1000ms per location) for 14000ms (see Figures 5 & 6 for illustration of tasks with interference filled delay). Instructions dictated that participants pay no attention to these stimuli – rather, they were to continue to view the central area of the screen while ignoring the irrelevant stimuli.

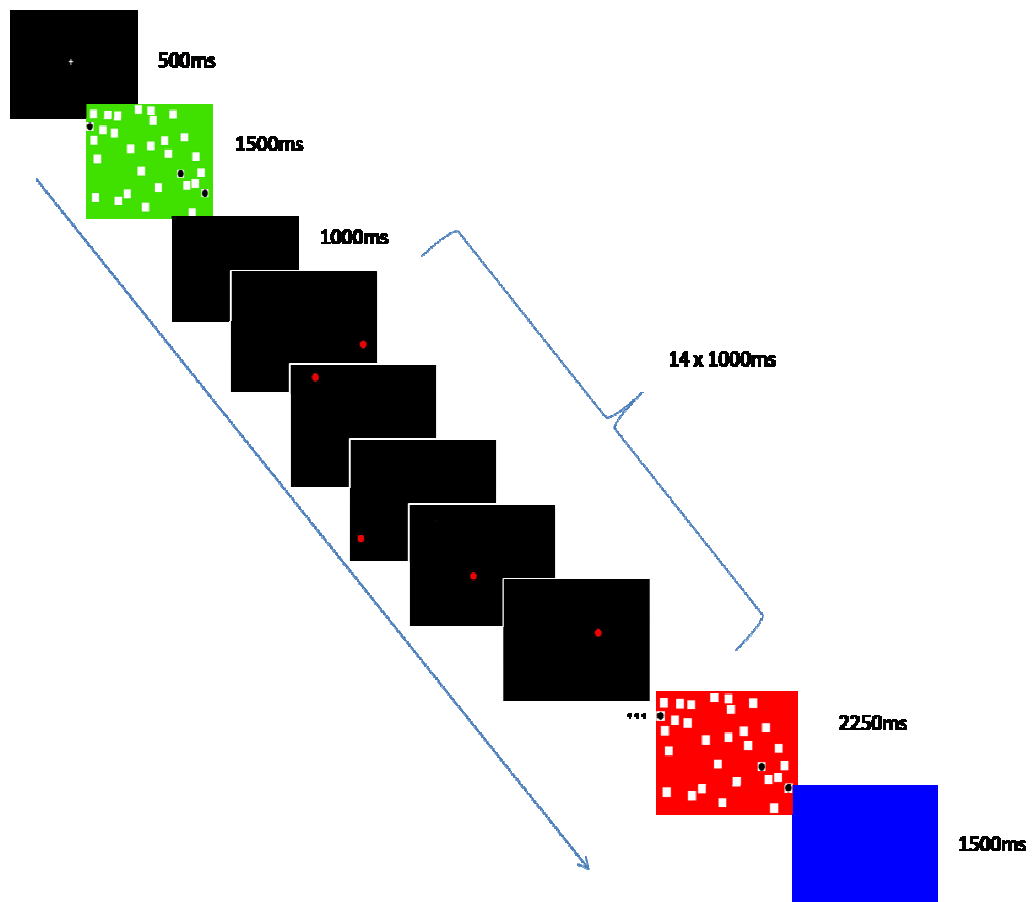


Figure 5: Example of experimental set up: simultaneous presentation with filled delay of sequential interference. Red recognition screen shows example of an unchanged trial. Black screen area surrounding all images has been removed for clarity.

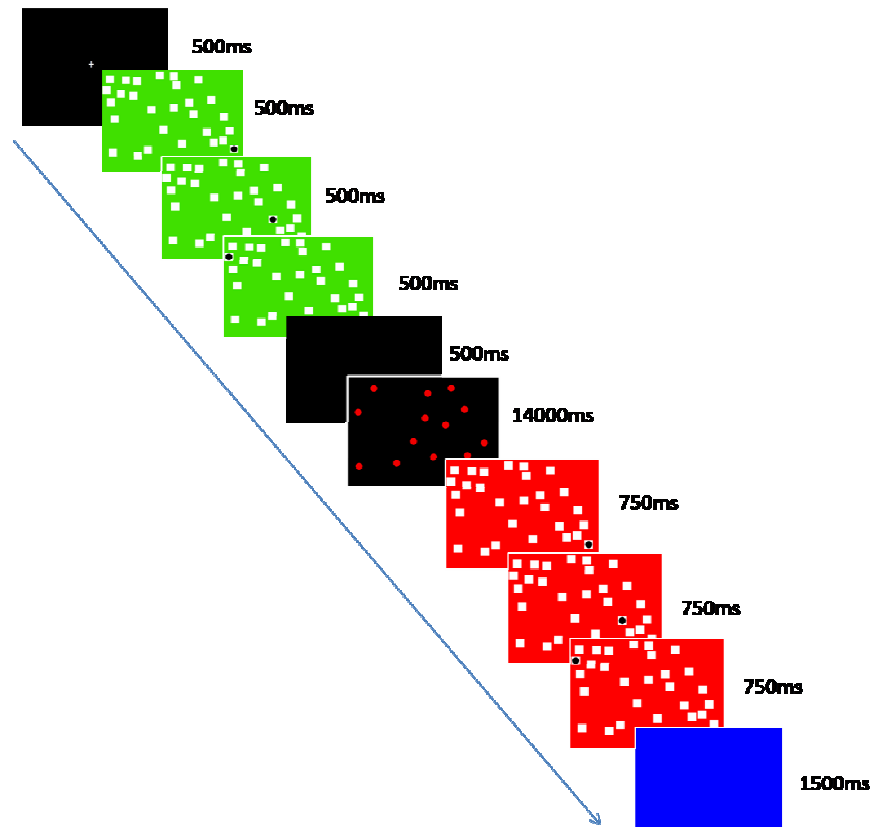


Figure 6: Example of experimental set up: sequential presentation with a filled delay of simultaneous interference. Red recognition screen shows example of an unchanged trial. Black screen area surrounding all images has been removed for clarity.

Results.

Of the eight participants excluded from the total 34 participants tested: one was excluded on basis of poor (2 SD below the mean) performance in both immediate and unfilled delay conditions, and seven participants (three simultaneous, four sequential presentation) were excluded due to performance 2 SD below the mean in the unfilled delay condition of their respective presentation conditions which served as a baseline control condition against which interference effects were tested.

Immediate recall scores were high (see Table 1), and an independent-samples t-test found performance did not differ between Simultaneous and Sequential presentation conditions, $t(22) = 1.79, p > .05$. High immediate recognition performance indicates participants are able to perceive stimuli and discern changes made in non-matching trials; the lack of presentation effect demonstrates that this was true of both presentation conditions.

	Condition			
	Immediate		Unfilled delay	
	Mean	SD	Mean	SD
Simultaneous Presentation	22.33	1.30	19.25	2.45
Sequential Presentation	21.17	1.90	18.33	2.15

Table 1: Mean (in bold) and SD descriptive statistics for each condition, based on recognition scores (out of maximum possible 24). Displayed according to presentation.

A drop in recognition performance was indicated, as displayed in Table 1, with introduction of a retention period. In order to assess the effect of the requirement to perform the primary recognition task over an unfilled retention delay, each participant's individual score in the unfilled delay period was converted to a ratio representation of their own immediate recognition performance score. These ratio scores were then subject to analysis; a one-sample t test, $t(23) = -5.91, p < .001$, found that, collapsed across presentation conditions, the resulting ratio measure (*Mean* .87, *SD* .11) was significantly different from 1. Using the same method of analysis, this significant decrement in performance was shown to be present in both Simultaneous (*Mean* .86, *SD* .10), $t(11) = -4.73, p = .001$, and in Sequential (*Mean* .87, *SD* .12), $t(11) = -3.61, p = .004$, presentation conditions separately. Furthermore, an independent-samples t-test revealed, via comparison of ratio scores under Simultaneous and Sequential presentation conditions, that the magnitude of decrement introduced by delay was not significantly different between conditions, $t(22) = -0.22, p > .05$. The finding that introduction of a delay period significantly impairs performance suggests that task performance is not too easy for participants to perform and is therefore potentially vulnerable to interference effects.

Of particular interest to the study was a comparison of simultaneous and sequential presentation with respect to the potential effects of simultaneous and sequential interference during a retention interval. For this purpose, unfilled delay performance was compared to filled delay performance on the basis of presentation and interference manipulations. As shown in Table 2 there was a subtle suggestion

present when viewing means of raw scores, of better performance in simultaneous presentation participants and of higher performance in sequential as compared to simultaneous interference conditions.

	Simultaneous Interference				Sequential Interference			
	Unfilled delay		Filled delay		Unfilled delay		Filled delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	18.83	2.71	16.50	4.09	19.67	2.33	19.17	1.94
Sequential Presentation	17.67	2.34	16.00	2.37	19.00	1.90	17.67	4.00

Table 2: Memory task performance represented as a mean (in bold) of raw score from all 24 trials performed by each participant. Displayed according to presentation and interference conditions.

Prior to analysis, participants' raw scores in the interference conditions were represented as a ratio of their own performance in the unfilled delay condition, in order to assess the impact of interference on retention of the information in the memory task. A one-sample t-test revealed that recognition performance, collapsed across presentation and interference manipulations, was significantly reduced by presence of interference (*Mean* .93, *SD* .16), $t(23) = -2.25, p = .03$. An independent-samples t-test found no significant difference in magnitude of interference effects when comparing the calculated ratio measure between Simultaneous (*Mean* .93, *SD* .17) and Sequential (*Mean* .92, *SD* .16) presentation conditions, $t(22) = 0.17, p > .05$. A further independent-samples t-test, collapsed across presentation type, also found no significant difference in magnitude of interference effects when comparing the aforementioned ratio measure on the basis of interference format, $t(22) = -0.84, p > .05$ (*Mean* .89, *SD* .18 and *Mean* .95, *SD* .14 of Simultaneous and Sequential interference conditions respectively).

A one-way Analysis of Variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) was conducted using the performance measure of scores in interference filled conditions represented as a ratio of performance in the unfilled

delay condition. There was no significant evidence of a difference in ratio measures across Simultaneous presentation-Simultaneous interference (*Mean* .88, *SD* .20), Simultaneous presentation-Sequential interference (*Mean* .98, *SD* .12), Sequential presentation-Simultaneous interference (*Mean* .92, *SD* .18) and Sequential presentation-Sequential interference (*Mean* .92, *SD* .16) groups, $F(3,20) = 0.38, p > .05$.

Reaction time analysis.

Descriptive statistics of correct response reaction time, shown in Table 3, indicate faster responses in immediate recognition performance as compared to delayed performance, and faster responses in the simultaneous as compared to sequentially presented recognition tasks. An independent-samples t-test found performance did not differ between Simultaneous and Sequential presentation in the immediate condition, $t(22) = -1.18, p > .05$. In order to assess the effect of an imposed delay between presentation and recognition, reaction time scores were subjected to the same transformation as accuracy scores – that is, each participant’s mean reaction time from unfilled delay conditions was represented as a ratio measure of their mean reaction time in the immediate condition. Using this ratio measure, a one-sample t-test found, collapsed over presentation condition, a significant effect of presence of a delay (*Mean* .1.31, *SD* .30), $t(23) = 5.09, p < 0.001$. This significant increase in reaction time, as measured through ratio scores, was subsequently shown to be present in both Simultaneous (*Mean* 1.34, *SD* .32) and Sequential (*Mean* .1.28, *SD* .28) presentation conditions, $t(11) = 3.62, p = .004$ and $t(11) = 3.45, p = .005$ respectively. An independent-samples t-test using the same ratio measure showed this increase in reaction time with presence of an unfilled delay was not significantly different between presentation conditions, $t(22) = 0.44, p > .05$. Reaction time results therefore offer further support of a detrimental effect of delay on recognition performance.

	Condition			
	Immediate		Unfilled delay	
	Mean	SD	Mean	SD
Simultaneous Presentation	471.24	176.36	592.24	135.48
Sequential Presentation	549.63	148.94	682.87	153.95

Table 3: Mean (in bold) and SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

Mean reaction time scores (as shown in Table 4) suggest that performance may change between unfilled and filled delay tasks and this change could differ on the basis of presentation and interference conditions. In order to conduct analysis on the effect of presence of interference, participants' mean reaction time in filled delay conditions was converted to a representation as a ratio of mean reaction time in unfilled delay conditions. A one-sample t-test revealed that, collapsed across presentation and interference conditions, this ratio measure of reaction times (*Mean* 1.03, *SD* .15) was not significantly different from 1, $t(23) = 1.07, p > .05$.

	Simultaneous Interference				Sequential Interference			
	Unfilled delay		Filled delay		Unfilled delay		Filled delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	683.26	57.20	666.87	101.59	501.21	131.23	518.56	177.33
Sequential Presentation	612.12	116.58	709.32	97.91	753.63	162.90	716.80	152.91

Table 4: Mean (in bold) and SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

Further independent-sample t-tests using the same immediately above described ratio measure of reaction time revealed presentation conditions

(Simultaneous and Sequential presentation) did not significantly differ in the extent to which they were affected by an interference filled delay, $t(22) = -0.98, p .05$, (*Mean* 1.00, *SD* .16 and *Mean* 1.06, *SD* .14 respectively). Effect of interference on reaction time, collapsed across presentation conditions, was also not found to differ significantly, $t(22) = 1.32, p > .05$, on the basis of interference type (Simultaneous and Sequential interference, *Mean* 1.07, *SD* .13 and *Mean* .99, *SD* .14 respectively).

A one-way analysis of variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) was conducted using the measure of mean filled delay condition reaction time as a ratio of mean unfilled delay condition reaction time. A significant main effect was found, $F(3, 20) = .341, p = .04$. Two independent-samples t-tests were subsequently conducted to investigate this main effect, with Bonferroni adjustments for multiple comparisons (significance level adjusted to .025). A significant difference in ratio scores was found between Simultaneous (*Mean* 1.17, *SD* .09) and Sequential interference (*Mean* .95, *SD* .07) in Sequential presentation conditions, $t(10) = 4.68, p = .001$, but not between Simultaneous (*Mean* .97, *SD* .09) and Sequential (*Mean* 1.03, *SD* .21) interference in Simultaneous presentation conditions, $t(10) = -0.62, p > .025$. Further one-sample t-tests were conducted to investigate the difference in reaction time ratio scores shown between interference conditions in Sequential presentation conditions, with Bonferroni corrections for multiple comparisons (significance level adjusted to 0.0125). Presence of Simultaneous interference was found to produce a reaction time ratio score significantly larger than 1, $t(5) = 4.50, p = .006$, while Sequential interference was not found to produce a reaction time ratio score significantly larger than 1, $t(5) = -1.73, p > .0125$.

The reaction time data results therefore do not cleanly suggest that presence of simultaneous interference increases time taken to make a recognition decision for simultaneous and sequentially presented memory stimuli. Despite the presence of longer reaction times for sequentially presented memory stimuli in the presence of simultaneous format interference, as time did not significantly differ between simultaneous presentation filled and unfilled conditions, interpretations of simultaneous format interference as detrimental to performance are tentative.

Variance in reaction time.

The variance in reaction time for each participant was calculated – that is, the standard deviation of each participant’s reaction time performance from their personal mean reaction time performance per condition was obtained - and subjected to analysis. Presence of increased variance in reaction time of correct responses in a condition could be taken as a measure which indicates less uniformity in response performance and therefore could be taken to indicate uncertainty in decision making.

Descriptive statistics of variance in correct reaction time, shown in Table 5, indicate less variance in reaction time performance in the simultaneous as compared to sequentially presented recognition tasks, however, an independent-samples t-test showed that this was not a significant difference, $t(22) = -1.60, p >.05$. In order to assess the impact of an unfilled delay on variance in reaction times in recognition performance, of a ratio measure was adopted. Each participant’s reaction time variance in the unfilled delay condition was represented as a ratio of their reaction time variance in the immediate condition. One-sample t-test analysis found these ratio scores (*Mean* 1.74, *SD* .71), collapsed across presentation conditions, to be significantly different from 1, $t(23) = 5.14, p < .001$. This significant difference was still found when Simultaneous presentation (*Mean* 1.93, *SD* .84), $t(11) = 3.82, p = .003$, and Sequential presentation (*Mean* 1.56, *SD* .52), $t(11) = 3.75, p = .003$, conditions were analysed separately. An independent-samples t-test found no significant difference in magnitude of ratio score between Simultaneous and Sequential presentation conditions, $t(22) = 1.30, p > .05$.

	Condition			
	Immediate		Unfilled delay	
	Mean	SD	Mean	SD
Simultaneous Presentation	143.56	78.08	222.47	52.45
Sequential Presentation	190.15	63.99	269.36	42.60

Table 5: Mean SD (in bold) and SD of the mean SD of correct reaction time performance (shown in milliseconds). Displayed according to presentation condition.

Mean and standard deviation in variance in reaction times for unfilled and interference filled delays are shown in Table 6. As performed for recognition accuracy

and reaction time data, each individual participant's variance in reaction time in the assigned interference condition was represented as a ratio of their performance in the unfilled delay condition in order to assess the impact of interference on recognition after a retention period.

	Simultaneous Interference				Sequential Interference			
	Unfilled delay		Filled delay		Unfilled delay		Filled delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	240.11	46.09	266.10	49.65	204.83	56.41	245.44	94.66
Sequential Presentation	266.42	40.75	280.11	64.03	272.29	48.07	232.51	25.81

Table 6: Mean SD (in bold) and SD of the mean SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

A one-sample t-test revealed the computed ratio scores (*Mean* 1.06, *SD* .24), collapsed across presentation and interference conditions, did not differ significantly from 1, $t(23) = 1.26$, $p > .05$. Further independent t-test analysis revealed, collapsed across interference conditions, ratio scores did not significantly differ between Simultaneous (*Mean* 1.15, *SD* .22) and Sequential presentation (*Mean* .97, *SD* .24), $t(22) = 1.96$, $p > .05$. Simultaneous interference (*Mean* 1.10, *SD* .23) and Sequential interference (*Mean* 1.03, *SD* .26), collapsed across presentation conditions, were shown by an independent-samples t-test not to differ significantly in magnitude, $t(22) = 0.68$, $p > .05$.

To determine whether a change in variance in reaction time may be observed on the basis of selective interference and presentation format combinations, a one-way Analysis of Variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) was conducted. The performance measure of variance in reaction time in interference filled conditions represented as a ratio of variance in reaction time in the unfilled delay condition was used. There was no significant evidence of a main effect of group across Simultaneous presentation-Simultaneous interference (*Mean* 1.12, *SD* .18), Simultaneous presentation-Sequential interference (*Mean* 1.19, *SD* .27), Sequential

presentation-Simultaneous interference (*Mean* 1.07, *SD* .29) and Sequential presentation-Sequential interference (*Mean* .89, *SD* .13) groups, $F(3,20) = 2.24, p > .05$.

Discussion.

As immediate recognition performance was high, it can be concluded that the distance presentation employed in the current task allows for accurate perception of stimuli and for the detection of location changes in changed trials. A drop in performance from immediate to delayed conditions indicates that maintenance processes are required that do not allow for ceiling performance – that is, at delay, the recognition task is not so easy that no effects of interference could be found. This difficulty is also evident in reaction time performance which is longer in the unfilled delay condition than in the immediate condition for both presentation formats. No significant effects of presentation condition accuracy and no interaction between presentation condition and immediate or delayed conditions suggests that neither presentation condition necessarily entails more fragile representations or representations that cannot be maintained over a 15000ms retention period. It would therefore be suggested that rehearsal or refreshing occurs for representations resulting from both presentation conditions over the retention delay.

Presence of static dots and presentation of a series of irrelevant sequential dots as interference during a filled delay was found to be detrimental to both simultaneous and sequential presentation as compared to performance in unfilled delay conditions; this interference was not found to be selective – that is, the effect on each presentation condition did not differ on the basis of interference type.

Simultaneous and Sequential presentation conditions did not significantly differ in performance in the immediate recognition condition. An increase in reaction time found between immediate and delayed performance was found for both presentation conditions, and the extent of this increase did not differ as a function of presentation. Additionally, reaction times reveal less variability when performance was immediate compared to when performance was after a delay period; this did not differ as a function of presentation. Reaction time analyses did not appear to provide any clear trend in the data on the basis of interference type; static array interference appeared to produce longer reaction times compared to unfilled conditions in the Sequential presentation condition, while such an effect was not found for sequential interference

in the Sequential presentation condition and there was no indication of a difference between interference conditions within Simultaneous presentation.

The finding that static and sequential interference procedures can interfere to a similar extent with simultaneous and sequentially retained information means there is no evidence to support fractionation of the visuo-spatial subsystem and no indication of distinct resources. It is possible that retention and rehearsal of simultaneously and sequentially presented stimuli were performed using common resources, however, it is also possible that performance in both presentation conditions of these recognition tasks draw on a common resource, or utilise a common process, which was affected by interference. For example, repeated use of the same locations over time as memory items (at presentation and test over all conditions completed) and again as interference items in interference conditions could lead to poorer encoding, due to reduced distinctiveness of the event of a location being occupied. Poorer quality of encoded information would lead to poorer retrieval- and thus recognition performance – and this could occur in both Simultaneous and in Sequential presentation conditions.

Viewing of irrelevant images, within foveal vision, would hardly be construed as an executive resource demanding task and, as stated in the introduction to the experiment, stimuli were created with an aim to be difficult to verbalise. It is therefore suggested that visuo-spatial resources are the most likely source of interference. As observed effects were small, it remained possible that interference may emerge as more selective if there was a greater magnitude of disruption. To investigate this possibility, further experiments were conducted with alteration of interference stimuli properties. Discussion of these findings in context of the models and views described in the introduction chapter will be provided at the end of the current chapter.

Experiment 2 (a; pilot experiment)

Recounted below is a pilot experiment conducted in order to refine the interference paradigm detailed in Experiment 1. Changes were made to the interference stimuli of Experiment 1 with an aim to increase salience and accordingly maximise effects of interference. This should better allow for any possibility of selective interference effects to emerge.

Changes made to interference included changing the colour of interference stimuli from red to white; this change was made based on feedback from participants from Experiment 1 who claimed that they did not find the red stimuli subjectively intrusive and suggested a brighter colour might be more difficult to ignore. A second change consisted of increasing the speed of appearance of sequential interference dots – so that one dot appeared every half second, with 28 dots appearing in total, in the sequential condition; this alteration was also made with the aim to increase stimuli salience.

Method.

Participants.

Seventeen undergraduate students from the University of Edinburgh were recruited through an advertisement on the University careers website for a one off testing session of one hour. Participants were provided with a single payment of £5.05 for taking part. Of the total 17 participants tested three were excluded due to poor performance in the baseline condition (as detailed in results). The data of 14 participants (3 males, mean age 21.36 years, SD 1.86, median 21.5, range 19-25) were included in analysis. All participants were right handed, and fulfilled the inclusion criteria of normal or corrected-to normal vision with no known problems with colour blindness. This experiment was intended as a pilot study with a new paradigm and so did not involve a completely counterbalanced design across participants.

Design.

As in Experiment 1, presentation format remained a between participants factor and an equal number of participants performed each condition (seven participants to each presentation format); within this division, interference format was a further between participants factor. In each presentation format four participants performed their interference filled condition with sequential interference while three participants performed the task with simultaneous format interference. Order of completion of conditions and memory list use was randomly chosen for each participant from the counterbalancing developed for Experiment 1.

Apparatus , materials and procedure.

Experiment 2 (a) used the same computer apparatus and set up as detailed in Experiment 1. Primary recognition tasks employed the same stimuli, memory lists and procedure as described in Experiment 1. Two alterations were made, however, to the interference tasks employed.

Sequential interference was presented at a rate of one dot per 500ms of the 1400ms during which interference occurred. This increased pace of appearance of interference stimuli was therefore equal to the pace of presentation of to-be-remembered stimuli. This increased rate of appearance in the sequential interference condition meant that double the amount of dots appeared in sequential interference (28 dots) compared to simultaneous interference (14 dots). Constraints on appearance of sequential interference dictated that the number of times a location could be used during interference in a given trial was limited to two. Within a sequential interference trial the availability of 30 locations to be used two times allowed for 60 possible appearances, of which only 28 would occur in any given trial. Furthermore, appearance in sequential interference had no constraints as to the sequence in which locations appeared. Therefore, despite limitation on locations and the higher number of items used in sequential interference, it was highly unlikely that sequential interference throughout a block of trials would produce sequences with any discernable replication or familiarity.

Both simultaneous and sequential interference were also altered such that interference dots were white rather than red, still appearing, as in Experiment 1, against a black background.

Results.

Of the 17 participants tested, three (two of which belonged to sequential presentation, one to simultaneous presentation condition) performed two Standard Deviations below the mean in the unfilled delay condition of their respective presentation condition. These participants were therefore removed from analysis. Analyses on recognition scores, reaction time and variance in reaction time were adopted in the manner undertaken in Experiment 1.

As in the previous experiment immediate recall scores were high (see Table 7), with little variation in performance observed across participants, and a drop in recognition performance was again indicated with introduction of a retention period.

An independent-samples t-test revealed immediate recognition performance was not significantly different between presentation conditions, $t(12) = 1.15, p > .05$, indicating – as in Experiment 1 – that a change in location was not easier or more difficult to detect on the basis of presentation format.

	Condition			
	Immediate		Unfilled delay	
	Mean	SD	Mean	SD
Simultaneous Presentation	22.00	2.00	18.86	2.41
Sequential Presentation	21.00	1.15	17.71	1.70

Table 7: Mean (in bold) and SD descriptive statistics for each condition, based on recognition scores (out of maximum possible 24). Displayed according to presentation.

As in Experiment 1, in order to assess the effect of introduction of a delay on recognition performance, each participant's individual score in the unfilled delay condition was converted to a ratio measure – derived by dividing the unfilled delay performance by the corresponding immediate recognition performance. These ratio scores were then subject to a one-sample t-test, with a comparison test value of 1. Introduction of a delay was found to, when collapsed across presentation formats, significantly reduce performance ($Mean .86, SD .14$), $t(14) = -3.85, p = .002$. When the same one-sample t-tests were conducted for each presentation condition, Sequential presentation ratio scores ($Mean .84, SD .12$) were found to be significantly different from 1, $t(6) = -3.42, p = .014$, revealing introduction of a delay reduces performance level. Simultaneous presentation ratio scores ($Mean .87, SD .17$) were not found to significantly differ from 1, $t(6) = -2.12, p > .05$. A further independent-samples t-test, however, revealed no difference between presentation conditions in magnitude of decrement introduced by a delay, $t(12) = 0.25, p > .05$.

	Simultaneous Interference				Sequential Interference			
	Unfilled delay		Filled delay		Unfilled delay		Filled delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	18.67	2.08	17.67	2.52	19.00	2.94	20.00	1.41
Sequential Presentation	18.67	1.53	16.33	2.08	17.00	1.63	18.75	1.26

Table 8: Memory task performance represented as a mean (in bold) of raw score from all 24 trials performed by each participant. Displayed according to presentation and interference conditions.

Performance in filled delay conditions, as shown in Table 8, was subject to conversion before analyses were run to investigate effects of interference; each participant's individual score in interference filled conditions was represented as a proportion of their performance in unfilled delay conditions. A one-sample t-test using this ratio measure found that recognition performance, collapsed across presentation and interference conditions, was not significantly reduced by the presence of interference (*Mean* 1.02, *SD* .17), $t(13) = .39, p > .05$. An independent-samples t-test found no significant difference between magnitude of interference effects (as represented by ratio measure) when comparing Simultaneous (*Mean* 1.02, *SD* .18) and Sequential (*Mean* 1.01, *SD* .17) primary task presentation conditions, collapsed over interference type, $t(12) = 0.12, p > .05$. A further independent-samples t-test found no significant difference between magnitude of interference effects (as represented by ratio measure) under Simultaneous (*Mean* .92, *SD* .18) and Sequential (*Mean* 1.10, *SD* .13) interference, collapsed across primary task presentation type, $t(12) = -2.00, p > .05$.

A one-way Analysis of Variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) was conducted using the computed ratio measure. There was no significant evidence of a main effect of group. That is, no significant difference in ratio measures across Simultaneous presentation-Simultaneous interference (*Mean* .96, *SD* .23), Simultaneous presentation-Sequential interference (*Mean* 1.07, *SD* .15), Sequential presentation-Simultaneous interference (*Mean* .88, *SD* .16) and Sequential

presentation-Sequential interference (*Mean* 1.11, *SD* .12) was found, $F(3,10) = 1.33$, $p > .05$.

Reaction time analysis.

Descriptive statistics of correct response reaction time, shown in Table 9, indicate faster responses in immediate recognition performance as compared to delayed performance, and faster response in the simultaneous as compared to sequentially presented recognition tasks. An independent-samples t-test found no significant difference in mean immediate reaction times between Simultaneous and Sequential presentation conditions, $t(12) = -.19$, $p > .05$.

	Condition			
	Immediate		Unfilled delay	
	Mean	SD	Mean	SD
Simultaneous Presentation	523.62	120.21	656.99	197.51
Sequential Presentation	535.27	112.11	683.00	96.14

Table 9: Mean (in bold) and SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

As in Experiment 1, assessment of the effect of an imposed delay between presentation and recognition required reaction time scores be subjected to a transformation—each participant’s mean reaction time from unfilled delay conditions were represented as a ratio measure of their mean reaction time in the immediate condition. Using this ratio measure a one-sample t-test found, collapsed over presentation condition, a significant effect of presence of a delay (*Mean* 1.29, *SD* .28), $t(14) = 3.77$, $p < 0.002$. This significant increase in reaction time, as measured through ratio scores, was subsequently shown to be present in Sequential (*Mean* 1.31, *SD* .25) presentation conditions, $t(6) = 3.26$, $p = .014$, but not in Simultaneous (*Mean* 1.26, *SD* .33) presentation conditions, $t(6) = 2.10$, $p > .05$. An independent-samples t-test using the same ratio measure, however, showed the increase in reaction time with presence of an unfilled delay was not significantly different between presentation conditions, $t(12) = -0.29$, $p > .05$.

Mean and standard deviation of reaction times for unfilled and interference filled delays are shown in Table 10. Presence of interference appears to produce longer reaction times in the case of simultaneous interference yet not in the case of sequential interference. To further investigate this, individuals' mean reaction times in the filled delay condition were represented as a ratio of their performance in the unfilled delay condition to assess the impact of presence of interference in a delay period. This ratio measure was used for further analyses.

	Simultaneous Interference				Sequential Interference			
	Unfilled delay		Filled delay		Unfilled delay		Filled delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	648.10	59.18	705.89	27.19	663.65	274.86	588.80	249.17
Sequential Presentation	669.49	135.06	691.10	185.24	693.14	77.49	609.49	155.89

Table 10: Mean (in bold) and SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

A one-sample t-test revealed that, overall, reaction time performance after a filled delay was not significantly different than after an unfilled delay – shown by no significant difference between mean ratio measure (*Mean* .96, *SD* .15) and test value 1, $t(13) = -1.07$, $p > .05$. Under Simultaneous (*Mean* .98, *SD* .15) and Sequential (*Mean* .94, *SD* .15) presentation of primary task conditions, and collapsed across interference type, the extent to which reaction time performance was affected by interference did not differ, $t(12) = 0.48$, $p > .05$. A further independent-samples t-test of reaction time ratio scores revealed Simultaneous (*Mean* 1.06, *SD* .11) and Sequential (*Mean* .88, *SD* .12) interference conditions, collapsed across primary task presentation type, did significantly differ in effect of interference on reaction time, $t(12) = 2.82$, $p = .016$, reflecting an increase in reaction time in the presence of Simultaneous format interference yet a reduction in reaction time under Sequential interference type. A specific comparison to investigate the main effect of interference type was conducted. A one-sample t-test using ratio performance score found no significant effect of presence of interference, $t(5) = 1.34$, $p > .05$ in Simultaneous interference conditions. A one-sample t-test using ratio performance score found a significant effect of presence of

interference, $t(7) = -2.75$, $p = .029$ in Sequential interference conditions, however, this was no longer significant after correction of significance levels for multiple comparisons (adjusted to 0.025, Bonferroni correction).

To determine whether a change in reaction time may be observed on the basis of selective interference and presentation format combinations, a one-way Analysis of Variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) was conducted. The performance measure of reaction time in interference filled conditions represented as a ratio of reaction time in the unfilled delay condition was used. There was no significant evidence of a main effect of group across Simultaneous presentation-Simultaneous interference ($Mean = 1.10$, $SD = .11$), Simultaneous presentation-Sequential interference ($Mean = .89$, $SD = .11$), Sequential presentation-Simultaneous interference ($Mean = 1.03$, $SD = .13$) and Sequential presentation-Sequential interference ($Mean = .88$, $SD = .13$) groups, $F(3,10) = 2.45$, $p > .05$.

Variance in reaction time.

Descriptive statistics of variance in each participant's correct reaction time, shown in Table 11, indicate less variance in immediate Sequential recognition performance as compared to immediate Simultaneous presentation performance. There was, however, no significant difference between presentation conditions, $t(12) = .96$, $p > .05$.

	Condition			
	Immediate		Unfilled delay	
	Mean	SD	Mean	SD
Simultaneous Presentation	218.22	74.46	274.69	58.63
Sequential Presentation	186.59	46.18	279.12	35.13

Table 11: Mean SD (in bold) and SD of the mean SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

In order to assess effect of an introduced delay on Variance in reaction time, reaction times were converted for analysis to a ratio measure. This was derived from each individual's variance in reaction time in the unfilled delay condition divided by their performance in the immediate condition. Analysis of these ratio scores found insertion of delay significantly increased the amount of variance present in reaction times (*Mean* 1.47, *SD* .45), collapsed across presentation conditions, $t(13) = 3.96, p = .002$. This was also found to be true when Sequential (*Mean* 1.57, *SD* .43) but not when Simultaneous (*Mean* 1.37, *SD* .48) presentation condition ratio measure one-sample t-tests were performed, $t(6) = 3.56, p = .012$ and $t(6) = 2.06, p > .05$ respectively. There was no significant difference, however, between magnitude of ratio measures of Simultaneous and Sequential presentation conditions in an independent-samples t-test, $t(12) = -0.83, p > .05$.

Variance in interference filled delay reaction times was converted for analysis, as in Experiment 1, to a measure where each individual's variance in reaction time in the interference condition performed is represented as a ratio of their performance in the unfilled delay condition. This enabled the assessment of impact of interference on recognition after a delay.

	Simultaneous Interference				Sequential Interference			
	Unfilled delay		Filled delay		Unfilled delay		Filled delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	303.08	64.71	263.52	5.09	253.39	51.71	267.14	26.27
Sequential Presentation	292.96	29.13	273.84	69.70	268.74	39.60	267.27	50.79

Table 12: Mean SD (in bold) and SD of the mean SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

A one-sample t-test of the above described ratio measure revealed overall variance in reaction time data, when collapsed across primary task presentation conditions, did not change after interference is introduced into the delay - as shown by

a ratio measure (*Mean* 1.00, *SD* .24) not significantly different from a value of 1, $t(14) = -0.08$, $p > .05$. Comparison of primary task presentation type, collapsed across interference type, by an independent-samples t-test found no significant difference between variance ratio scores in Simultaneous (*Mean* 1.01, *SD* .27) and Sequential (*Mean* .98, *SD* .23) conditions, $t(12) = 0.23$, $p > .05$. Comparison of interference type, collapsed across primary task presentation type, by an independent-samples t-test also found no significant difference between variance ratio scores representing Simultaneous (*Mean* .91, *SD* .15) and Sequential (*Mean* 1.06, *SD* .28) interference conditions, $t(12) = -1.16$, $p > .05$.

To determine whether a change in variance in reaction time may be observed on the basis of selective interference and presentation format combinations, a one-way Analysis of Variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) was carried out. The performance measure of variance in reaction time in interference filled conditions represented as a ratio of variance in reaction time in the unfilled delay condition was again used. There was no significant evidence of a main effect of group across Simultaneous presentation-Simultaneous interference (*Mean* .89, *SD* .18), Simultaneous presentation-Sequential interference (*Mean* 1.09, *SD* .31), Sequential presentation-Simultaneous interference (*Mean* .93, *SD* .14) and Sequential presentation-Sequential interference (*Mean* 1.02, *SD* .29) groups, $F(3,10) = 0.46$, $p > .05$.

Discussion.

Accuracy, reaction time and reaction time variance all indicated impaired performance on the basis of having to maintain representations over an unfilled delay compared to immediate performance. Though, when presentation conditions were tested separately, Simultaneous condition performance did not show significant decline in score or reaction time measures, comparison of magnitude of decline in performance did not appear to differ between presentation formats, again suggesting, as in Experiment 1, that neither presentation condition necessarily entails representations more vulnerable to effects of retention.

This pilot experiment was conducted in order to allow for selective interference effects, if present, to emerge due to theoretically more intrusive interference. There was, however, little to no evidence of interference effects in this experiment. Accuracy, and reaction time variance measures both indicated that there was no significant impairment in performance in an interference filled condition compared to an unfilled condition. Furthermore, an indication of an effect of sequential interference, as measured through reaction time, proved non-significant after correction for multiple comparisons and did not exhibit influence in analysis of the main effect of presentation and interference combination. Interference effects observed in Experiment 1 were small, and the current experiment revealed no reliable interference effects; it is therefore possible that interference effects are not strong or reliable, rather than a lack of interference effects in the current experiment reflecting methodology change.

It was hypothesised that due to the distance at which presentation screens were shown, and the size of the visual screen which they occupied, that participants might be benefiting from interference stimuli demarking the test area of the screen – for example, raw mean score measures suggested in the sequential interference conditions there was an increase in performance observed between unfilled and interference filled delays. This unforeseen benefit could be masking any detrimental effect of visually presented stimuli compared to an unfilled test screen. A further pilot experiment was therefore conducted in order to address this disparity between unfilled and filled conditions and to limit potential beneficial effects interference may have in helping to maintain array structure.

Experiment 2 (b; pilot experiment)

Two additional changes were made to the recognition and interference task paradigm of Experiment 2 (a). A border was introduced to both unfilled and filled delay conditions in order to clearly mark the area of the screen in which all presentation, interference and test stimuli would occur. This was implemented to correct a difference which previously existed (Experiments 1 & 2 a) in unfilled and filled conditions and would allow any differences between unfilled and interference filled conditions to be more clearly attributed to a result of interference alone. Secondly, interference locations were changed so that on any one trial 50% of locations

corresponded to the original test array and 50% corresponded to thirty locations which did not feature as squares on the template array. This was implemented in order to make it less likely participants could use locations to support maintenance by hosting part of the structure of the template array throughout the retention interval.

Method.

Participants.

Through the University careers website, participants were recruited for a one off testing session of one hour and provided with a single payment of £5.05 for taking part. Six participants (2 male, mean age 21.17 years, SD 1.47, median = 20.5, range = 20-23), who were all right handed, took part before testing in this round was terminated in favour of further development of the paradigm.

Apparatus, Materials and Procedure.

Experiment 2 (b) used the same apparatus and set up as detailed in Experiment 1. As in Experiments 1 and 2(a), all participants performed the primary recognition task in an immediate (500ms), an unfilled delay (15000ms) and a filled delay (15000ms) condition; the order in which these conditions were performed was varied across participants. Presentation and interference were again manipulated as between participants factors, however, given that this was a pilot experiment, no attempt was made to have equal numbers in each group. Primary recognition tasks employed the same stimuli, memory lists and procedure as described in Experiment 1. The two modifications made in this experiment therefore related to the retention period between presentation and test recognition screens.

In the unfilled delay condition a border was introduced in order to better define the portion of the screen in which items would reappear. Four thin white lines – together making a rectangle - appeared as soon as the presentation screens disappeared. This border remained throughout the delay period, indicating the area which at all other times of a trial was occupied by presentation or recognition screens.

In the interference conditions this border was also employed. Furthermore, interference stimuli from Experiment 2 (a; after Experiment 1) were changed so that rather than all possible interference locations originating from the template used for the primary memory task, 30 novel locations were introduced. These locations were

randomly chosen from the area unoccupied by white locations used in the primary memory template. In each interference trial, the locations at which interference dots appeared comprised 50% memory template locations, 50% novel locations. The interference locations which were used on any given interference trial were randomly generated within this constraint, in order to create 14 locations for simultaneous interference and 28 locations for sequential interference. Twenty-four trials worth of locations were generated for each participant, using formula available within Excel software, and then inserted into E-Prime to serve as interference locations.

Results.

No analysis of the data was carried out as only six participants were tested, however, descriptive statistics were inspected. As shown in Table 13 there was little suggestion of a detrimental effect of interference in simultaneously presented memory trials; in the case of sequential interference in sequentially presented memory trials, of the three participants tested in this condition one participant improved in performance between unfilled and filled conditions, one remained the same and one participant's performance decreased in the filled condition.

	Condition					
	Unfilled delay		Filled - simultaneous		Filled - sequential	
	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	17.33	4.16	20.00	-	19.00	2.00
Sequential Presentation	19.00	2.65	-	-	17.50	3.54

Table 13: Memory task performance represented as a mean (in bold) of raw score from all 24 trials performed by each participant. Displayed according to presentation condition; note unfilled delay is collapsed across interference groups. Dash indicates no data for this cell due to termination of testing.

As in the previous experiments above, immediate recognition performance was high in both simultaneous (*Mean 21, SD 3.61*) and sequential (*Mean 22.33, SD 0.58*) presentation conditions.

Discussion.

There was little evidence of interference effects present: simultaneous presentation showed no susceptibility to interference and of the sequential presentation-sequential interference participants, one showed impairment under interference, one showed no change and one displayed improvement.

A review of Experiments 1 to 2 b indicates that any observed interference effect appears to be unreliable and, when observed, was small. There was no evidence of selective interference. A final passive interference experiment was therefore required, in which a larger number of participants were tested, in order to increase the power to detect any possible effects. A number of participants were removed in previous experiments due to poor performance - yet still, unfilled delay performance was relatively low as a mean across participants. Modifications were therefore devised in order to improve performance on the task – such as further training on responding within the reaction time presentation screen, and providing feedback in a training session so that participants could have confidence in knowing how to detect a changed trial. These changes could allow for a greater drop between a well performed baseline and any effects of interference to emerge.

It is also possible that in interference conditions participants were neglecting to pay attention to the screen in front of them; in previous experiments there had been instructions to fixate in the centre of the screen, however, the experimenter was situated next to the participant and could not completely observe compliance with instructions. A change in task set-up whereby participants were required to consistently keep their eyes on the screen in front of them would maximise chances of obtaining interference.

Experiment 2 (c)

As previously pointed out, the high level of performance observed in the immediate (500ms) condition throughout pilot testing, Experiments 1, 2(a) and 2 (b) indicates that presentation stimuli can be seen, and the subtle changes in 'changed'

location trials detected, at the distance presented. Therefore, no immediate condition was included in Experiment 2 c.

A number of new steps, as detailed in the procedure section below, were introduced to the testing procedure with a view to increasing baseline performance (that is, performance in the unfilled delay condition) in order to reduce the need to remove or replace participants and, furthermore, to generate a more consistent level of performance across participants against which any possible effect of interference would be easily detectable (that is, unfilled delay performance at well above chance levels). Of note, a camera set-up was introduced so that the experimenter could view the participant throughout a trial; this procedure was implemented in order to minimise the chances that participants would voluntarily look away from the screen, close their eyes or neglect to try and comply with these instructions. No claim can be made that eye movements were not made throughout the task; an attempt was made to prevent participants from not viewing the interference stimuli presented and to prevent participants moving their eyes around the screen or room during an unfilled interval.

Alterations were made to interference stimuli, as detailed in the materials section below, in order to maximise the possibility that participants would spontaneously encode irrelevant information and therefore maximise the chances that selective interference effects could, if present, emerge.

Method.

Participants.

Fifty-three undergraduate students were recruited through the university careers website for participation in a one off testing session of approximately an hour. Each participant was provided with an honorarium of £5.05 for taking part. Of the total 53 participants tested, the data of 48 were analysed; five participants were excluded from the study due to poor performance in the baseline condition (as detailed in results). Of the 48 participants (mean age 20.40 years, SD 1.92, median 20, range 18-24) included in analysis 21 were male and four were left handed (determined by self report only). All participants fulfilled the inclusion criteria of normal or corrected-to-normal vision with no known problems with colour blindness.

Design.

A (2 x 2 x 2) mixed design was employed: presentation format of stimuli was manipulated (simultaneous or sequential presentation) as a between participants factor, as was format of interference task (simultaneous interference or sequential interference). All participants performed the primary recognition task in two conditions: recognition after an unfilled delay (15000ms) and recognition after an interference filled delay (15000ms). There were therefore four comparable groups (simultaneous presentation, simultaneous interference; simultaneous presentation, sequential interference; sequential presentation, simultaneous interference; sequential presentation, sequential interference) of 12 participants created, with performance recorded for each in delayed and interference filled delay conditions.

Apparatus.

The testing apparatus described in Experiment 1 was employed to run the current experiment, display all screens of the task and record all responses.

An additional computer and apparatus set up was also required. Participants were monitored through use of a Mikomi webcam situated centrally above the presentation monitor. This webcam was linked via USB (that is, without use of internet) to a Pentium 4 ® processor PC which displayed the continual image captured by webcam on a screen of size 35cm diagonal (28 x 20.5cm) through AMCAP Directshow Video Capture (version 8.11) preview function. Screen resolution of the monitor (Samsung Syncmaster 550s), which used an NVIDIA Vanta graphics processor, was set at 1024 x 768 pixels with high (16 bit) colour quality. This monitor was viewed by the experimenter throughout the entirety of the experiment. No video data was recorded, transferred to any other computer nor viewed by anyone except the experimenter.

Materials.

Two memory lists created in Experiment 1 (see Experiment 1 for details) were employed for use with the primary memory task. All participants completed both memory lists; whether a memory list was carried out in an unfilled or filled delay condition was counterbalanced across participants.

The interference materials created in Experiment 1 (see Experiment 1 for details) were modified for use in the current experiment. The dot stimuli presented as interference were altered to increase their similarity to stimuli used in the memory portion of the task – specifically, black dots presented within white squares were used. White squares were not present by themselves at any point throughout an interference delay; each individual interference stimuli item consisted of a black dot within a white square (dot and square of same size and proportion as memory stimuli) while the rest of the display area that did not support an interference item remained uniform. In a further change to the interference materials of Experiment 1 a green background was introduced as the blank screen for unfilled delay condition and as the background against which interference stimuli were presented in the filled conditions. The green background was of the same colour used in the green template memory presentation screens⁸; use of this green background served two purposes. Firstly, a constant screen array throughout delay periods (excluding the initial 1000ms black blank screen following presentation screens) helped to define the area, out of the whole computer screen, in which the task took place. This development follows and replaces the use of a border display as described in Experiment 2 (b). Secondly, use of a green background further increased the similarity between presentation and interference, whereby both sections of the task employed a black dot within a white square presented against a green background (though memory and interference portions of a task were easily defined by the presence or absence, respectively, of additional template squares).

Following the developments made to interference in Experiments 2(a) and 2(b), the pace of presentation of sequential interference dots was held at one every 500ms, thus 28 dot locations were used in sequential interference (while the number of locations appearing in simultaneous presentation remained at 14). Furthermore, following Experiment 2 (b), the locations for interference dots randomly generated for use in any given interference trial consisted of 50% of memory template locations and 50% of 30 new locations created in Experiment 2 (b; see Figure 7 for examples of interference stimuli).

⁸ Details: Luminance 108; red 0; green 230; blue 0; saturation 240; hue 80

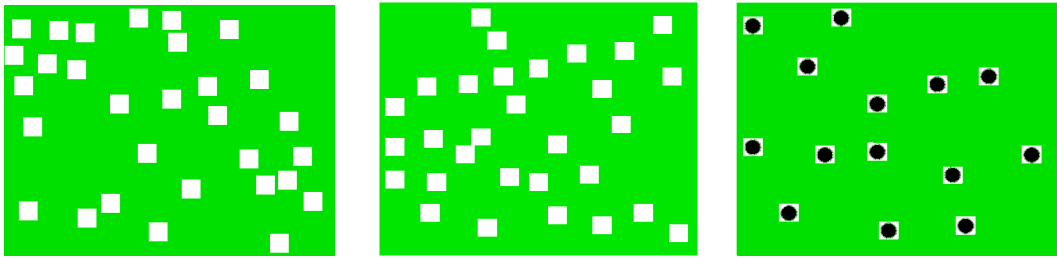


Figure 7: Left panel shows memory location template; central panel shows 30 novel locations for interference use alone, as created in Experiment 2(b); right panel shows example of a simultaneous format interference presentation of composition 50% template locations 50% novel locations.

Procedure.

The same basic procedure as Experiments 1, 2(a) and 2(b) was employed whereby participants had to remember the locations of three black dots presented within a green template array. Participants had to respond after viewing a red recognition test screen whether the dots re-presented were in the initial positions (press a key indicating 'same') or whether a single dot had changed location (press a key indicating 'different'). Responses and reaction times were recorded in a blue response screen following the recognition test screens. All participants performed the recognition task in a block of 24 trials where recognition was after an unfilled 15000ms delay and also in a block of 24 trials where recognition was after an interference filled 15000ms delay. Half of the participants completed the task with presentation of dots in a simultaneous format and half of the participants completed the task with presentation of dots in a sequential format. Within each half of this division, half the participants completed the task with the interference filled condition consisting of interference appearing in a simultaneous format and half of the participants completed the task with interference appearing in a sequential format (see Experiment 1 procedure for details; see Figures 8 & 9 for example of experimental trials). Order of completion of conditions was counterbalanced across participants.

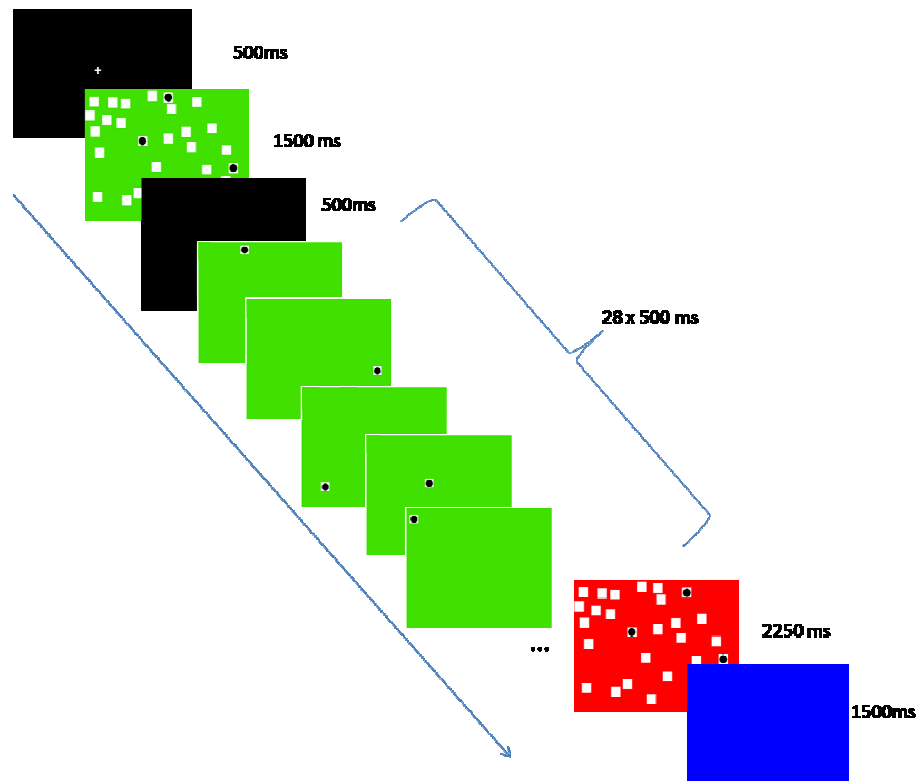


Figure 8: Example of experimental set up: simultaneous presentation with a filled delay of sequential interference. Red recognition screen shows example of a changed trial. Black screen area surrounding all images has been removed for clarity.

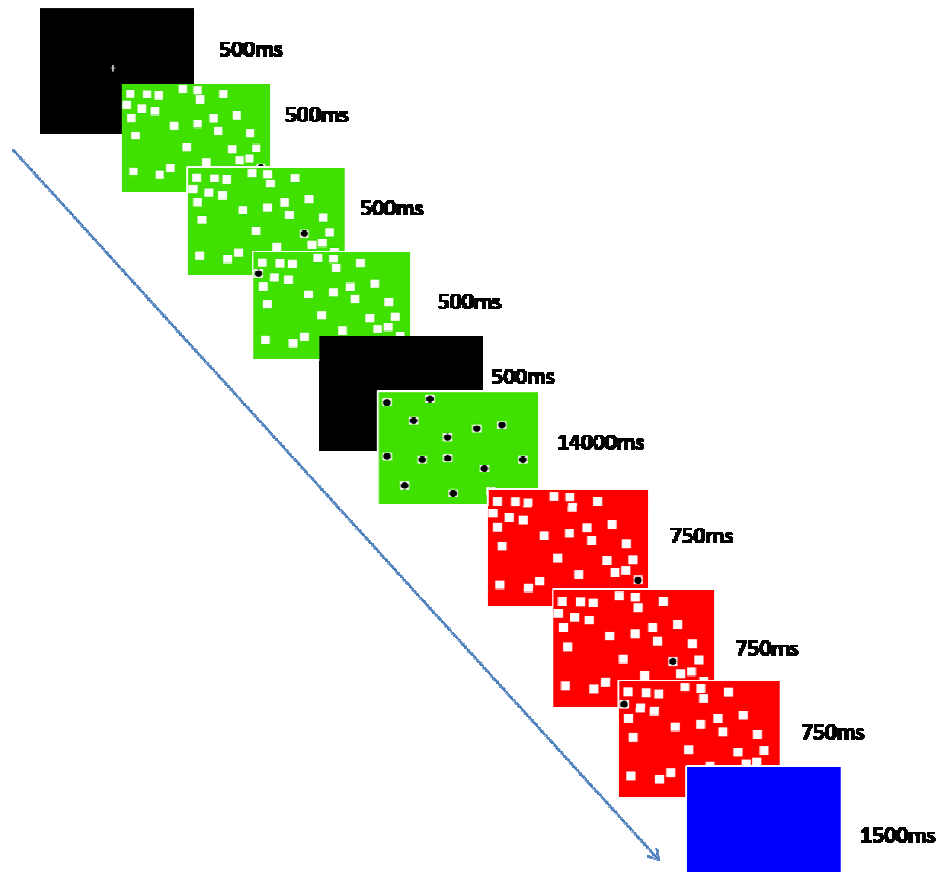


Figure 9: Example of experimental set up: sequential presentation with a filled delay of simultaneous interference. Red recognition screen shows example of an unchanged trial. Black screen area surrounding all images has been removed for clarity.

Five changes to the procedure described in Experiment 1 were made. As reflected in the above procedure, design and materials descriptions, Experiment 2c did not contain an immediate recognition condition. Two of the changes made to the basic procedure were additional steps taken before beginning experimental trials. Participants were shown a step-by-step visual illustration of the task (in the unfilled delay condition) which they were required to complete, before starting the experiment – that is, while discussing instructions and task requirements, the display screens corresponding to each section of the task were shown. This was also taken as an opportunity to emphasise the requirement to respond within the time limited blue screen. Secondly, introduction of a minimum level of performance achievement in practice trials prior to commencing experimental trials was also introduced.

Implementation of this latter addition to procedure existed as a form of training: participants continued to perform practice trials until a performance level of within 70-80% correct responses was reached. Once the required level of performance was achieved participants moved on to the experiment proper.

A further addition to procedure was the introduction of a verbal instruction to participants, provided alongside the step-by-step screen instructions that presented patterns and sequences should be remembered visually; participants were explicitly discouraged from using verbal or conceptual strategies. An example was provided to participants of an idiosyncratic strategy which had been reportedly used in a previous version of the experiment whereby the locations of dots were likened to musical notes; it was emphasised that use of any such method which could be considered unusual or abstract would be detrimental to task aims.

The final modification to the basic procedure entailed the experimenter observing the participant performing the task through a screen mounted web-camera. The image captured by the camera fed directly to a nearby computer, through which the experimenter was provided with a direct view of the faces of participants as they performed the task. Participants were informed prior to beginning the experiment that their performance would be monitored using this apparatus in order to continually determine whether instructions to restrict viewing throughout a trial to the centre of the presentation screen (without closing their eyes or looking around the screen or room) were being adequately complied with. A demonstration was provided to emphasise that eye movements could be detected and that information was not recorded nor transferred to another computer outside of the testing room.

Results.

Of the five participants excluded from the total 53 participants tested: two participants were excluded from the simultaneous presentation condition and three were excluded from the sequential presentation condition on the basis of performance 2 SD below the mean in the unfilled delay condition of their respective presentation conditions. The unfilled delay condition served as a baseline control condition against which interference effects were tested (see Table 14).

	Simultaneous Interference				Sequential Interference			
	Unfilled		Filled delay		Unfilled		Filled delay	
	delay		delay		delay		delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	18.33	1.67	17.92	2.58	18.67	2.50	17.75	2.56
Sequential Presentation	18.58	2.11	18.83	2.59	17.42	1.73	15.58	2.47

Table 14: Memory task performance represented as a mean (in bold) of raw score from all 24 trials performed by each participant. Displayed according to presentation and interference conditions.

As in Experiments 1 and 2a, a ratio measure derived from each individual participant's score under interference conditions divided by their score in the unfilled delay condition was used for statistical analyses in order to assess the effects of interference and presentation manipulations. A one-sample t-test revealed that recognition performance in the presence of interference (*Mean* .96, *SD* .15), collapsed across presentation and interference types, was not significantly different from the value 1, $t(47) = -1.67, p > .05$. An independent-samples t-test found no significant difference in magnitude of ratio score –and thus interference effects – when comparing Simultaneous (*Mean* .97, *SD* .14) and Sequential (*Mean* .96, *SD* .15) presentation conditions, collapsed across interference type, $t(46) = 0.27, p > .05$. There was also no significant difference found by an independent-samples t-test between Simultaneous (*Mean* 1.00, *SD* .15) and Sequential (*Mean* .93, *SD* .13) interference types in magnitude of effect caused to performance, collapsed across presentation conditions, $t(46) = 1.83, p > .05$.

A one-way Analysis of Variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) was conducted using the computed ratio measure. There was no significant evidence of a main effect of group. That is, difference in ratio measures across Simultaneous presentation-Simultaneous interference (*Mean* .98, *SD* .14), Simultaneous presentation-Sequential interference (*Mean* .96, *SD* .15), Sequential presentation-Simultaneous interference (*Mean* 1.02, *SD* .17) and Sequential

presentation-Sequential interference (*Mean* .89, *SD* .10) groups were not shown to significantly differ, $F(3,44) = 1.70, p > .05$.

Reaction time analysis.

As in Experiments 1 and 2a, participants' individual mean reaction time in interference filled recognition performance (see Table 15) was represented for analysis as a ratio of their mean performance in the unfilled delay condition in order to assess the impact of interference on recognition reaction time.

	Simultaneous Interference				Sequential Interference			
	Unfilled delay		Filled delay		Unfilled delay		Filled delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	635.39	176.70	635.82	157.29	611.64	199.30	549.60	168.72
Sequential Presentation	561.94	113.00	580.38	131.62	621.36	117.97	603.64	117.21

Table 15: Mean (in bold) and SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

A one-sample t-test revealed that, overall, reaction time performance after a filled delay was not significantly different than after an unfilled delay – as shown by a mean ratio score (*Mean* 1.00, *SD* .20) not significantly different from 1, $t(47) = -0.65, p > .05$. An independent-samples t-test further found that the extent to which reaction time was affected by interference in Simultaneous (*Mean* .98, *SD* .20) and Sequential (*Mean* 1.2, *SD* .20) presentation conditions, collapsed across interference type, did not significantly differ, $t(46) = -0.73, p > .05$. Ratio representation measures of reaction time under Simultaneous (*Mean* 1.04, *SD* .20) and Sequential (*Mean* .96, *SD* .20) interference, collapsed across primary task presentation type, were also found by an independent-samples t-test to not differ significantly, $t(46) = 1.34, p > .05$.

A one-way Analysis of Variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) conducted using the computed ratio measure found no significant evidence of a main effect of group. Ratio measures across Simultaneous

presentation-Simultaneous interference (*Mean* 1.02, *SD* .20), Simultaneous presentation-Sequential interference (*Mean* .93, *SD* .20), Sequential presentation-Simultaneous interference (*Mean* 1.05, *SD* .21) and Sequential presentation-Sequential interference (*Mean* .99, *SD* .20) groups were not shown to significantly differ, $F(3,44) = 0.79, p > .05$.

Variance in reaction time.

No clear pattern of variance in reaction time is immediately apparent (see Table 16), however, there is a suggestion for increased variance in filled as compared to unfilled conditions – with the exception of the simultaneous presentation-simultaneous interference group.

Variance in reaction times was converted for analysis, as in Experiments 1 and 2c, to a measure where each individual’s variance in reaction time in the interference condition performed is represented as a ratio of their performance in the unfilled delay condition. This enabled the assessment of impact of interference on recognition after a delay.

	Simultaneous Interference				Sequential Interference			
	Unfilled delay		Filled delay		Unfilled delay		Filled delay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	302.49	238.72	210.64	70.42	201.40	71.80	233.43	70.06
Sequential Presentation	229.79	91.33	250.75	90.98	279.61	104.34	283.73	97.38

Table 16: Mean (in bold) and SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

A one-sample t-test of the above described ratio measure revealed overall variance in reaction time data, when collapsed across primary task presentation conditions, did not change after interference is introduced into the delay - as shown by a ratio measure (*Mean* 1.04, *SD* .51) not significantly different to a value of 1, $t(46) = .53, p > .05$. Comparison of primary task presentation type, collapsed across interference type, by an independent-samples t-test found no significant difference between variance ratio scores in Simultaneous (*Mean* .99, *SD* .33) and Sequential (*Mean* 1.09, *SD* .64) conditions, $t(46) = -.66, p > .05$. Comparison of interference type,

collapsed across primary task presentation type, by an independent-samples t-test also found no significant difference between variance ratio scores representing Simultaneous (*Mean* 1.04, *SD* .37) and Sequential (*Mean* 1.03, *SD* .62) interference conditions, $t(46) = 0.06, p > .05$.

To determine whether a change in variance in reaction time may be observed on the basis of selective interference and presentation format combinations, a one-way Analysis of Variance (ANOVA) (Group: Simultaneous presentation-Simultaneous interference vs. Simultaneous presentation-Sequential interference vs. Sequential presentation-Simultaneous interference vs. Sequential presentation-Sequential interference) was conducted. The performance measure of variance in reaction time in interference filled conditions represented as a ratio of variance in reaction time in the unfilled delay condition was again used. There was no significant evidence of a main effect, $F(3,44) = 0.53, p > .05$, of group across Simultaneous presentation-Simultaneous interference (*Mean* 1.07, *SD* .33), Simultaneous presentation-Sequential interference (*Mean* .91, *SD* .33), Sequential presentation-Simultaneous interference (*Mean* 1.01, *SD* .42) and Sequential presentation-Sequential interference (*Mean* 1.16, *SD* .82) groups.

Discussion.

A trend for a slight decline in accuracy in interference compared to unfilled conditions failed to reach significance. There was also no evidence from accuracy scores for a difference in magnitude of change between unfilled and filled performance on the basis of presentation condition nor on the basis of interference condition. Analysis for the possibility of selective interference effects on the basis of presentation and interference combination found no significant evidence of differences in accuracy performance. Reaction time and variance in reaction time data showed no significant effect of interference filled compared to unfilled conditions nor any effect in the presentation-interference combinations tested.

The above experiment therefore does not provide evidence for a reliable interference effect of either statically presented or sequentially presented visual stimuli on the retention of memory for the location of three dots.

General Discussion: Experiments 1-2c

Passive interference techniques were employed in Experiments 1-2c to investigate a possible effect of presentation on the subsequent representations and maintenance mechanisms in visuo-spatial working memory. A number of studies have employed interference with an aim to selectively disrupt the rehearsal of a series of locations through mechanisms which could be based on control of targeted movement (e.g. spatial tapping – Smyth et al., 1988; Alloway et al., 2010; Della Sala et al., 1999), control of targeted eye movements (e.g. tracking a visual stimulus - Pearson & Sahraie, 2003) or shifts of spatial attention (e.g. attending to a moving stimulus while fixating – see e.g. Pearson & Sahraie, 2003). An effect of a passively viewed sequence of locations was also indicated to produce a disruptive effect on memory for a series of locations (Smyth and Scholey, 1994a, Experiment 2; Klauer and Stegmaier, 1997, Experiment 1). Passive viewing of visual interference has been shown to disrupt memory for pattern information (Della Sala et al., 1999) and memory for the visual appearance of colours (Logie & Marchetti, 1991). The methodology adopted was therefore derived from numerous experiments with an aim to create two forms of comparable interference which differed only on an aspect intended to affect possible maintenance subsystems – that of presentation. Sequential presentation was adopted after Smyth and Scholey (1994a) and Klauer and Stegmaier (1997) and simultaneous presentation of dots was adopted after an effect of irrelevant visual images found by Della Sala et al. (1999) and Logie and Marchetti (1991).

In the current set of experiments, passive interference was not found to produce a reliable effect (Experiments 2a – 2c) and, when present (Experiment 1), these effects were small. Furthermore, in Experiment 1, there was no significant indication that static or sequential presentation of interference stimuli affected retention any differently for simultaneously or sequentially presented memory stimuli.

It could be suggested that training and associated measures introduced in Experiment 2c raised performance such that participants were too familiar with the task, or had developed strategies resistant to interference, and that observed effects in Experiment 1 reflected a vulnerability of retention when these factors were absent. It seems unlikely, however, that participants would be able to engage verbal rehearsal strategies to support performance as, due to the small presentation screen, multiple location unstructured template array and small changes made on ‘changed’ trials,

verbal coding would provide little help other than allowing for coding general areas such as 'top left' or 'top right'. This would not allow for adequate detection of changes. Idiosyncratic strategies – such as the example obtained whereby locations were related to musical notes – are near impossible to guard against, moreover, in order to provide accurate recognition judgements these supporting associations would need to be linked to a representation of the template array. Performance in unfilled conditions after training was also not at a higher level of performance than that observed in the first experiment (indeed, mean performance was actually lower) and still participants had to be removed due to poor performance after training. It could also be argued that the contrast of presented interference stimuli (red dots against a black background) in Experiment 1 was more prominent than the contrast of stimuli in Experiment 2c (black dots within white squares, appearing against a green background). The contrast of stimuli had, however, been heightened between Experiments 1 and 2a (using white dots against a black background) and there were no significant effects of interference observed in Experiment 2a.

It is therefore suggested that the small interference effect observed in Experiment 1 could be due to participants spontaneously encoding the presented stimuli for use in support of maintenance. It has been observed previously (e.g. Smyth & Scholey, 1994a) that presence of an array throughout a retention interval can support rehearsal and that participants actively engage in this strategy (Tremblay et al., 2006). It is possible that the presence of an array which corresponded to locations of the template array – though not the locations used in a given trial – could lead participants to actively encode the presented interference items. This approach could lead to interference by, for example, participants attempting to relate interference stimuli and an associated long term memory representation for the template array to presented items; the voluntary encoding of representations could disrupt memory for the information they are otherwise holding. Similarly, participants may have tried to use the presentation of interference stimuli to mark the area of the screen in which the experiment occurs; this may not counteract any effect of encoded interference (Experiment 1). This suggestion could find support in the situations where speeded presentation of sequential interference stimuli (Experiment 2a) and demarcation of screen area were introduced (Experiments 2b, 2c) thereby making spontaneous encoding more difficult and unnecessary, respectively. These are tentative suggestions, however, comparison of Experiments 1-2c make clear that presentation of irrelevant

visual stimuli cannot be said to have an automatic interference effect on memory for three visually presented locations.

While the continuity model of Cornoldi and Vecchi (2003) is a strong advocate for different presentation methods resulting in representations which reflect these presentations (i.e. spatial-simultaneous and spatial-sequential), the manner in which passively viewed interference may affect representations is not possible to predict a priori on the basis of this model. The continuity model holds that for tasks in which little active control is employed, representations will be held on the basis of the manner in which stimuli were presented. Allocation of resources to be able to perform two tasks is determined on the basis of active control: the more active control required the more resources will be employed and, consequently, the less likely two tasks can be performed together. Resources are also required, however, in order to carry out two tasks at once and distance on the horizontal continuum – that is, whether a task conforms to verbal, spatial-sequential, spatial-simultaneous and visual positions – is factored in to the ability to carry out these tasks simultaneously. While it could be predicted that it is less likely to be able to perform two tasks which use the same materials and require a high level of active control than it is to be able to perform two tasks which use different materials and a medium level of active control, it is not possible to make falsifiable hypotheses on the basis of this model.

A lack of automatic access of perceptual information to stored representation of visually presented stimuli is consistent with the model of Logie (1995; 2003; Logie & van der Meulen, 2009), in which all information in visuo-spatial working memory has been interpreted through long term memory representations. By this model, information stored within working memory has been actively encoded; irrelevant images only have an effect on processes which underlie visuo-spatial imagery. Logie (1995) proposes the generation of images, and subsequent hosting of short-lived imagery, is attributed to the central executive - irrelevant perceptual information can result in competition at the level of activation from long term memory thereby disrupting the generation process. Information held in working memory, however, is not susceptible to this competition as it is already held in a functionally separate manner than representations residing only in long term memory. Any representations held in the visual cache and rehearsed or represented by the inner scribe would, therefore, be predicted to be immune to the effect of the passively viewed irrelevant images employed in the current experiments (Logie, 2003; Logie & van der Meulen, 2009).

In contrast to the model of Logie (1995; 2003; Logie & van der Meulen, 2009), Pearson (2001) proposed that conscious visual images represented in the visual buffer, whether generated from long term memory or as the result of perceptual input, are susceptible to disruption from irrelevant perceptual input. Quinn and McConnell (2006; Quinn, 2008) also maintain that conscious visual images are held in a visual buffer that is accessible, and therefore vulnerable to passive visual interference, directly from perception (see also, Andrade et al., 2002). Quinn (2008; Quinn & McConnell, 2006) advocates executive resource based rehearsal of spatio-temporal or spatial information; a division between retention of serially presented location information and simultaneously presented information (attributed to either the visual buffer or a reinterpretation of the visual cache) is therefore implied. No specific mechanism by which a subsystem dealing with spatio-temporal information may interact with the conscious visual image, or with retained visually-presented information, is proposed. Pearson (2001), however, suggests that the visual buffer is - though maintained by the central executive - accessed by the inner scribe which deals with rehearsal of sequences; the inner scribe is proposed to manipulate information within the visual buffer. In the context of Pearson's (2001) model - which predicts perceptual access to the visual buffer - a lack of interference effect could reflect either insufficient magnitude of disruption, or alternatively, visually retained information could be held in the visual cache while sequence information is maintained through the inner scribe. Baddeley (1986; 2007) proposes that the components which constitute visuo-spatial working memory - tentatively considered as dual storage and rehearsal mechanisms for appearance and location memory - are directly accessible by perceptual input; a lack of passive visually presented interference effects are therefore inconsistent with this interpretation, however, again, lack of evidence of interference could be due to insufficient magnitude of disruption rather an absence of interference per se.

An absence of interference effects on the retention of visual information is not without precedent. In literature concerned with establishing the effect of passively viewed irrelevant images on visual retention and visual imagery mechanisms, a selective disruptive effect of visually presented information on mechanisms supporting visual imagery has been found. As detailed above, Quinn (2008; Quinn & McConnell, 2006) and Pearson (2001) have suggested that maintenance of a conscious visual image is vulnerable to disruption by perception while Logie (1995; 2003; Logie & van der Meulen, 2009) posits the locus of interference effects occur at generation of a visual image. Though this point is still debated, the evidence accumulated thus far is largely

consistent – demonstrating an effect of irrelevant interference in visual imagery tasks yet an absence of effect on retention of visual information. For example, one of the most extensively studied imagery tasks, the pegword mnemonic – in which participants remember a list of words through forming visual associations integrating the to-be-remembered item with a standard image ascribed to a position in the list – has been shown to be disrupted during encoding and retrieval stages by a variety of irrelevant visual information including viewing of irrelevant pictures (e.g. Logie, 1986; Andrade et al., 2002; Quinn & McConnell, 1996a). Much evidence has shown that pegword mnemonic performance is susceptible to disruption by Dynamic Visual Noise (DVN; Andrade et al., 2002; McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1996a, 1999, 2006, though see Zimmer & Speiser, 2002), while static visual noise (a presentation of stationary black and white dots) has shown no effect (McConnell & Quinn, 2000). Research has also shown that the extent of disruption effect is related to properties of the visual noise including number of dots present and speed with which these dots alternate (McConnell & Quinn, 2004) and DVN is reported as disruptive to many other imagery tasks tested including visualisation of a known route (Smyth & Waller, 1998) and remembering words through visual associations with known locations of a predetermined route (method of loci, see Quinn & McConnell, 1996b).

Evidence also suggests that retention of formed associations from pegword tasks - that is, when the images are not actively being visualised or retrieved from memory – is not disrupted by DVN (e.g. Quinn & McConnell, 2006; Zimmer & Speiser, 2002). Indeed the list lengths typically required in pegword mnemonic performance (e.g. ten image combinations, McConnell & Quinn, 2000; 2004) are considered beyond the capacity of short-term storage (after Cowan, 2005; see Quinn, 2008, p40) and reliant on support from semantic, long term representations (McConnell & Quinn, 2000). In describing the processes exhibited in pegword performance van der Meulen, Logie and Della Sala (2009) point out generation of images from long term memory in order to encode dictated combinations and generation from long term memory in order to recall formed images; no requirement of short term storage is noted.

In contrast to the effects of visual interference on visual imagery, DVN has been shown to have no disruptive effect on memory for visually presented stimuli in the form of patterns within a matrix (Avons & Sestieri, 2005; Andrade et al., 2002; Dean, Dewhurst & Whittaker, 2008, see also Zimmer & Speiser, 2002), array of simple shapes (Baddeley & Andrade, 2000), location of four presented unnameable characters (Andrade et al., 2002), location of presented letters (Darling et al., 2007; 2009) and

location of four dots (Dent, 2010). Dynamic visual noise has, however been found to affect memory for appearance (font and size) of letter stimuli (Darling et al., 2007, 2009), for exact colour presented (Dent, 2010), for patterns as defined by colour and texture (Dean et al., 2008) and the maintenance of the precise size of a presented stimulus for comparison to test stimulus (Size-JND, Quinn & McConnell, 2004). From instances in which DVN has been found to be disruptive to retention, a common theme has emerged: that visual detail is required to make accurate comparisons to test stimuli (Quinn & McConnell, 2004; Dent, 2010). While it has also been argued that precision could be affected (Quinn & McConnell, 2004), Dent (2010), in a task requiring reproduction of dot location and reproduction of colour (selected from a presented spectrum), found only colour performance and not dot location was disrupted by DVN; Dent (2010) employed sensitive measures of performance and thus it was argued that DVN results in loss of detail rather than a distortion of, or loss of precision in, representation (see also Baddeley & Andrade, 2000). The loss of information in 'retained' visual information by exposure to DVN can be interpreted as disruption to images that need to be continuously, consciously experienced in the visual buffer (e.g. Quinn & McConnell, 2006; Quinn, 2008) or through continuous regeneration of information from long term memory representations to support vivid detail (van der Meulen, et al., 2009). Regardless of interpretation of found effects, it has become apparent that passively viewed irrelevant interference will not have an automatic disruptive effect on non-consciously experienced, stored visual information (Quinn, 2008).

The literature reviewed directly above would imply that the tasks which were used to inform the current methods (Della Sala et al., 1999; Logie & Marchetti, 1991), despite an influential status in studies of visuo-spatial fractionation, do not exemplify the best way in which to target disruption of stored visuo-spatial information. For example, the colour identification task of Logie and Marchetti (1991) which was disrupted by presentation of irrelevant images could have required continual visualisation in order to retain specific colour shades for identification amongst distracters at the end of a trial. The interference effect need not, therefore, be attributed to occurring in a retention subsystem (the visual cache). It has recently been suggested (van der Meulen et al., 2009) that specific aspects of the methodology employed by Della Sala et al. (1999) could have led to interference effects observed; use of successive presentations of irrelevant images was by cardboard mounted images, swapped over by the experimenter – it is suggested this may have resulted in

participants following the cards with their eyes and thus producing some disruption via eye movements (though the irrelevant images showed relatively little effect on CBT performance). Alternatively, as the interference images were abstract paintings from famous painters, it is possible participants actively encoded the content of the irrelevant information.

The use of passive presentation of information as distilled from interference studies which have disrupted memory for series of locations could also be questioned. Smyth and Scholey (1994a) and Klauer and Stegmaier (1997) found a disruptive effect of repeated presentation of two locations throughout the retention interval of a computerised Corsi block procedure, even when participants were not to attend to the presentations. Smyth and Scholey (1994a) had also, however, found an effect of passive listening to tones originating from two different locations; this effect of passive listening was later (Smyth, 1996; Klauer & Stegmaier, 1997) attributed to within-subjects design which led to participants judging spatial attributes of tones even when not instructed to do so. The effect was not present when passive listening was the only condition performed. This investigation was not carried out for the effect found for passive visually presented stimuli, however, it is possible that the same claim could be made. Moreover, the two locations used during interference by Smyth and Scholey (1994a) and by Klauer and Stegmaier (1997) were located at either side of the presentation screen (exact distances not provided). It is possible participants looked at, or covertly shifted attention to, the locations; in the current experiment all information was presented within foveal vision, therefore irrelevant dot appearances need not induce shifts of attention to presented locations. If the effects of Smyth and Scholey (1994a) and Klauer and Stegmaier (1997) were due to either artefacts of experimental design or induced shifts of attention, the interference paradigm of the current experiment would not be expected to produce a disruptive effect.

In sum, Experiments 1-2c found no replicable effects of passive interference and, in light of the literature reviewed above, there is therefore reason to doubt that the retention of dot location is supported by maintenance as a conscious visual image. The following chapter details the development and subsequent implementation of a new interference paradigm targeted to disrupt temporarily stored information.

Chapter Four

Experiment 3 (a; pilot and materials development)

Following an interpretation of the slight disruption to recognition performance found in Experiment 1, it was deemed possible that some form of encoding of visually presented information may lead to interference with concurrent storage of visual information. A task was therefore developed in order to test this idea empirically and in the context of the primary question of storage of location information. This task required participants to view a visual display comprising two forms of visual information which have been determined, in previous studies, to produce no disruption to stored visual information when viewed passively. Processing judgements and storage have been elsewhere argued as supported by independent resources (e.g. Duff & Logie, 1999; 2001; Daneman & Hannon, 2007; Logie & Duff, 2007; Waters & Caplan, 1996). There is, however, argument that depletion of executive resources can affect storage or rehearsal of information (e.g. Klauer and Stegmaier, 1997; Barrouillet et al., 2004; Camos et al., 2009; Hamilton et al., 2003; Quinn, 2008). For this reason, a visual interference task which would involve no choice or judgement requirements was devised: a visual detection task requiring only that participants view the array in front of them and press a button when an image appeared.

It has been repeatedly shown that passive viewing of DVN during the delay period of a memory task for composition of half filled matrices (whether simultaneously or sequentially presented), or for unambiguous location information, does not impair performance. Andrade et al. (2002) found viewing of DVN during either a four second (Experiment 3) or a 36 second (Experiment 2) retention interval did not impair recall of nine filled squares presented simultaneously within a four by four matrix. Avons and Sestieri (2005) found no effect of DVN on recognition ability for composition of a statically presented half-filled (five by five) matrix. Participants viewed one matrix (300ms brief presentation) and then, after either a two or eight second retention delay, were presented with a similar matrix with only one cell's location changed. A lack of effect of viewing DVN throughout a retention interval on a similar matrix recognition task was reported by Dean et al. (2008). Dent (2010) found no effect of DVN on retention of four simultaneously presented spatial locations (identified by dots) in either recognition – where whole arrays were represented with

one location change or not - or recall (positional reconstruction) conditions. Darling et al. (2009) found no effect of DVN viewed throughout a 15 second retention interval on remembering the location of four simultaneously presented items (item to location information not required), tested using a single probe location which was either of the presented locations or a new location. Darling et al. (2009) also found no effect of DVN throughout a delay on recognition performance for the same task when items were presented sequentially (while test format was simultaneous whole array presentation). Avons and Sestieri (2005) reported no effect of DVN when viewed during a one second retention interval after cells within a matrix had been sequentially presented. Though termed a 'cumulative imagery' task, Avons and Sestieri (2005) presented participants with a series of individual cells within a matrix (only the border of the matrix was provided rather than cell division) at a rate of 500ms each and then showed all the cells again simultaneously at test, requiring participants to identify whether one location had been altered or not – the task could thus be interpreted as a recognition memory task. A lack of effect of visual noise on serial recall of locations has also been demonstrated as a filled retention interval made no difference to computerised CBT performance (Pearson & Sahraie, 2003).

The above reviewed studies together provide substantial evidence that passive viewing of DVN does not cause disruption to performance on tasks requiring memory about location in an array -whether the information is simultaneously or sequentially presented. This suggested a DVN display could provide a background against which to implement a detection task; if successful in producing disruption, the detection task would provide both a means by which to disrupt a visual storage mechanism for the purposes of the current investigation and could also indicate an avenue of further research for studies concerned specifically with perceptual access to visual storage. In one study of this nature van der Meulen et al. (2009) found no effect of passively viewing irrelevant pictures throughout a retention delay on recall of the appearance of a series of letters, though a disruptive effect on an imagery task had been obtained. The authors also report a previous study in which viewing DVN throughout retention did not disrupt recall (van der Meulen, 2008 as cited in van der Meulen et al., 2009).

A task in which irrelevant images were presented for detection against a DVN background was therefore developed with the suggestion that, though irrelevant images (van der Meulen et al., 2009) and DVN (as reviewed above) do not in and of themselves disrupt visual storage, a requirement to encode this information in some way may enable access to stored visual information and thus create an interference

effect. Two versions of this novel task were created and piloted in order to ascertain which presentation rate would also enable measurement of performance.

Method.

Participants.

Seven postgraduate students from the University of Edinburgh voluntarily took part in a one off 15 minute testing session. Of the participants tested (mean age 26.1 years, SD 1.35, median 26, range 24-28), three were male and all were right handed. All participants fulfilled the inclusion criteria of normal or corrected-to-normal vision with no known problems with colour blindness.

Design.

Two different versions of one task were tested within participants in order to ascertain which version produced clearer results and higher scores.

Apparatus.

The same testing computer employed in Experiment 1 was again used. That is, presentation of stimuli was by computer and involved an LCD screen of size 43cm diagonal (33.8 x 27cm). Screen resolution of the monitor (CTX S700A), which used an Intel (R) 82865G Graphics Controller, was set at 1024 x 768 pixels at the highest colour quality (32 bit) with a refresh rate of 75 Hertz. Stimuli were presented, and processing responses were recorded, using E-Prime (Version 1.1) software which was run using an RM innovator Pentium 4 @processor PC.

Presentation of images throughout the task was at a distance of 70cm from the participant. All images presented to participants were located in the centre of the testing screen and measured 8.4 x 8.4 cm. Images were presented against a completely black background which served to fill the surrounding screen area.

Materials.

Testing materials were developed through combining images of real and non real objects with single static visual noise images that, when run in succession, constitute Dynamic Visual Noise (DVN).

Dynamic Visual Noise (DVN).

A version of DVN was developed based on the specifications of Quinn and McConnell (1996a). Single static visual noise images were presented in a predetermined order for a total of 100ms each⁹ – that is, at a rate of ten static images per second. DVN consisted of 6400 squares onscreen at any one time, presented as an 80 square x 80 square matrix. Each square measured 4 pixels x 4 pixels, thus the matrix was of the dimensions 320 x 320 pixels (measuring 8.4 x 8.4 cm onscreen). The single static images used to create DVN were bitmap images consistent with these properties.

When run as DVN the matrix began with the composition of 3200 white squares to 3200 black squares, randomly arranged within the matrix; squares changed from black to white or from white to black at an average rate of 300 squares per second. The change of squares to white or to black occurred at random (within the given constraint of an average of 300 changes per second); therefore each static image used to create DVN was not necessarily of 50% black, 50% white composition.

DVN was presented in the centre of the screen and against a black background, which filled the rest of the screen area; static noise images were therefore of centrally located black and white matrices presented against a black background

Real and non-real images.

Images which served as items to be detected were drawn from three different pools. Pictures of real objects and items were line drawings taken from Snodgrass and Vanderwart (1980) and the International Picture Naming Project (for example, Szekely et al., 2004). Line drawings of non-real objects were taken from a database made available by van Diepen and De Graef (1994) providing images from Kroll & Potter (1984). From these sources nine, three and two images were used respectively.

Each original black and white line drawing image was subjected to a process whereby definition of lines and contours was reduced; this was achieved using an erosion function option of GNU Image Manipulation Program. The erosion of each image was carried out to varying extents. This process made some images fainter and composed of thinner lines while the original image still remained intact. In other images, intentional extreme erosion created very thin lines which often disappeared at points thus the structure appeared to break up. Eroded images were therefore harder

⁹ With thanks to Steve Darling who provided these original DVN materials (after Darling et al., 2007; Darling et al., 2009), created using Visual Basic software.

to perceive and identify than original images and at times would barely resemble an image. On the basis of proposed ease of perception, images were categorized as being of easy, medium and hard difficulty. Seven easy, two medium, five hard images were produced (see appendix for images used).

Embedding images within DVN.

Before the selected images were inserted into DVN materials all International Picture Naming Project derived images and all non-real van Diepen and De Graef (1994) images were cropped and resized to fit within the dimensions of 200 x 200 pixels: images conformed to 200 x 180 or 180 x 200 pixel templates if of a rectangular shape, or 180 x 180 pixel templates if of a square shape. These images were then placed into blank templates of 281x197 or 197x281 pixels (respectively, with 180 x 180 images in either) in order to be of a similar size to the Snodgrass and Vanderwart (1980) images used (281x197 or 197x281 pixels).

The background of each image was then converted to be transparent, allowing the eroded line drawings to be placed, using GNU Image Manipulation Program software, into static visual noise images (see Figure 10 below). As can be seen in Figure 10, while line drawings were all originally black, the process of erosion, creation of a transparent background, and insertion into another image further distorted the appearance of the original drawings. Thinned lines and sections which appeared broken in the eroded line drawing image before transparency conversion could, at points, appear as white rather than the original black; the placement of black and white drawings into a complex black and white background meant that at any one time only certain portions of the image were perceptible (for example, a black continuous line would be visible against the white squares in the visual noise but would not be detectable against the black squares). It should be noted that it is *not* the case that lines of an image would be automatically be shown as white against black squares and black against white squares; lines of an image were, after the conversion to hold a transparent background, either black or white at any given portion and this was a fixed property. Embedded line drawing images were, therefore, not complete images.

Images, when inserted into visual noise, were centrally placed. Placement of a given image into consecutive frames of visual noise created, when the visual noise frames were viewed one after the other, the appearance of a stable (though fractured) central image while visual noise continuously changed. Therefore, when run as DVN

rather than viewed as static visual noise images, the inserted line drawing images could be seen as ‘disrupting’ the regulated movement of the black and white squares.

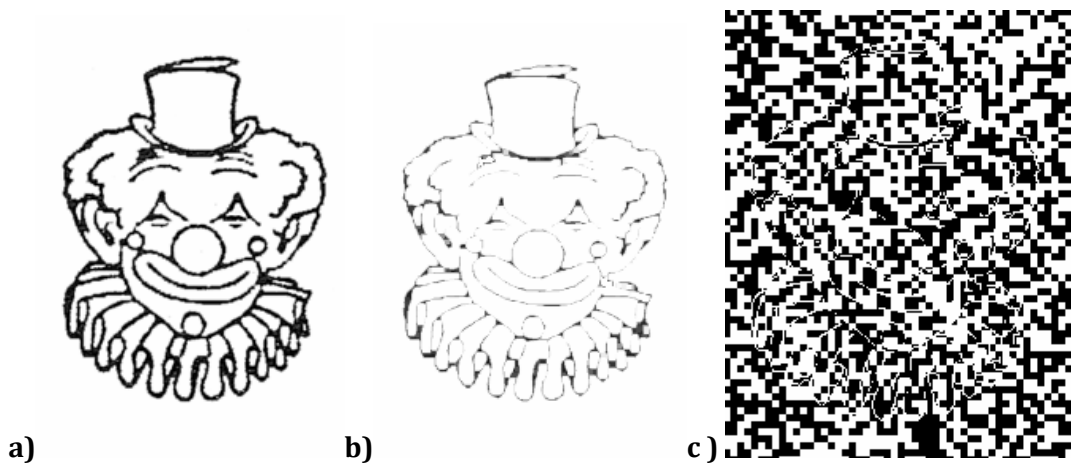


Figure 10: Example of a line drawing image (a), the same image after passing through the process of erosion (b) and placed within a backdrop of visual noise (c). Note DVN display is cropped to size of image.

Two versions of fourteen seconds worth of embedded-images DVN was created, in preparation for use in a future memory task retention period. In each version created, the 14 above detailed (easy, medium and hard to detect) images were inserted within the 140 frames of visual noise required to create 14000ms of DVN. In Version 1, a given eroded image was inserted into three static visual noise files which would be presented consecutively, each for 100ms; in Version 1, images to be detected were thus presented for 300ms. In the second version of the task a given eroded image was inserted into five static visual noise files which would be presented consecutively, each for 100ms; in the second version of the task, images to be detected were thus presented for 500ms. In the first version of the task, each of the 14 to-be-detected images were presented within an absolute second, as defined from initiation of DVN. It did not necessarily follow that each image occurred within a second of another – for example, if an image occurred in the first 300ms of one absolute second and the next image occurred in the last 300ms of the following absolute second, presented images would be separated by 1400ms. In the second version of the task, each of the 14 to-be-detected images occurred at random – that is, images were randomly placed so that placement did not conform to one image per absolute second. In this second version, a

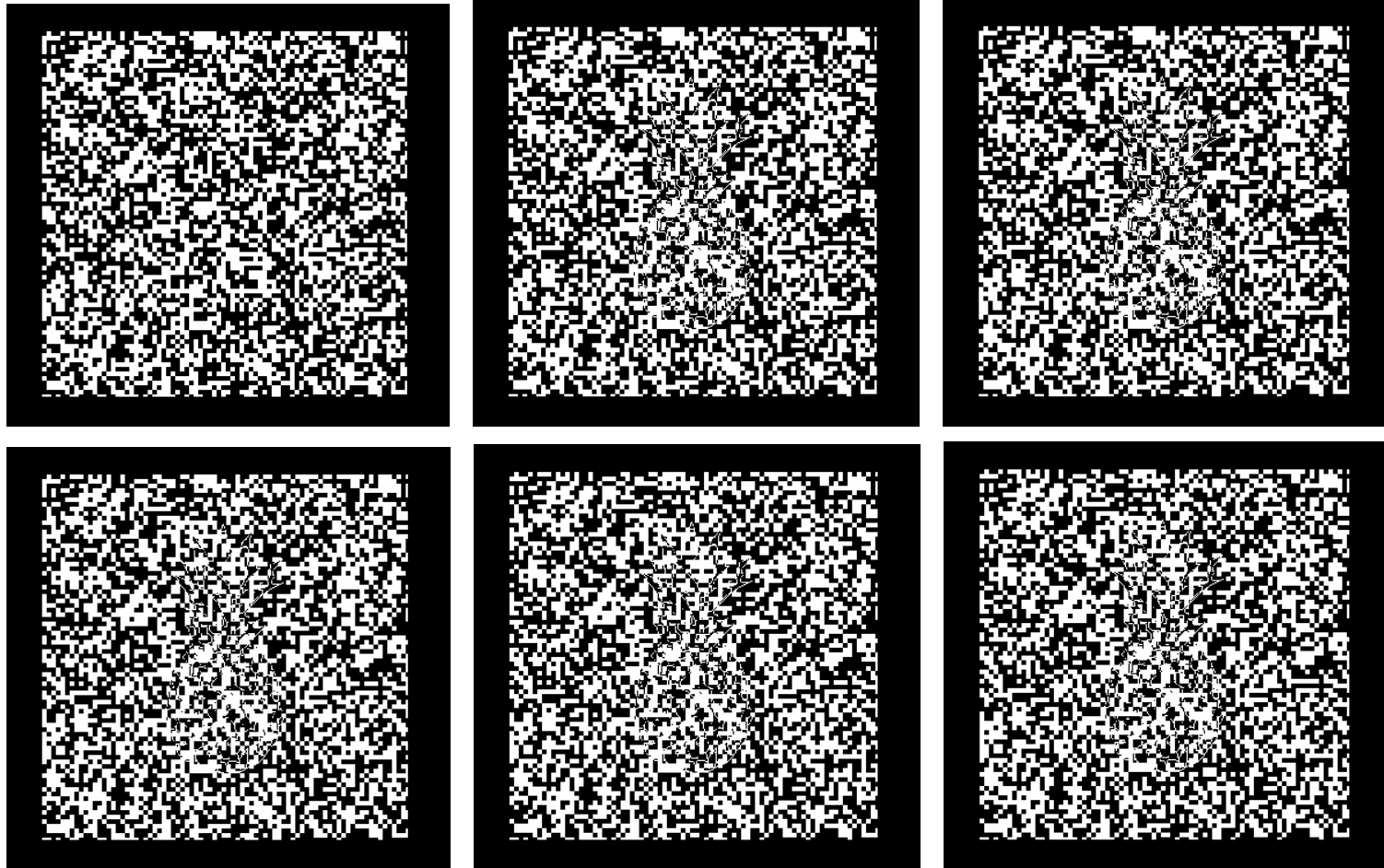
number of images could therefore occur in succession and this also allowed for the possibility of longer periods of unfilled DVN in comparison to Version 1.

The order in which images of easy, medium and hard to detect difficulty occurred was randomised and then fixed, so that the order of occurrence was the same between both versions of task.

Procedure.

Participants were instructed that in viewing the computer screen in front of them they would see what would appear as 'block of movement' - squares that move at a regulated pace and in a regulated manner - and that, against this background, line drawings would be shown. It was made known that, more often than not, these line drawings would be difficult to perceive and much of the time it would not be possible to discern what an image being shown was. Moreover, participants were informed that nonsense (non real) images were included in the presentation and that many images, originally identifiable objects, had been broken down so that they too may resemble nonsense. It was stressed that, regardless of whether it was possible to make out what an image was, anything that appeared to interrupt the regulated block of movement constituted an item being presented. Participants were instructed that their task was to detect when these images appeared.

Participants were informed that they would experience two slightly different versions of the same task. Each version of the task ran for 14500ms: participants initiated each task by pressing the spacebar of the key board, after which a 500ms centrally presented fixation cross appeared. Following the fixation cross the DVN containing images ran for 14000ms, after which a red screen would appear to indicate the end of the task. In each version of the task the objective was the same: press the spacebar, as quickly as possible, every time an image is detected. Figure 11 below demonstrates an excerpt of a presentation that would conform to Version 2 specifics - participants would be expected to respond to the appearance of each of the two images shown - that is, respond to appearance at the second and seventh screens (first page and second page respectively). Order of completion of the two versions of the task was counterbalanced as much as possible across participants, given the uneven number of participants tested. All images were presented, and responses recorded, using E-prime software.



This way up

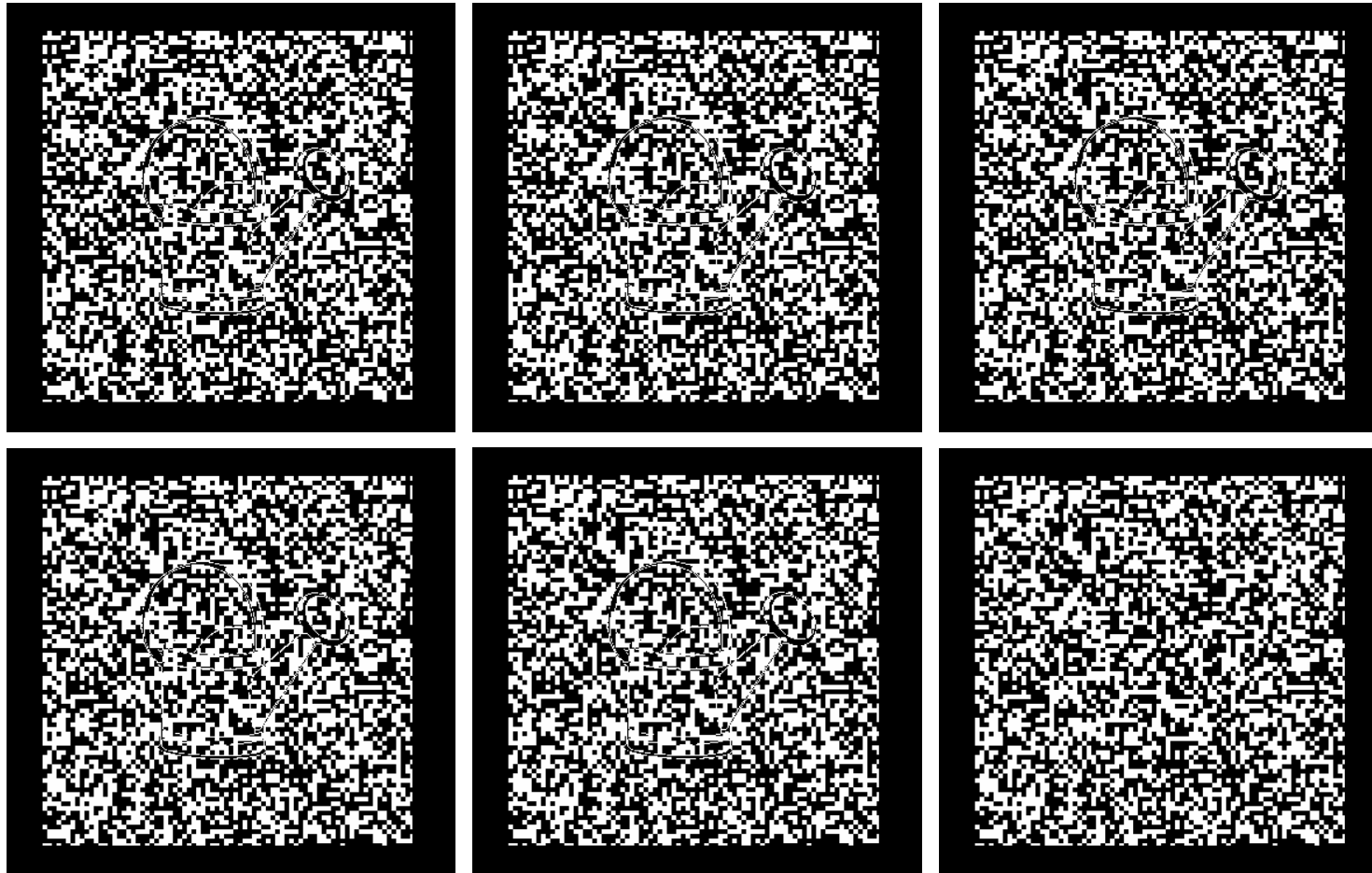


Figure 11: Example of 12 consecutive 100ms screens of embedded-image DVN stimuli (Version 2 specifics). Previous page: first screen of top row contains unfilled visual noise, second, third and all bottom row screens contain a medium difficulty embedded item. Current page: first screen of top row contains an embedded item of easy difficulty; second, third and first two screens of bottom row contain this same item. Last screen of bottom row contains unfilled visual noise. Black surrounding screen has been removed for clarity.

Scoring, Results and Discussion.

Four different scoring methods were considered; a correct 'hit' - that is, a detection of an image - was considered as represented by a response recorded while the embedded image was on the screen and when there was a response one, two or three frames after the embedded image had been presented. The presentation times of images in Version 1 allowed three 100ms frames for a response to be considered as within onscreen presentation, while Version 2 allowed five 100ms frames for a response to be considered as within onscreen presentation. Table 17 below shows the mean number of responses in each version, derived from all participants, separated into columns representing when these responses were recorded; Version 2 provided more responses within the time an image is presented onscreen than did Version 1. Version 1 also produced more responses in later frames (two frames late, three frames late) than did Version 2.

Frame of response in relation to presentation frames				
	Within	1 frame late	2 frames late	3 frames late
Version 1	1.57	5.14	2.43	0.86
Version 2	9.29	1.86	0.86	0.14

Table 17: Mean number of responses recorded in each frame.

A presentation time of 300ms (3 x 100ms frames) could be too limited a time to allow for recording a response; response to an item would not be expected within the first 100ms (in either version) therefore the remaining two frames of Version 1 are a rather short response window. Extending recording of responses to two frames after presentation has ended provides a more generous response window and captures additional responses within both versions. Extension of response window to additional frames after presentation has ended can, however produce further problems with scoring. If images are presented back to back it becomes unclear which image a spacebar press is in response to; as previously stated, the first 100ms of an image would not be expected to acquire a response, therefore if two images were presented back to back a response in the first 100ms of the second image could be interpreted as pertaining to the first image. This crossover becomes more problematic when

response windows are extended to two or three frames late. In anticipation of future studies perhaps making use of the distinction between easy and medium or hard difficulty items it was proposed as beneficial to enable responses to be attributable to presentation images as much as possible.

When response window was limited to within two frames of presentation Version 2 provided a higher mean response with less variability (see Table 18). Version 2 was therefore selected as the version allowing for clearer, better performance - whether this be due to a longer appearance of images onscreen allowing for better response collection or for improved visual perception (the latter is a possibility given a mean of all responses up to three frames late in Version 1 is less than a mean of all responses up to three frames late in Version 2¹⁰).

Response within 2 frames of presentation				
	Mean	SD	Range	Median
Version 1	9.14	3.67	6.00-14.00	7.00
Version 2	12.00	2.08	8.00-14.00	12.00

Table 18: Mean number of detections (in bold) and SD for each version completed, provided with range of detections and median.

On the above described basis, Version 2 - where embedded images are presented for five consecutive 100ms frames and 14 images occur anywhere within the first 13500ms of DVN - was chosen for use in future experiments. A scoring method could be adopted in this task whereby responses up to two frames late are attributed to detection of a presentation when an image is followed by unfilled DVN; when an image is followed by another image and a response occurs after the first 100ms of the second image, this response is attributable to the first image. When two consecutive images are presented and a response occurs within the second frame of the second image, this response is determined a 'hit'; the image to which the detection pertains is decided on the basis of two criteria. If the first image is an easy item, the hit is allocated to the first item; if the second item is an easy item, the hit is allocated to the second item. In the case of two easy items occurring in succession or in the case of two non-easy to detect items, the second criterion applies: if a second response can be attributed to the second

¹⁰ It is also a possibility that participants neglected to respond to items if their response would fall too late after a quickly presented image has disappeared.

image (a response occurring within, or within two frames following, presentation) then the first response is attributed to the first item, if there is no second response then the sole response is attributed to the second item.

Experiment 3 (b; pilot)

The chosen embedded-images DVN set up (version 2) was subsequently piloted for use within a memory task context; the recognition task employed in Experiments 1 and 2 was employed. A second interference task of spatial tapping – a task frequently used to disrupt serial location retention (e.g. Smyth, Pearson and Pendleton, 1988; Smyth & Scholey 1994a; Pearson & Sahraie, 2003; Vandierendonck et al., 2004; Logie & Vecchi 2006), through hypothetical interference with an attention (e.g. Awh & Jonides, 2001) or motor control (e.g. Logie, 1995; Pearson, 2001; Pearson & Sahraie, 2003) based system, was also piloted for use during the retention interval of the three dots recognition task.

Method.

Participants.

Seven postgraduate students from the University of Edinburgh were provided with an honorarium of £6.05 to take part in a one off hour long testing session. Of the participants tested (mean age 26.9 years, SD 1.21, median 27, range 25-28), one was male and all were right handed. All participants fulfilled the inclusion criteria of normal or corrected-to normal vision with no known problems with colour blindness.

Design.

A (2 x 3) mixed design was employed: presentation format of stimuli was manipulated (simultaneous or sequential presentation) as a between participants factor, while condition of 15000ms delayed recall (unfilled, tapping filled, embedded-images DVN filled) was manipulated within participants.

Apparatus.

All visual stimuli and responses to these stimuli were presented and recorded respectively using the testing computer as described in Experiment 1. Presentation of images throughout the task was, as in previous memory experiments, at a minimum distance of 172cm from the participant. This was again achieved by situating the chair of the participant in a position whereby the front of the chair was a distance of 180cm from the computer screen, moreover, the table which supported the response keyboard prevented participants from moving any closer to the screen than 172cm (diagram of physical set up available in appendix). Participants never attempted to move beyond this limit. Memory task stimuli (of dimensions 6 x 4.5cm and centrally presented) were presented within participants' foveal vision. All embedded-images DVN was presented in the centre of the testing screen and measured 8.4 x 8.4 cm; embedded-images DVN was, therefore, in contrast to previous interference, not set to appear within foveal vision. All images were presented against a completely black background which served to fill the surrounding screen area.

A webcam and computer apparatus as described in Experiment 2(c) was again employed in order to visually monitor participants' performance. As in Experiment 2(c), no video data was recorded, transferred to any other computer nor viewed by anyone except the experimenter.

A nine button (3 x 3) tapping pad was used in conjunction with Timekey computer software run on the same Pentium 4 ® processor PC as the webcam equipment. Each square key of the tapping pad measured 4 cm x 4 cm. Timekey software records data in the form of: the button tapped, the point in time at which each button was tapped and the inter-tap intervals – that is, the time taken to press a button in relation to the time at which the last button was pressed. As a tapping task is carried out, Timekey can provide running feedback onscreen of each inter-tap interval. This feedback was, in the current task, accessible by the computer viewed only by the experimenter.

Materials.

For the primary memory task three lists of 24 trials were used which dictated the location of dot stimuli to be remembered in each trial, which stimuli were altered in changed trials and where changed dots were moved location to. Details of these lists are as provided in Experiment 1. Lists were counterbalanced for use with simultaneous and sequential presentation, and across the three conditions of the task, as much as possible given the uneven number of participants.

DVN.

DVN materials were as described in Experiment 3(a). Twenty-four trials worth of 14000ms of DVN were each produced by presenting 140 consecutive visual noise frames for 100ms. Four different sets of 140 consecutive visual noise frames were available. As visual noise frames had to be run consecutively in order to maintain the specifications of Quinn and McConnell (1996a) the four sets of visual noise were run forward in half the trials and backwards in half the trials in order to create eight different versions of DVN from the same materials. These eight versions of DVN were used three times each, in order to provide 24 trials of DVN.

Real and non-real images.

All images used were obtained from the same sources as detailed in Experiment 3 (a) – that is Snodgrass and Vanderwart (1980), the International Picture Naming Project (for example, Szekely et al., 2004) and Kroll and Potter (1984) by way of van Diepen and De Graef (1994). In total 211, 95 and 30 images were taken from these sources respectively for use in experimental trials; a further seven, six and 12 images were taken for use in practice trials and as demonstration materials. Once passed through the process of erosion (as detailed in Experiment 3 a), images were categorised as easy, medium or hard to detect, based on proposed ease of perception. In keeping with the composition of Experiment 3(a) the 336 images were allocated for use in a trial on the basis of difficulty with each of the 24 trials created receiving five easy images, two medium images and five hard to detect images. Each trial also contained one non-real image, which was always of an easy difficulty rating. The first trial created was identical to that of Experiment 3(a), version 2. After this division, 23 images remained, and a single image from this pool was randomly distributed to each

of the remaining 23 trials. A practice trial consisting of nine images, a demonstration containing nine images and a preparatory screen-by-screen demonstration containing seven images were also created from the pool acquired for practice materials.

Embedding images in DVN.

The method employed to erode and embed images within DVN was as described in Experiment 3(a). See Figure 12 below for examples of easy, medium and hard to detect images and Figure 13 for these same images embedded in visual noise.

Trial structure was made to specifications of version 2, Experiment 3(a). In summary, 14 images were presented for 500ms each within 13500ms of DVN, with the last 500ms of DVN remaining unfilled; each eroded image was, therefore, embedded within five consecutive visual noise images out of the total 140 visual noise images used in a trial. The time point at which an image occurred within a trial was pseudo-randomly chosen; images were placed at the experimenter's discretion in order to create variety within trial structure. For example, easy to detect images were sometimes followed by hard to detect images and at other times by another easy to detect image. Likewise, sometimes images to be detected occurred one after the other and were then followed by a longer period of unfilled visual noise as compared to other instances where images to be detected were more evenly distributed throughout the visual noise. Twenty four trials worth of embedded-images DVN were created. The run of a trial was, due to the above described nature of the stimuli contained, fixed; all participants, therefore, saw exactly the same embedded-images DVN stimuli. The order in which the trials of embedded-images DVN were performed by a participant, however, was randomised.

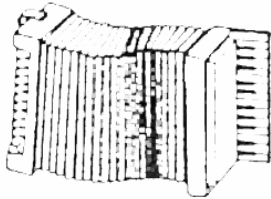
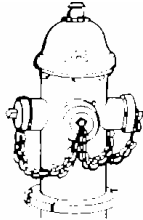

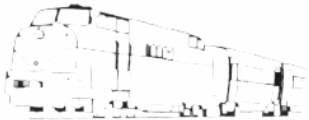
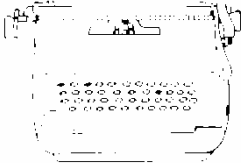


	Snodgrass & Vanderwart (1980)	IPNP (e.g., Szekely et al., 2004)	van Diepen & De Graef (1994)
Easy			
Medium			
Hard			

Figure 12: Examples of Easy, Medium and Hard images after process of erosion. Respective origins also provided.

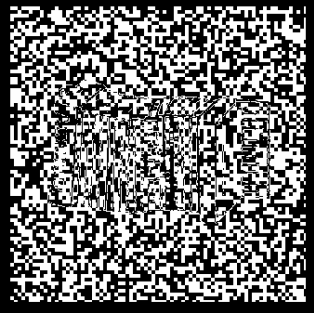
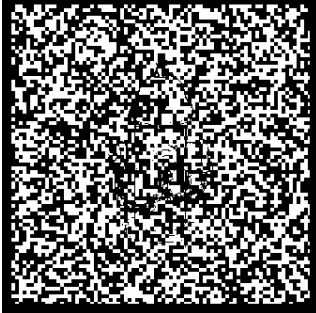



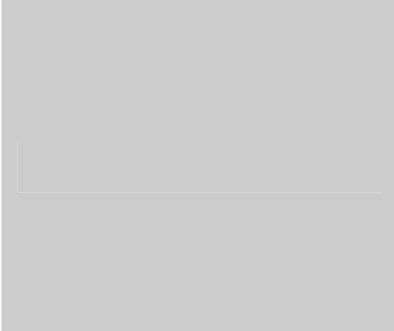



	Snodgrass & Vanderwart (1980)	IPNP (e.g. Székely et al., 2004)	van Diepen & De Graef (1994)
Easy			
Medium			
Hard			

Figure 13: Example of images from Figure 12 in Visual Noise.

Procedure.

The primary memory task was that of Experiments 1 and 2 (see Experiment 1 for details) whereby all participants were required to memorise the location of three black dots presented within a green and white template array. Participants were then required, after a 15000ms delay, to view a red and white template array and decide whether the three black dots presented against this background were in the same location as those in the green and white array, or whether one dot had changed location. In a blue screen which followed, participants were required to indicate via button press whether items were in the same or in a different location (pressing the 's' key of the keyboard for same and the 'k' key of the keyboard, labelled 'd', for different). Presentation of items to be remembered was either in a simultaneous format or a sequential format; four participants completed the task with simultaneous presentation and three participants completed the task with sequential presentation. All participants completed the primary memory task in three different conditions – recognition after 15000ms unfilled delay, after a 15000ms delay in which a tapping task was performed, and after a 15000ms in which detection of images embedded in DVN was performed. The order in which these conditions were performed was counterbalanced as much as possible, given the limited and uneven number of participants, across all participants in a given presentation condition.

At the beginning of the experiment participants were shown the components of the memory task in screen-by-screen steps on the computer, along with verbal and written instructions; the information and requirements present in these instructions were discussed with the experimenter. Participants subsequently performed five practice trials on an unfilled delay version of their allocated presentation condition.

Before beginning the embedded-images DVN condition each participant was shown a nine second demonstration of what the task would entail and was provided with instructions that were accompanied by a experimenter controlled slide-by-slide illustration of how the DVN 'moves' and how images would appear and disappear within this DVN. Participants were, in this illustrated instruction condition, informed as to when and how to respond to images detected – that is, participants were instructed to press the spacebar as quickly as possible once an image had been presented and to press the spacebar for every image presented. For example, if multiple images appeared one after the other with no unfilled DVN between them, the spacebar was to be pressed for each image shown. Participants were then given a nine second practice

with embedded-images DVN where the DVN occurred between a blank presentation and a blank recognition screen – in effect, a mock up of an experimental trial without any memory requirement. Any participant who did not understand the task, or who desired more explanation, was taken through this demonstration and practice process again.

In the embedded-images DVN condition of the memory task, DVN started after the appearance of a 1000ms blank black display screen which followed the (last) memory presentation screen. Participants were required to view the embedded-images DVN and press the spacebar when they detected an image. As soon as the DVN terminated, the recognition screen of the memory task appeared and participants were required to complete the memory task (see Figure 14 for example of an embedded-images DVN condition trial and relevant timings).

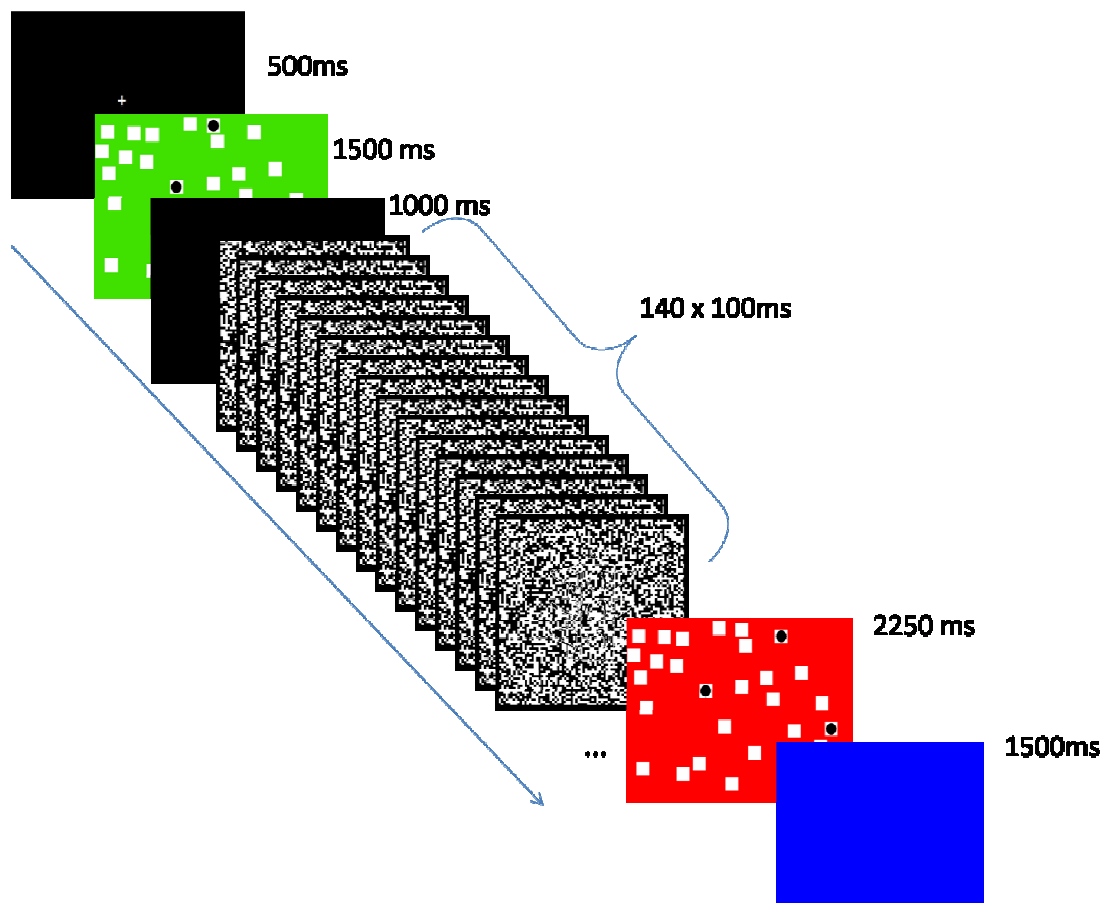


Figure 14: Example of experimental set up: simultaneous presentation with a filled delay of embedded-images DVN interference. Red recognition screen shows example of a changed trial. Black screen area surrounding all images has been removed for clarity.

In the tapping condition participants were required to steadily and repeatedly tap a dictated pattern in the retention period between presentation and recognition screens of the primary memory task, beginning as soon as the (last) presentation screen had disappeared and stopping as soon as the red recognition screen appeared. Participants were instructed to keep their eyes focused on the central area of the blank black screen in front of them while performing the tapping task. The tapping task required participants to move their hand over to the tapping board, on which the task was carried out, at the start of a trial - that is, before initiating the trial by pressing the spacebar.

Instructions of the tapping task were provided alongside a demonstration of the required continual paced tapping of the pattern required - which was in the form of a figure of eight (e.g. Darling et al., 2009; van der Meulen et al., 2009). This pattern was verbally explained throughout the demonstration in the following manner. It required that participants started with their finger on the top left button of the 3 x 3 tapping pad. The first tap in the figure was the next button to the right, then of the following trail: the next to the right, down one, one to the left, one to the left, down one, one to the right, one to the right, up one, one to the left, one to the left, and then up one to the starting position. Participants were therefore to begin each tapping trial in the same initial starting square; where in a pattern a previous trial had finished was stressed as unimportant. Tapping was required to be performed at a steady pace of two taps per second. Participants were given practice on tapping the required pattern prior to beginning the experimental trials of the tapping condition. Feedback on tapping performance, which was monitored through the instant display of performance of rate of inter-tap interval provided by Timekey software, was given to participants in order to tailor their tapping to the required pace.

Scoring

Interference tasks

All embedded-images DVN responses were scored adopting the procedure proposed following examination of responses in Experiment 3(a).

A fault in the tapping pad apparatus meant that the accuracy of a pattern could not be analysed; the inter-tap interval - that is, pace at which participants tapped the pattern, provided a measure of participants' performance in the task. Moreover, the

variability in participant's tapping performance was of interest as the steady pace requirement of the task was stressed in instructions as of primary importance.

Results.

While simultaneous presentation appeared to give a higher level of unfilled delayed recognition performance than sequential presentation (see Table 19) completion of the embedded-images DVN task within the retention delay appeared to effect performance on both simultaneously and sequentially trials. Analysis confirmed that the interference task had reduced performance ($Mdn = 14$) relative to unfilled delay performance ($Mdn = 17$), $t(6) = -6.36, p = .001$.

	Condition					
	Unfilled		DVN		Tapping	
	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	18.75	3.30	16.75	2.50	15.50	2.65
Sequential Presentation	16.00	1.00	13.33	0.58	11.00	1.73

Table 19: Memory task performance represented as a mean (in bold) of raw score from all 24 trials performed by each participant. Displayed according to presentation condition.

Performance of the embedded-images DVN task (see Table 20) appears to be higher when the task is completed in the retention interval of a memory task with simultaneous presentation ($Mdn = 5.19$) than when performed in the retention interval of a memory task where items were sequentially presented ($Mdn = 5.13$), however this comparison was not significant, $t(5) = 0.89, p > .05$. The items which were classified as easy to perceive were also detected to a similar extent, $t(5) = 0.70, p > .05$, when embedded-images DVN was performed in the simultaneous presentation memory condition ($Mdn = 0.37$) to when performed in the sequential presentation condition ($Mdn = 0.34$) (see Table 21).

	Mean	SD
Simultaneous Presentation	5.33	1.87
Sequential Presentation	3.99	1.12

Table 20: Mean (in bold) number of detections and SD of all 14 items in a DVN trial. Displayed according to presentation condition.

	Mean proportion correct	SD
Simultaneous Presentation	0.35	0.12
Sequential Presentation	0.28	0.18

Table 21: Mean (in bold) proportion correct detections, with SD provided, of easy items in a DVN trial. Displayed according to presentation condition.

When a tapping task was carried out in the retention delay (see Table 19), recognition performance also appeared to be reduced ($Mdn = 13$) relative to performance in an unfilled delay ($Mdn = 17$). Analysis revealed that this comparison was significant, $t(6) = -3.24, p = .02$. Consideration of performance in the tapping interference task reveals performance is closer to the instructed two taps per second when the task is completed with a sequentially presented memory task than when performed with a memory task of simultaneous presentation (see Table 22). Analysis found no difference between simultaneous ($Mdn = 0.37$) and sequential ($Mdn = 0.44$) conditions, $t(5) = -0.65, p > .05$. When variation of pace of participants' performance is considered, as shown in Table 22, there appears to be more variation when the tapping task is performed with sequentially presented memory items ($Mdn = 0.14$) than in a simultaneous presentation task ($Mdn = 0.10$). This comparison was also not found to be significant, $t(5) = -1.25, p > .05$.

	Mean Inter-tap interval	SD of the mean	Mean SD	SD of the SD
Simultaneous Presentation	0.39	0.11	0.10	0.03
Sequential Presentation	0.44	0.10	0.19	0.15

Table 22: Mean of inter-tap interval (with SD provided) across participants and mean of each participants' variation (with SD provided) in inter-tap interval (all shown in seconds). Displayed according to presentation condition. Means are shown in bold.

Discussion.

The embedded-images DVN was found to significantly affect memory task recognition accuracy when carried out during a retention interval. Piloting of secondary task use also revealed that performance of a tapping task during retention delay significantly affected memory recognition performance and analysis of secondary task performance revealed these tasks were not performed differently as a function of memory task presentation condition. These measures suggest that the visual interference task developed is appropriate for use in investigating the possibility of selective interference effects on the basis of presentation.

Embedded-images DVN and tapping tasks were piloted for use in order to be sure that interference effects would emerge when they were employed; a second, full-scale experiment was subsequently conducted in order to determine whether selective effects of interference could be observed on the basis of presentation format of the primary memory task.

Experiment 3 (c)

Embedded-images DVN and spatial tapping interference tasks were employed within the retention period in a task requiring memory for three dots (Experiments 1-2c) which were either presented simultaneously or sequentially. Embedded-images DVN was developed as an active interference task designed to target any possible visual image based subsystem of visuo-spatial working memory; spatial tapping has been used as an effective interference task to disrupt memory for a series of locations. If simultaneously and sequentially presented dot locations are retained by separable

subsystems it could be expected that performance of embedded-images DVN throughout retention would disrupt memory for simultaneously presented locations more than would spatial tapping and spatial tapping would disrupt memory for sequentially presented locations more than would spatial tapping.

Method.

Participants.

Thirty-two undergraduate students from the University of Edinburgh were recruited through an advertisement on the University careers website for a one off testing session of one hour. Participants were provided with a single payment of £6.05 for taking part. Of the total 32 participants tested eight were excluded. Five participants were replaced due to computer error in presenting and recording data, one participant was excluded from analysis due to providing no responses to one interference task, one participant was excluded due to providing no responses to the primary memory task in one condition and one participant was excluded due to poor performance in the baseline condition (as detailed in results). The data of 24 participants (6 males, mean age 22.38 years, SD 1.91, median 23, range 18-25) were included in analysis. All participants were right handed, and fulfilled the inclusion criteria of normal or corrected-to normal vision with no known problems with colour blindness.

Apparatus, Design, Materials, and Procedure.

Apparatus, design, materials, and procedure employed were as detailed in Experiment 3 (b). To summarise: presentation of items in a primary memory task was either in a simultaneous format or a sequential format. Half of the participants completed the memory task with simultaneous presentation and half of the participants completed the memory task with sequential presentation. All participants completed the primary memory task in three different conditions – recognition after 1500ms unfilled delay, after a 1500ms delay in which a tapping task was performed, and after a 1500ms in which detection of images embedded in DVN was performed. The order in which these conditions were performed was counterbalanced across all participants in a given presentation condition.

Scoring.

Scoring of embedded-images DVN and measurement of tapping performance was as described in Experiment 3(b).

Results.

One participant was removed from analysis, and replaced, due to a score two standard deviations below mean performance (simultaneous presentation condition) in the unfilled delayed recognition condition.

Inspection of mean scores (see Table 23) indicated a drop in recognition performance for both simultaneously and sequentially presented stimuli when embedded-images DVN or tapping were present during the 14000ms retention delay, as compared to an unfilled delay.

	Condition					
	Unfilled delay		DVN		Tapping	
	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	19.33	1.87	16.08	2.35	15.33	2.42
Sequential Presentation	18.41	2.31	15.00	2.89	14.17	2.25

Table 23: Memory task performance represented as a mean (in bold) of raw score from all 24 trials performed by each participant. Displayed according to presentation condition.

A mixed 2 (Presentation: simultaneous vs. sequential) x 3 (Condition: unfilled vs. embedded images DVN vs. tapping) ANOVA was performed with each factor as independent and repeated measures respectively. Presentation condition did not produce a significant main effect, $F(1,22) = 2.77, p > .05$, partial $\eta^2 = .12$, and there was no presentation by condition interaction, $F(2,44) = 0.02, p > .05$, partial $\eta^2 = .01$, however, there was a main effect of condition, $F(2,44) = 23.90, p = .001$, partial $\eta^2 = .52$, observed.

Further analyses to investigate effect of condition were conducted on performance collapsed across presentation conditions. Embedded-images DVN performance (*Mean* 15.54, *SD* 2.64) was found to be significantly worse than

performance in an unfilled condition (*Mean* 18.88, *SD* 2.11), $t(23) = -5.29, p = .01$, and tapping filled retention interval performance (*Mean* 14.75, *SD* 2.36) was also significantly worse than unfilled retention interval performance, $t(23) = -7.70, p = .01$. There was no difference in performance between embedded-images DVN filled task performance and tapping filled task performance, $t(23) = 1.19, p > .05$.

Timing analysis.

Descriptive statistics of correct response reaction time, shown in Table 24, indicate faster responses in unfilled recognition condition performance as compared to both of the interference filled delay conditions. A two-way ANOVA (Presentation: simultaneous vs. sequential x Condition: unfilled vs. embedded-images DVN vs. tapping), with presentation as a between participants manipulation and condition as repeated measures, was conducted.

	Condition					
	Unfilled delay		DVN		Tapping	
	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	607.64	107.56	630.97	110.24	746.35	162.56
Sequential Presentation	515.75	111.74	607.32	119.53	742.07	138.76

Table 24: Mean (in bold) and SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

A significant difference in reaction time performance was found across the three conditions, $F(2,44) = 68.62, p < .001$, partial $\eta^2 = .57$. There was no significant evidence for differences in reaction times between presentation conditions, $F(1,22) = 0.86, p > .05$, partial $\eta^2 = .04$, however, and no significant evidence of differences in the effects of condition between presentation conditions, $F(2,44) = 1.74, p > .05$, partial $\eta^2 = .07$.

Further analyses to investigate the discovered effect of condition were conducted on reaction time performance collapsed across presentation conditions. Embedded images DVN performance (*Mean* 619.15, *SD* 113.10) was found to be worse

than performance in an unfilled condition (*Mean* 561.71, *SD* 117.17), however, this difference just missed the required significance level of .0167 after employing Bonferroni correction for multiple comparisons, $t(23) = -2.53, p = .019$. Tapping filled retention interval performance (*Mean* 744.21, *SD* 147.83) was found to be significantly slower than that in the unfilled retention interval performance, $t(23) = -7.15, p < .001$. There was also a significant difference in performance between embedded-images DVN filled reaction time performance and that in the tapping condition, $t(23) = -4.66, p < .001$, whereby correct recognition responses were slower after the tapping filled retention interval.

Variance in reaction times.

Initial inspection of participants' variance in reaction time, which is shown in Table 25, revealed performance was not normally distributed in the tapping condition of participants who observed sequential presentation, $D(12) = .26, p = .03$. For the sake of clarity, in light of issues to be discussed, participants' variance in reaction time will be termed 'performance inconsistency'.

Proceeding with parametric analysis revealed variances of performance inconsistency for each presentation group were not equal in the unfilled condition $F(1,22) = 3.13, p = .01$, moreover, variances in performance inconsistency were not equal across unfilled, DVN and tapping conditions, $\chi^2(2) = 9.13, p = .01$. The data was therefore transformed, and analysis was carried out on the squared values of performance inconsistency (summary table of squared values available in appendix).

	Condition					
	Unfilled delay		DVN		Tapping	
	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	257.68	33.24	265.40	68.88	286.74	39.25
Sequential Presentation	225.01	64.23	277.10	67.64	270.08	73.24

Table 25: Mean SD (in bold) and SD of the mean SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition.

After transformation, squared values of performance inconsistency still revealed non-normal distribution in the tapping filled condition of sequential presentation participants, $D(12) = .31$, $p = .01$, however, all other conditions were normally distributed and so parametric analysis was adopted. A 2 (Presentation: simultaneous vs. sequential) x 3 (Condition: unfilled vs. DVN vs. tapping) ANOVA found equivalent variances for presentation across each condition, though the unfilled condition came close to significance, $F(1,22) = 4.22$, $p = .052$, therefore analysis should be interpreted cautiously.

Mauchly's test again revealed that the assumption of sphericity had not been met, $\chi^2(2) = 10.94$, $p = .04$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = .71$). A main effect of condition was found, $F(1.42,31.29) = 3.85$, $p = .05$, partial $\eta^2 = .15$, but no condition by presentation interaction, $F(1.42,31.29) = 0.79$, $p > .05$, partial $\eta^2 = .04$. There was also no main effect of presentation $F(2,44) = 0.18$, $p > .05$, partial $\eta^2 = .01$.

Collapsed over presentation type, each squared value shows normal distribution; a series of comparisons between conditions were carried out. Squared values of performance inconsistency in the tapping condition were significantly different from squared values in the unfilled condition, $t(23) = 3.18$, $p = .01$. While indicating a trend towards significance, squared inconsistency values in embedded-images DVN condition were not significantly different from those in the unfilled condition after Bonferroni correction for multiple comparisons had been made, $t(23) = 2.57$, $p > .0167$. Performance in tapping and embedded-images DVN were also not found to significantly differ in this comparison, $t(23) = -0.29$, $p > .0167$.

By items analysis of memory stimuli.

A supplementary by-items analysis was conducted on the data of Experiment 3 (c) for the three memory lists (also used in Experiments 1 through 3) in order to ascertain whether there was any difference in performance level associated with a particular list.

A proportion correct score was derived for each item of each list; this score was taken as the amount of times that each item was correctly responded to in the experiment, divided by the amount of times it was responded to in total. Score was therefore collapsed across conditions and collapsed across presentations. The mean proportion correct score of items for each list is shown in Table 26.

	Mean	SD
List 1	0.71	0.03
List 2	0.64	0.02
List 3	0.70	0.02

Table 26: Mean (in bold) proportion correct score, with SD provided, of each memory list.

Responses to List 3 were not normally distributed, $D(24) = .21$, $p = .01$, therefore a non-parametric analysis was adopted. A Kruskal-Wallis analysis found lists were not significantly different in the extent to which items were correctly recalled, $H(2) = 4.22$, $p > .05$.

Embedded-images DVN.

Detection performance in the embedded-images DVN task (see Table 27) was not found to differ, $t(22) = -0.18$, $p > .05$, when the task was completed in the retention interval of a memory task with simultaneous presentation compared to when performed in the retention interval of a memory task where items were sequentially presented.

	Mean	SD
Simultaneous Presentation	4.86	1.54
Sequential Presentation	4.97	1.60

Table 27: Mean (in bold) and SD of mean number of detections and of all 14 items in a DVN trial. Displayed according to presentation condition.

Consideration of detection performance for items deemed easily perceivable also shows no significant difference, $t(22) = -0.42$, $p > .05$, between presentation conditions (see Table 28).

	Mean proportion correct	SD
Simultaneous Presentation	0.38	0.09
Sequential Presentation	0.40	0.09

Table 28: Mean (in bold) proportion correct detections, with SD provided, of easy items in a DVN trial. Displayed according to presentation condition.

Tapping performance.

Consideration of performance in the tapping interference task reveals performance is close to the instructed two taps per second both when the task is completed with a sequentially presented memory task and when performed with a memory task of simultaneous presentation (see Table 29).

	Mean Inter- tap interval	SD of the mean	Mean SD	SD of the SD
Simultaneous Presentation	0.53	0.08	0.10	0.03
Sequential Presentation	0.51	0.11	0.10	0.04

Table 29: Mean of inter-tap interval (with SD provided) across participants and mean of participants' variation (with SD provided) in inter-tap interval (all shown in seconds). Displayed according to presentation condition. Means are shown in bold.

Mean inter-tap interval performance was not found to be significantly different between presentation conditions, $t(22) = .063, p > .05$. Moreover, variation of pace of participants' performance was revealed to be equivalent between memory task presentation conditions, $t(22) = 0.10, p > .05$.

Discussion.

Completion of embedded-images DVN and spatial tapping tasks throughout the retention interval of a recognition memory task was found to impair accuracy performance, compared to when no interference task was present, whether the three locations to be remembered were presented simultaneously or presented sequentially. There was no evidence of one of these interference tasks causing more disruption to recognition accuracy than the other, and no evidence of selective interference – that is, effect of either interference task did not differ on the basis of presentation condition.

Completion of tapping performance was found to produce longer and more variable reaction times in recognition performance compared to when recognition was performed after an unfilled delay or after embedded-images DVN delay. While this could be taken to indicate that the tapping task produced more uncertainty in recognition judgements, it must also be considered that the movement required by participants to disengage their hand from the tapping board and subsequent preparation to press the recognition response button, rather than an interference effect on recognition judgments, could be the source of timing differences.

Secondary task performance was not found to differ, through any of the measures used, between the two presentation conditions of the memory recognition task. This can be taken as reassurance that performance on each interference task was not sacrificed more in one presentation condition than the other in order to try to preserve primary task performance. It is therefore suggested that the interpretation of equivalent disruption by interference tasks for each presentation condition is sound.

The indication from these results is that maintenance of three locations is, regardless of presentation, completed using the same or overlapping processes; these processes appear to involve a form of short term storage susceptible to visual image based interference and a mechanism vulnerable to interference from a spatial tapping task. As the embedded-images DVN interference task detailed has not been employed with visual storage tasks before, and previous research has emphasised that visual storage is resistant to immediate products of perception (e.g. Andrade et al., 2002; Avons & Sestieri, 2005; Baddeley & Andrade, 2000; Dean et al., 2008; Dent, 2010; Quinn & McConnell, 2006) it was necessary to confirm that the new task could disrupt a visual storage task. Specifically, in order to compare the lack of passive interference effects in

Experiments 1-2 with the present observed interference effect it was necessary to provide corroborating evidence that the active interference could disrupt visual storage. To this end, a replication of a published study which exhibited selective interference effects (visual imagery susceptible to irrelevant interference, visual storage resistant to irrelevant interference) was carried out with a modification of using the embedded-images DVN in place of passive interference.

Experiment 4

In a recent study, van der Meulen and colleagues (2009) reported a double dissociation between effects of spatial tapping and viewing irrelevant images on a visuo-spatial memory task and visual imagery. In their temporary memory task van der Meulen et al. had participants retain the visual appearance (size and shape) of a series of letters over a duration of fifteen seconds before recalling the items in the order presented; this task was completed with concurrent articulatory suppression which has been demonstrated to reduce the presence of phonological coding when information is visually presented (see e.g. Larsen & Baddeley, 2003; Baddeley, 2007 for reviews). Moreover, the use of letters as stimuli in a visuo-spatial task followed research by Logie, Della Sala, Wynn and Baddeley (2000) and Saito et al. (2008) demonstrating that visual codes support memory for visually presented letter stimuli. Logie et al. revealed that when a series of visually similar letters – that is, letters which use the same form when in capital or lower case and differ only in size – are to be remembered, items are less well recalled than in trials where all letters are of distinctly different capital and lower case forms. Words which contained similar phonological sounds but were either visually similar or dissimilar also produced poorer recall in visually similar conditions. These visual similarity effects were also present when articulatory suppression was performed throughout. Saito et al. (2008) provided complementary evidence for visual code use in a study which manipulated phonological similarity and visual similarity within the same visually presented stimuli (Japanese kanji characters). It was shown that, while phonological similarity effects disappeared under articulatory suppression, visual similarity effects remained.

The imagery task employed by van der Meulen et al. (2009) required participants to repeatedly generate a visual image of a letter corresponding to an aural

prompt and a judgement as to the appearance of each letter generated was to be reported (after e.g. Weber & Castleman, 1970). The generation (Logie, 1995; 2003; Logie & van der Meulen, 2009) or conscious visual experience (e.g. Pearson, 2001; Quinn, 2008) required to perform this task was found to be disrupted by presentation of irrelevant images, but not by spatial tapping which involved no visual input.

The present experiment replicated this experimental design with embedded-images DVN in place of irrelevant images; as recounted earlier, van der Meulen et al. (2009) report both an absence of effect of irrelevant images and a previous lack of effect of viewing DVN (van der Meulen, 2008) on the visuo-spatial memory task. If embedded-images DVN detection can disrupt visual storage then, in contrast to the studies of van der Meulen and colleagues, an interference effect should be observed in both the imagery and memory task, while spatial tapping would be expected to again only affect visuo-spatial memory.

Method.

Participants.

In total, 64 participants were recruited from the University of Edinburgh student population (mean age 20.75 years, SD 1.65, median 20, range 19-25)¹¹. Nine of these participants were male and three were left handed. Thirty-one participants were unpaid 3rd year psychology student volunteers who took part to gain experience of experimental techniques, 29 participants were 1st year psychology students who took part in return for 60 minutes worth of course credit. The remaining four participants were recruited through the University of Edinburgh careers website for a one off testing session of one hour and were provided with an honorarium of £6.05 for taking part.

All participants had normal or corrected to normal vision and reported no known dyslexia.

¹¹ With thanks to five undergraduate psychology students who assisted in recruitment and data collection for 31 participants. All student experimenters were trained and monitored, furthermore, all testing followed a strict experimental procedure which was identical for all participants. Age specifics were not available for 15 participants who were tested by student volunteers in the tapping interference condition, however, participants were drawn from the same population and were of the same age range as the participants whose details were recorded.

Design.

A (2 x 2 x 2) mixed design was adopted: two primary tasks – a memory task and an imagery task - were employed and each was performed in two different conditions – that is, with and without interference. All participants completed both primary tasks, and performed them with and without interference. Two different interference tasks were employed – embedded images in DVN and tapping. Interference task condition was manipulated between participants, with half the participants performing the embedded images task in the interference conditions of the two primary tasks and half the participants performing a tapping task in the interference conditions of the two primary tasks.

Apparatus.

The computer used to present all visual stimuli was the same testing computer employed in running the primary tasks in Experiments 1, 2 and 3. The screen was at a distance of 70cm from participants.

A second Pentium 4 ® processor PC, Windows media player and Multi Media Speaker Systems speakers were used to present auditory stimuli in the two conditions of the imagery task; volume of presentation was not preset, rather it was tailored to each participant's preferred volume throughout practice trials of the task.

Responses to both conditions of the memory component task were recorded by paper and pencil methods; sheets provided structured grids, for each trial, in which participants were to write their responses. Each version of the imagery task required verbal response from participants, however, experimenters required structured grids specific to each trial in which to record participants' responses.

A nine button (3 x 3) tapping pad - as detailed in Experiment 3(b), and subsequently used in Experiment 3(c) - connected to a third Pentium 4 ® processor PC served as apparatus for the tapping interference task. Used in conjunction with Timekey software, this apparatus enabled the experimenter to monitor participants' performance in real time, as the keys pressed and time taken between each key-press were displayed on a screen visible to the experimenter. The tapping pad was positioned for use with each participant's dominant hand – that is, the tapping pad was situated on the left of participant who were left handed and on the right of participants who were right handed.

Materials.

Primary task: Memory task.

Stimuli employed were those of van der Meulen (2008, Experiments 4-6; van der Meulen et al., 2009), which consisted of two lists of 18 trials. Each trial contained four letters to be recalled and the order of these trials within a list was fixed. These lists were counterbalanced for use across conditions (control and interference) for both interference task participant groups. Each list also contained two practice trials.

Lists were created (van der Meulen, 2008) using items from a limited pool of six letters (Rr, Ll, Nn, Dd, & Hh) which were chosen on the property of dissimilar appearance when presented in upper and lower case (after Logie, et al., 2000). Throughout both memory lists used the number of times each item was presented in upper and lower case, occurred in each serial position in a trial and featured in control and interference conditions, was equalled.

Letters were presented in Arial bold font, size 48, and were presented, in black, against a white background. All letters were presented in the centre of the computer screen using E-Prime software (version 1.1).

Primary task: Imagery task.

Stimuli and criteria developed by van der Meulen (2008, Experiments 3-6; van der Meulen et al., 2009) were employed. Two lists of letters and associated criteria were counterbalanced for use in control and interference conditions, for both interference task groups. In each memory list letters of the alphabet A through M and letters N through Z were used for alternate trials; occurrence of a letter within a trial was randomised and then fixed. Each list was fixed in both presentation of items within a trial and the order of trials. Presentation of letters to be imaged utilised .wav files for each trial. Each .wav file contained a neutrally accented voice reading out a succession of 13 letters; there were nine trials for each condition thus 18 trials in total. Nine criteria judgements existed (stimuli used and criteria judgements available in appendix) and these were counterbalanced for use with A-M and N-Z letter trials between lists. Order of criteria judgements within a list was fixed.

Two practice files which used numbers, and criteria judgments of presence of straight lines and of curved lines respectively, were presented at the start of each imagery task.

Volume of presentation of sound files was tailored to each participant's need, using speakers situated equidistant on either side of testing computer screen. Judgements as to letters were verbal and recorded by the experimenter writing down participants' responses.

Secondary tasks

The embedded images DVN task developed and detailed in Experiment 3(a) was employed; twenty-four trials worth of embedded images DVN, the specifics of which are detailed in Experiment 3(b), served as interference materials for use with the primary imagery and memory tasks. Of these trials, 20 trials were randomly implemented for use with each participant in the memory task and 11 trials were randomly implemented for use with each participant in the imagery task (there was, therefore, replication of interference trials within participant).

In summary: each trial of embedded images DVN consisted of 1400 frames of visual noise run in a specific and consecutive manner, with each frame presented for 100ms thereby creating 14000ms of DVN. Into the first 13500ms of this visual noise 14 eroded black and white line drawings of real and non-real images had been inserted such that images appeared against the visual noise background. Each image was placed into five consecutive frames of visual noise and therefore appeared for 500ms; occurrence of an image within a trial of DVN was pseudo-random and once created was then fixed.

Procedure.

As stated above, participants performed each primary task in an unfilled and in an interference filled condition. Interference type was manipulated between participants. For all participants, the completion of both conditions of the memory task always occurred in succession, as did both conditions of the imagery task. Whether an interference or an unfilled condition was performed first within the two memory tasks was counterbalanced across participants within a given interference condition, as was the order in which interference and unfilled conditions of the imagery task were performed. Completion of the two successive imagery tasks and the two successive

memory tasks was also counterbalanced across participants within a given interference condition. Each condition of each task began with two practice trials, in which participants were familiarised with the procedure of each task, before commencing the experimental trials.

Primary task: Memory task.

Participants were informed they would see a series of four letters and they were to remember the visual presentation of these letters – that is, the identity of the letter, the case in which it was presented and the order in which the letters occurred. A response sheet was shown and a demonstration was given of the manner in which this would be required to be filled in. Participants were required to write in a structured response box, at the end of a trial, the four letters presented. Case of letters presented was to be indicated both in the manner in which letters were reproduced and in the positioning of written recall: capital letters were to be produced above a horizontal line bisecting cells in which recall was to be written. Order of letters was to be reproduced by filing in the first cell of a response box with the first letter presented, the second cell with the second letter and so on. See Figure 15 for an example of correctly reproduced recall. Participants were made aware that stimuli were from a limited pool and the letters in this pool (presented in both upper and lower case) were printed as a reminder at the top of participants’ response sheets for reference.

Trial	Response			
	Q			H
		r	l	

Figure 15: Example of a correctly reproduced sequence in response box for presented letters Q,r,l,H.

Each trial was participant initiated by the pressing of the keyboard’s spacebar at the screen ‘press trial when ready’. After a fixation cross, presented for 500ms, a series of four letters appeared. These letters were centrally presented (Arial bold font, size 48, black writing on white background) and each letter was individually presented for 500ms, with inter stimulus intervals of 500ms. Following these letters a blank

screen appeared for either 15000ms (unfilled delay and tapping filled conditions) or for 1000ms followed by 14000ms of the embedded-image-DVN task (embedded image filled task). After this 15000ms period a red screen appeared, accompanied by the sounding of a tone, indicating that participants were to commence written recall of the items. Time for recall was indefinite.

For all versions of the memory task, articulatory suppression was employed - continual repetition of the word 'the' - and this was to be initiated as soon as a trial began. This suppression was used in order to encourage visual encoding of the letters and reduce participants' ability for verbal encoding. Articulatory suppression was continued throughout item presentation, delay period activity (be it unfilled retention, embedded images detection or tapping) and ceased when the 'red for recall' screen appeared.

Primary task: Imagery task

Participants were informed they would hear a series of letters in a given trial and that they would be required to provide an immediate verbal response to those letters as soon as they heard them. There was emphasis placed on speed of response, with the explanation that the experimenter would be recording responses and would only be able to coordinate response to presentation if responses were immediate. Participants were informed that the verbal response would be in the form of a judgement 'yes' or 'no' as to the attributes of the letters they heard.

In all trials of the task, letters were to be imagined in capital letter format - specifically, as they would appear on a standard keyboard. Prior to starting trials, before judgement criteria were announced, participants were allowed to look at the computer keyboard to re-confirm that they were correctly imaging letters (for example, whether a capital letter J was presented with a 'hat'/horizontal line at the top).

Criteria on which judgements were to be made changed from trial to trial. Prior to each trial, detailed criteria explanations were given and examples corresponding to criteria were provided via a sheet of symbols. For example, one judgement criteria required participants to decide if the letters they heard possessed left-right symmetry - that is, if a central vertical line dividing the letters would produce two sides that were the mirror image of each other. This description would be modelled with the drawing of a vertical line on a symbol (*not* letters) to allow the participant to consider the

meaning of the description prior to starting trials. For full list of criteria and explanations, see appendix.

Participants performed nine trials in each condition, and preceded each condition with completion of two practice trials. Number stimuli were used in practice trials to familiarise participants with the requirements of the task. In all trials, participants were required to view the screen presented in front of them throughout the entirety of the trial. In all conditions a trial began with a white fixation cross presented centrally on a black screen for 500ms. This was followed by a blank (black) screen for 14000ms in unfilled and tapping conditions, and by a visual display (14000ms) requiring responses in the embedded-images DVN filled condition. Each trial finished with the appearance of a fully red screen, which occurred 1000ms after the presentation of the final auditory stimuli in a trial. Participants initiated each trial by pressing the spacebar of a keyboard.

Interference condition: Embedded- images DVN

During embedded-images DVN participants were instructed to detect images occurring within an apparent block of movement (DVN). It was stated that the small black and white squares on screen changed in a controlled manner, and against this background black and white line drawings would be presented. It was stressed that presented images may be real objects, non-real objects or real objects which have been eroded to an extent that they are no longer perceivable as objects; moreover, participants were encouraged not to pay attention to what a presented object may or may not be identified as. Participants were also informed that some items may be displayed in such a degraded manner that only single lines or corners are visible. It was therefore instructed that participants remained vigilant for anything which could be seen to disrupt the seemingly regulated block of movement.

Detection of images was to be indicated by immediate pressing of the spacebar. For instances in which images followed each other in appearance without any unfilled DVN between them, participants were instructed to press the spacebar for appearance of each image. Prior to the first embedded images condition performed participants were shown a demonstration (9000ms) of embedded images in DVN, were given a slide by slide breakdown of how images appear within the DVN and were given a 9000ms practice on this task. This procedure was repeated if necessary. Conditions in which

embedded images-DVN was carried out began with including use of this interference task with the two practice trials of each primary task.

In the memory trials embedded images DVN was carried out in the delay period of the task, beginning 1000ms after the last letter was presented and continued for 14000ms, until a red screen appeared indicating that memory items were to be recalled. See Figure 16 for a demonstration of this set up. Articulatory suppression was undertaken throughout all of the trial until recall, including while performing this secondary task.

When paired with the primary imagery task, embedded-images DVN was carried out throughout the entirety of the imagery trial - that is, both tasks began simultaneously. This required the participant to press the spacebar on two keyboards at once - one to initiate presentation of auditory stimuli, one to start the E-prime software for embedded images-DVN task - so that both trials started at the same time. While responding verbally to letters for the primary imagery task participants were to view the screen in front of them and respond to the embedded images-DVN task by pressing the spacebar at detection of images. Figure 17 shows a pictorial demonstration of these tasks (see appendix for diagram of physical set up of experiment).

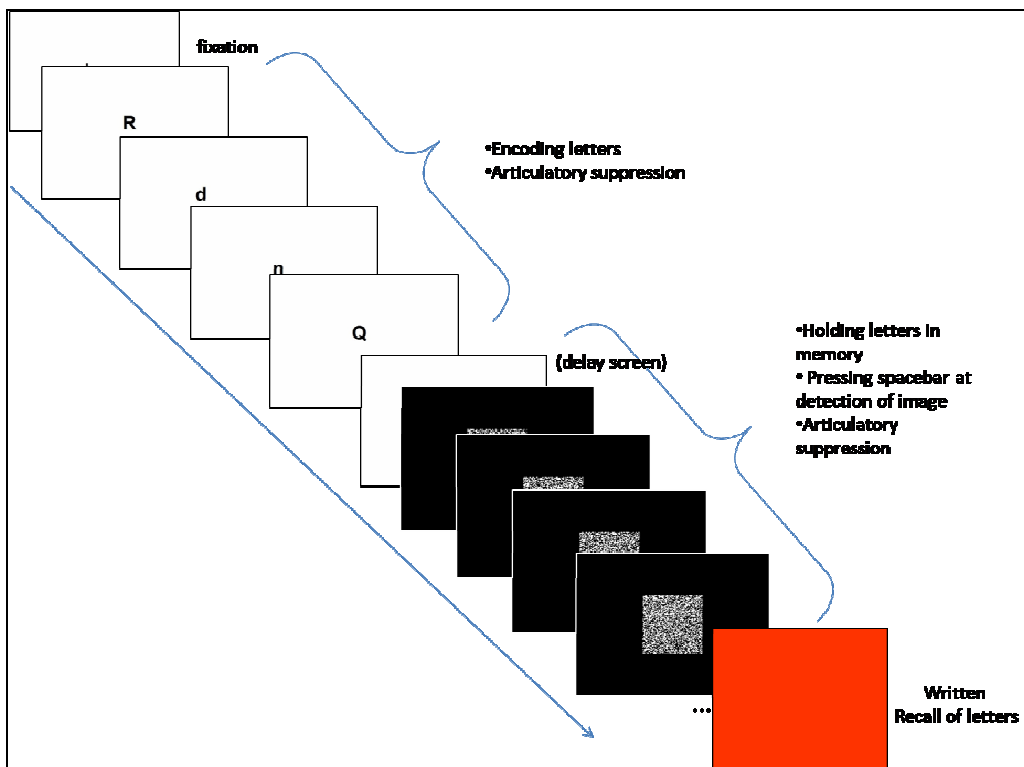
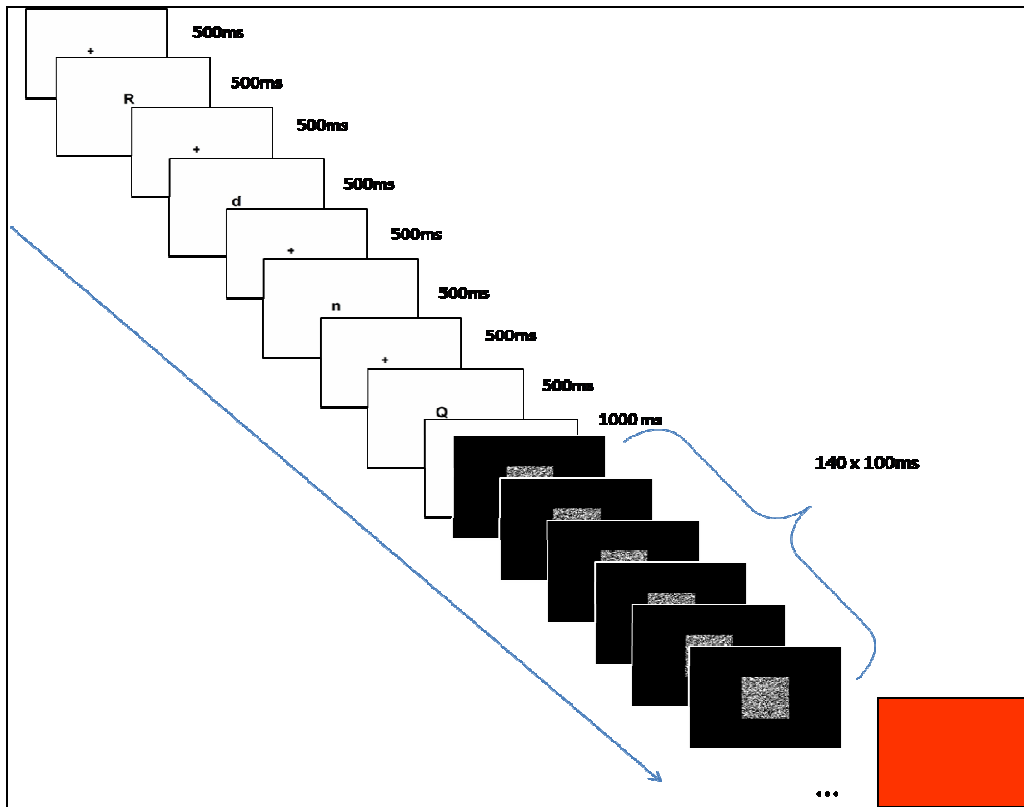


Figure 16: Top: progression and timing of memory trial in which embedded-images DVN is interference task during memory delay period. Bottom: summary of tasks participant is carrying out at any one time (ISIs during encoding removed for visual clarity).

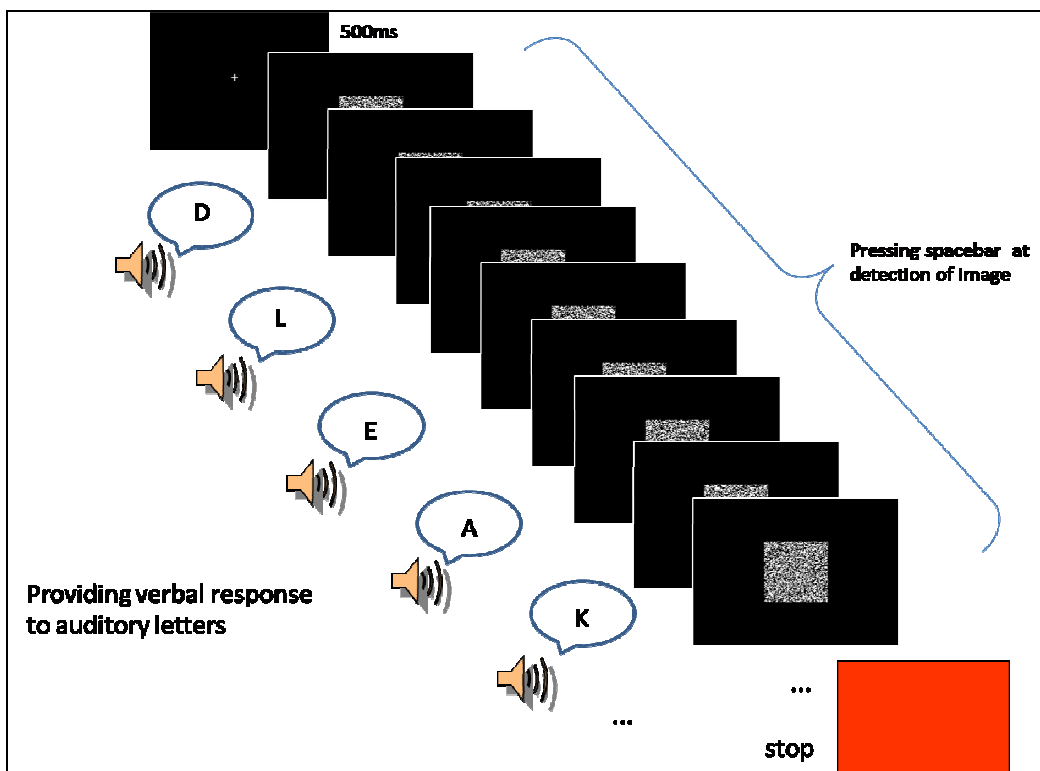
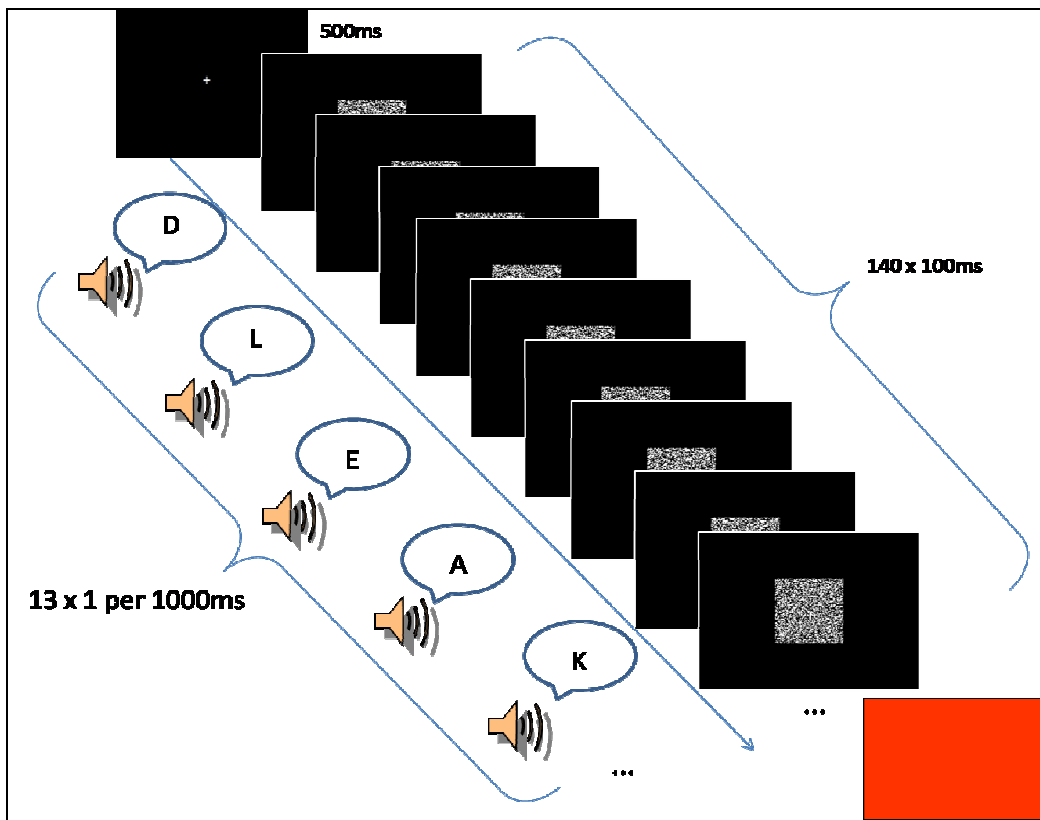


Figure 17: Top: progression and timing of imagery trial in which embedded-images DVN is interference task during memory delay period. Bottom: summary of tasks participant is carrying out at any one time.

Interference task: Tapping

The tapping task procedure was that of Experiments 3 (b) and (c). Participants were required to continually tap out a figure of eight on a 3 x 3 button tapping pad at a steady pace of two taps per second, using one finger of their dominant hand. This pattern was repeated until the end of the trial. Required pattern and speed was demonstrated by the experimenter for each participant and, prior to beginning any tapping condition, an initial practice session of the tapping task was given to participants in order to tailor performance speed to two taps per second (facilitated by the immediate information made available through Timekey software on rate of tapping).

As performed with Memory task: This condition required participants to stare straight ahead at a blank screen throughout delay period between presentation and recall of letters; while doing so they were to carry out (with their preferred hand) the above described tapping task on the tapping keyboard next to them. They were not to look at their hand or the tapping the board at any point during a trial, only between trials to reposition their hands at the starting point.

As performed with imagery task: This condition required participants to stare straight ahead at a blank screen throughout the continual presentation and response requirements of the imagery task. While responding to the imagery task, participants were to complete the tapping task in the above described manner; they were not to look at their hand or the board throughout a trial, only between trials to reposition at starting point. Initiation of auditory stimuli was participant controlled by the pressing of a spacebar with their non-preferred hand while they were to commence tapping task at the same time, with their preferred hand.

Scoring

Memory task

Following the procedure used by Logie et al. (2000; see also van der Meulen et al., 2009), three measures were taken for recall: correct item-correct position, correct letter-correct position and correct case-correct position. Correct item-correct position represented the correct recall of both the letter and the case of the item, as well as the correct reproduction of order of presentation. Correct letter-correct position represented the reproduction of the correct letters in a sequence and the order in

which they were presented; this marking procedure was scored with no regard to the case in which a letter was reproduced. Correct case-correct position represented the reproduction of the correct letter case (upper or lower) in a sequence and the order in which letter cases were presented; this marking procedure was scored with no regard to which letter was produced.

In all measures of scoring, participants could score a possible maximum of four per trial; a participant's score was then totalled across all trials in a condition and represented as proportion correct. Primary analysis was conducted on the correct item-correct position marking procedure.

Imagery task

Participants' responses to each item were scored as either correct or incorrect – there was no subjectivity in marking. It could be argued that some judgments as to letters may be questionable - for example, the judgement criterion of whether a letter can be drawn using a single continuous line may be influenced by the manner in which participants routinely write the letter rather than judged solely on the visual attributes of a letter. A blanket policy of adopting the criteria of van der Meulen (2008; van der Meulen et al., 2009), however, was enforced for all participants in all conditions, thus maintaining consistency. Number of correct responses for each participant for each trial were then converted into proportion correct scores (proportion of correct items from all possible items presented) and a mean proportion correct over all trials in a condition was used for analysis.

Results.

The mean proportion correct score derived for the imagery task and the above described mean proportion correct score for correct item-correct position in the memory task indicated a drop in performance in both tasks when performed with an interference task compared to when performed alone (see Table 30).

	DVN				Tapping			
	Control		Interference		Control		Interference	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Memory Task	.69	.18	.59	.20	.67	.20	.51	.22
Imagery Task	.73	.11	.68	.11	.73	.09	.71	.11

Table 30: Memory and Imagery task performance represented as a mean (in bold) proportion correct score, with SD provided. Displayed according to interference condition.

The Imagery control condition performance of the embedded-images DVN group was not normally distributed, $D(32) = .16$, $p = .03$, however, all other measured performances were normally distributed, and so parametric tests were carried out.

A 2 (Primary task: memory vs. imagery) x 2 (Condition: control vs. interference) x 2 (Interference type: embedded-images DVN vs. tapping) analysis of variance (ANOVA) was conducted with repeated measures on the first two variables and independent measures on interference type variable. A significant main effect of task was found, $F(1,62) = 21.61$, $p = .001$, partial $\eta^2 = .26$, with higher overall performance in the imagery task than in the memory task. Performance was not found to differ on the basis of interference type, $F(1,62) = 0.23$, $p > 0.05$, partial $\eta^2 = .00$, however, overall, performance in interference conditions was observed to be significantly worse than that of performance in control conditions, $F(1,62) = 61.89$, $p = .001$, partial $\eta^2 = .50$. No task by interference group interaction was found, $F(1,62) = 2.84$, $p > .05$, partial $\eta^2 = .05$, nor was there significant evidence of differential performance between overall control and interference conditions by each interference group, $F(1,62) = .45$, $p > .05$, partial $\eta^2 = .01$. A significant task by condition interaction, however, $F(1,62) = 20.93$, $p = .001$, partial $\eta^2 = .25$, was found, reflecting a greater drop in performance between control and interference conditions in the memory task than in the imagery task. A three-way interaction of Task x Condition x Interference group was indicated in analysis but failed to reach significance, $F(1,62) = 3.17$, $p = .08$, partial $\eta^2 = .05$.

Further analyses to investigate the significant task by condition interaction were conducted. Imagery task performance was significantly worse (*Mean .69, SD .11*) in interference filled conditions compared to when performed alone (*Mean .73, SD .10*), $t(63) = 4.05$, $p = 0.001$, and this was also found to be true (*Mean .54, SD .20; Mean .68, SD .19* respectively) for the memory task, $t(63) = 6.96$, $p = 0.001$.

Further memory task analyses.

Further analyses were carried out, pertaining to recall of the correct letter case in correct position, regardless of letter identity. A 2 (Condition: control vs. interference) x 2 (Interference type: embedded-images DVN vs. tapping) comparison, with condition as repeated measures and interference type as a between participants variable, was conducted. A main effect of condition, $F(1,62) = 39.50$, $p = .001$, partial $\eta^2 = .39$, whereby performance in interference conditions ($Mean .75$, $SD .15$) was lower than that recorded in control conditions ($Mean .84$, $SD .14$) was found. Performance of tapping and of embedded-images DVN groups was not found to differ overall, $F(1,62) = 0.26$, $p > .05$, partial $\eta^2 = .01$. Effect of interference on performance was not found to differ significantly on the basis of interference type, however, this interaction did approach significance, $F(1,62) = 3.21$, $p = .08$, partial $\eta^2 = .05$, reflecting a slightly bigger decrease in recall of letter case in the tapping filled condition ($Mean .75$, $SD .15$) than in the embedded-images DVN filled condition ($Mean .76$, $SD .16$) relative to their unfilled condition performance ($Mean .86$, $SD .14$; $Mean .82$, $SD .14$, respectively).

Analysis of letter identity recall, when recalled in the correct position yet regardless of case presented in, found a main effect of condition, $F(1,62) = 37.64$, $p = .001$, partial $\eta^2 = .38$, reflecting lower identity recall performance in interference conditions ($Mean .64$, $SD .21$) than in control conditions ($Mean .75$, $SD .17$). There was no main effect of interference type, $F(1,62) = 2.59$, $p > .05$, partial $\eta^2 = .04$, on overall identity recall, and no condition by interference type interaction $F(1,62) = 1.17$, $p > .05$, partial $\eta^2 = .02$.

Embedded-images DVN.

For a subset of sixteen participants, embedded-images DVN performance was monitored for between condition differences. Detection performance in the embedded-images DVN task (see Table 31) was not found to differ, $t(15) = -0.84$, $p > .05$, when the task was completed in the retention interval of a memory task compared to when performed during completion of the imagery task.

	Mean	SD
Memory	8.71	1.24
Imagery	8.48	1.50

Table 31: Mean (in bold) and SD of mean number of detections and of all 14 items in a DVN trial. Displayed according to primary task condition.

Consideration of detection performance for items deemed easily perceivable revealed that scores in the memory task were not normally distributed, $D(16) = .26$, $p = .01$, Comparison of performance by task condition found superior performance in the memory task ($Mdn = .82$) compared to when performed during the imagery task ($Mdn = .78$), $T = 14$, $z = -2.61$, $p = .01$, $r = -0.46$ (see Table 32).

	Mean proportion correct	SD
Memory	0.80	0.07
Imagery	0.76	0.09

Table 32: Mean (in bold) proportion correct detections, with SD provided, of easy items in a DVN trial. Displayed according to primary task condition.

Tapping performance.

For a subset of sixteen participants, performance in the tapping interference task was monitored for between condition differences. Performance in the tapping interference task was close to the instructed two taps per second whether completed during the retention interval of the memory task or throughout completion of the imagery task (see Table 33).

	Mean Inter- tap interval	SD of the mean	Mean SD	SD of the SD
Memory	.45	.11	.03	.02
Imagery	.45	.09	.04	.03

Table 33: Mean of inter-tap interval (with SD provided) across participants and mean of participants' variation (with SD provided) in inter-tap interval (all shown in seconds). Displayed according to primary task condition. Means are shown in bold.

Mean inter-tap interval performance was not found to be significantly different whether performed during the memory task retention interval or concurrently with a visual imagery task, $t(15) = -0.29, p > .05$. Variation of pace of participants' performance was also equivalent between performance of the two primary tasks, $t(15) = 1.33, p > .05$.

Discussion.

In both imagery and memory tasks, completion of interference tasks was found to produce significant impairment in performance; embedded-images DVN and spatial tapping were not found to significantly differ in magnitude of resultant interference to primary task performance overall nor by combination with task type. Embedded-images DVN detection performance was of equivalent standard in both primary tasks and spatial tapping performance did not differ, regardless of primary task it was coupled with. The presence of impairment in memory performance from unfilled to filled conditions suggests disruption of stored information. All measures of memory task performance (identity and case; identity; case) revealed effects of interference – and this did not significantly differ between interference types – suggesting that no particular aspect of visual form was preserved.

The three way interaction (task by interference by condition), which only just missed significance, reflected the effect of tapping on imagery as the smallest of all the observed interference effects. An indication that performance in the imagery task was slightly poorer when carried out at the same time as spatial tapping compared to when performed alone is not, however, entirely consistent with a lack of effect of tapping on imagery in the study of van der Meulen et al. (2009). No visual input was involved in the tapping task (participants' hands were out of their line of vision as they viewed the screen in front of them), however, it is possible that the need to monitor current position in tapping out the complex figure of eight pattern within the nine square padded participants to generate an image of the tapping matrix at points in their performance. This generation (Logie, 1995; 2003; Logie & van der Meulen, 2009) or conscious visual experience (e.g. Pearson, 2001; Quinn, 2008) could produce disruption to imagery performance – for example, through competition at the level of long term activation when generating images for primary task performance (Logie, 1995; 2003; Logie & van der Meulen, 2009) or as a visual image experienced in a visual buffer (e.g.

Pearson, 2001; Quinn, 2008). It is possible this is a strategy which is not necessarily adopted in order to perform the task; van der Meulen et al.'s (2009) participants may not have engaged this strategy. Consequently, a blanket argument that tapping performance affects visual imagery will not be made, rather it is more cautiously suggested that tapping performance can impact on visual imagery, but this might depend on how the tapping task is performed.

The effect of embedded-images DVN in the current experiment and of passively viewing irrelevant images in van der Meulen et al. (2009), on imagery performance is compatible with most notable interpretations of imagery performance, though for different reasons - direct access of perceptual information to generated or consciously experienced images (Baddeley, 2007; Quinn, 2008; Pearson, 2001) or competition at the level of long term memory activation when generating images (Logie, 1995; 2003; Logie & van der Meulen, 2009). The findings of van der Meulen et al. (2009; van der Meulen, 2008) that passive viewing of visual images did not interfere with maintenance of a series of visual items was considered as incompatible with models which posit direct access of perceptual information to temporarily stored representations (e.g. Baddeley, 2007). Rather, the findings were interpreted within the workspace model of Logie (1995; 2003; Logie & van der Meulen, 2009) in which irrelevant information may disrupt the image generation process but temporarily stored information is not automatically accessible; the effect of spatial tapping on recall of the series of letters could be interpreted as disruption to the rehearsal function of the inner scribe. The workspace model could also potentially account for the current findings of interference to temporary visuo-spatial memory from an active visual detection task if participants are considered to encode visual interference in a manner that grants access to the visual cache. As discussed below, models in which spatially based rehearsal mechanisms for sequences of information are separate from visual storage which is not the visual buffer (Pearson, 2001; Quinn, 2008) do not provide a good account of the full pattern of interference.

General Discussion: Experiments 1-4

In contrast to a lack of disruption observed throughout Experiment 2 from passively viewing interference stimuli (see also e.g. Andrade et al., 2002; Avons &

Sestieri, 2005; Baddeley & Andrade, 2000; Dean et al., 2008; Dent, 2010), Experiment 3 revealed an effect of visual detection on maintenance of location information. Experiment 4 extended this finding to show disruption to serial recall of the appearance of letters – a task which had previously (van der Meulen et al., 2009) been shown to exhibit no negative impact on performance from passive viewing of irrelevant pictures. The interference to maintenance of location information (Experiment 3) did not differ on the basis of presentation and was equivalent in magnitude to disruptive effects of spatial tapping; effect of spatial tapping was also not shown to differ on the basis of primary task presentation format. A lack of interaction between presentation format and interference task provides no evidence of use of different maintenance mechanisms on the basis of whether static arrays or sequential locations are shown. However, interference by two rather different tasks – spatial tapping and visual detection – suggests that different processes may be contributing to location maintenance. There was therefore evidence that overlapping processes are involved in maintenance of location information regardless of presentation format, when only three locations are to be remembered.

Logie (1995; 2003; Logie & van der Meulen, 2009) proposes a visual cache which retains representations of static arrays, appearance information and images of scenes; an ‘inner scribe’ maintains information about paths and sequences of movement or locations. These subsystems are proposed to be largely separable – as demonstrated through different developmental trajectories (e.g. Logie & Pearson, 1997) and largely selective impairment (e.g. Della Sala et al., 1999; Lafranchi et al., 2009; Mammarella et al., 2003; Mammarella et al., 2006; Mammarella et al., 2009) for tasks considered to most reflect the operations of each component. They are, however, considered to commonly work in concert. In particular, the scribe is assumed to provide a rehearsal function to the cache and the cache can provide an image base upon which to anchor path and sequence information. When information is maintained via these subsystems, it is believed to be held functionally separately from long term memory representations and thus not automatically accessible by perceptual input; the lack of interference from passive viewing of images in Experiment 2 is therefore consistent with this model. On the basis of this organisation, it could be argued that spatial tapping would affect representations reliant primarily on the inner scribe more than would targeted disruption of the visual cache and visual interference would disrupt representations reliant on the visual cache more than would spatial tapping (e.g. as demonstrated in Klauer & Zhao, 2004). Disruption to maintenance of

representations primarily reliant on either system by both spatial tapping and visual interference would, however, be in keeping with the interactive nature of the system's components; the use of a fifteen second delay period between presentation and test (as employed in Experiments 1-3) could be expected to maximise this interaction - for example, the need to rehearse visual cache representations. Evidence consistent with this interpretation has already been reported: spatial tapping has previously been shown to affect delayed matrix pattern and VPT recall (Andrade et al., 2002; Della Sala et al., 1999); Cocchini et al. (2002) also demonstrated a modest effect of interpolated spatial tracking, a task assumed to tap the inner scribe, on span level recall of a statically presented matrix. On the basis of previous research (e.g. Lecerf & de Ribaupierre, 2005) it could be argued that simultaneously presented locations were held as one image within the visual cache (rehearsed by the inner scribe) and sequentially presented locations were held and maintained by the inner scribe (with use of the visual cache) in a manner which preserved the temporal properties of the sequence (e.g. Bor et al., 2003; Parmentier et al., 2006). It is also possible, however, that sequentially shown locations were formed into a static pattern after encoding and stored within the visual cache or that locations within statically shown images were encoded sequentially and maintained within the inner scribe; the equal interference effects observed between tapping and visual detection cannot distinguish between these three possibilities. The interactive and flexible nature of the subsystems proposed by Logie (1995, 2003; Logie & van der Meulen, 2009) mean the model does not set explicit boundaries on the contribution of each part of the system in a given task; the interference effects observed in Experiment 3 can, under any of the above described alternative interpretations of performance, be considered as consistent with the architecture of this model. The proposed revisions to Logie's (1995) model (e.g. Baddeley, 2007; Pearson, 2001; Quinn & McConnell, 2006; Quinn, 2008), however, reduce this explanatory capability.

That passive viewing of visual interference stimuli did not prove disruptive to maintenance of location information provides no evidence to support the claim that stored representations can be directly accessed by passively viewed visual information (Repovs & Baddeley, 2006; Baddeley 2007). It also provides no support for a premise of maintenance through imagery, where images are held as a conscious experience via a visual buffer which is susceptible to immediate products of perception (e.g. Pearson, 2001; Quinn, 2008). It could be argued that the visual interference information used in Experiments 1 and 2 did not conform to specifications devised to explain apparent

demonstrations of automatic access to a theoretical visual buffer (for reviews see e.g. McConnell & Quinn, 2004; Quinn & McConnell, 2006); for example, in investigating properties of visual noise which produced disruption to pegword mnemonic performance (visual noise present throughout encoding, maintenance and recall), McConnell and Quinn (2000) found that presented visual noise had to contain dynamic properties - such as the rapid changing of dots observed in standard DVN or a repeated presentation of a static noise screen - in order to be disruptive. Moreover, Quinn and McConnell (1999) found that on-to-off changes (i.e. black to white or vice versa) of a single dot at single location had to occur within a non-uniform array (e.g. visual noise field) in order to be disruptive (though see e.g. Quinn & McConnell, 1999, Experiment 2 for disruptive single item at different locations in a uniform display). As previously stated, however, a summary of recent studies provides strong corroborating evidence that conscious visual imagery is not employed in statically or sequentially presented tasks with similar memory content to the current experiments. For example, in experiments which employed the DVN of Quinn and McConnell (1996a) - or close approximations to mimic the task - no disruption was found for static matrix recognition (Avons & Sestieri, 2005; Dean et al., 2008), static matrix recall (Andrade et al., 2002), memory for the location of four dots tested by recognition or reconstruction (Dent, 2010), memory for a single location (Darling et al., 2007), recognition performance for four locations used which were originally presented simultaneously or three locations presented sequentially (Darling et al., 2009), sequential presentation of cells within a matrix to be tested by recognition (Avons & Sestieri, 2005) and CBT performance (Pearson & Sahraie, 2003). Pearson and Sahraie (2003) pointed out that the lack of effect of DVN on span level CBT performance indicated CBT performance was not achieved via a mental imagery strategy; the evidence reviewed immediately above indicates this is also true for maintenance of simultaneously presented matrix and location information. It would therefore follow that the interference observed in Experiment 3 (and additionally, in Experiment 4) occurs within working memory storage systems distinct from any proposed visual buffer (Pearson, 2001; Quinn & McConnell, 2006; Quinn, 2008).

Baddeley (2007) proposed separate storage and associated rehearsal mechanisms for visual and spatial information. Within this proposal, patterns or arrays (including static matrices) are considered as held by a visual system, rehearsal of which is associated with a visual attention mechanism, and memory for location - either a single position or a sequence of locations - involves a spatial system which is suggested

as linked to oculomotor programmes and spatial attention (Repovs & Baddeley, 2006). In addition to lack of evidence to support Baddeley's suggestion of immediate perceptual access to storage systems, the current interference evidence appears incompatible with this organisation. A targeted tapping task is acknowledged as requiring a spatial system, while visually perceived information such as irrelevant pictures is suggested to disrupt the visual system (Repovs & Baddeley, 2006; Baddeley, 2007). The finding of interference from tapping and embedded-images DVN performance to memory for both simultaneously and sequentially presented locations is therefore difficult to explain within such a segregated organisation; if static arrays are represented by the visual storage and rehearsal system, there is no stated means by which spatial tapping could produce interference to such storage. Equally, if sequentially presented locations are held within a spatial storage and rehearsal system there is no explicit means by which visually presented stimuli would produce a disruption. If it was argued that sequential items are formed into a static representation immediately after encoding or that static arrays were represented as a series of individually encoded items there is still no apparent link to account for effects of *both* types of interference. It is recognised that such a strategy has not been suggested to account for previously demonstrated modest effects of tapping on matrix retention (e.g. Andrade et al., 2002; Della Sala et al., 1999) in the context of this organisation. However, Baddeley (2007) emphasises that visual storage is not considered as susceptible as spatial storage may be to forgetting due to a concurrent attentional demand. Therefore, even if tapping effects were considered to occur at a general attention level, rather than controlled motor or oculomotor planning competition in the spatial system, the present finding of equivalent disruption to simultaneously and sequentially presented information by tapping seems at odds with this conceptualisation of the visuo-spatial system. There is, with the concept of the episodic buffer (Baddeley, 2000; Baddeley, 2007), a possibility that interference occurs at a level where multiple modality codes can be associated with representations; indeed, the visual components are suggested as closely linked to the episodic buffer. However, retrieval from the episodic buffer is associated with conscious awareness and, for example, Repovs and Baddeley (2006), pointed out the ineffectiveness of DVN interference on matrix retention compared to interference with pegword performance as reflecting possible use of the episodic buffer in pegword performance; this would imply that matrix retention does not rely on the episodic buffer. It would be difficult to argue that the statically presented images of the current task would be represented in

the episodic buffer when other simple 'pattern' information is not. While the current model appears incompatible with the present and reviewed data, research on the episodic buffer is ongoing, especially in regards to representation of multiple features of stimuli (e.g. Allen, Baddeley & Hitch, 2006, see Baddeley, 2007 for a review); it is possible that this may provide more answers than are immediately present.

Disruption to maintenance of information presented as either a static array or a sequence of locations from both spatial tapping and visually based interference, when maintenance is considered to take place outside of conscious awareness (i.e. therefore not within any proposed visual buffer), also proves problematic to the proposals of Pearson (2001) and Quinn (2008). Pearson (2001) posited a far greater division between the inner scribe and a visual cache than that of Logie (1995); the inner scribe was proposed as a rehearsal mechanism only for sequences of locations and movements, while maintenance of information in the visual cache was suggested as dependent on unspecified visual mechanisms. The only described interaction between visual information otherwise stored in the visual cache and the operation of the inner scribe was in the form of the inner scribe manipulating conscious visual image information within the visual buffer (Pearson, 2001). Though images within embedded-images DVN were centrally presented, it is possible that participants moved their vision around the central square in order to try to detect any changes – it could therefore be argued that voluntary eye movement or shifts of attention in the visual detection task disrupted the maintenance of any stimuli represented sequentially within the inner scribe (i.e. presented sequences or a single image parsed into individual locations). By what means a spatial tapping task would disrupt any information stored as a visual image (i.e. a static array or information presented as sequences and formed into a single image) is, however, unclear in this model. Quinn (2008), uncomfortable with a rehearsal mechanism as movement or oculomotor based, suggests executive resources underlie representation of sequences of locations. Though Quinn states that a spatial component is necessary within visuo-spatial working memory, the extent to which this executively resourced component or operation is expected to interact with Quinn's concept of a visual cache is not specified. Both Pearson (2001) and Quinn (2008; Quinn & McConnell, 2006) have suggested that the visual cache could be likened to a Pattern Activation System proposed by Kosslyn (e.g. Kosslyn, 1994) though it should be noted that this interpretation is not fixed and an openness to alternative representation systems is stated (Quinn, 2008). As emphasised by Quinn (2008) a pattern activation system interpretation suggests representation in a rather different form than does the

visual cache described by Logie (1995; 2003; Logie & van der Meulen, 2009). The cache of Logie is thought to retain representations of images in a form which retains visual properties (e.g. size, shape, appearance) in a manner which would, for example, underlie the superior recall performance for visually dissimilar letters and characters observed in the recall studies of Logie et al. (2000) and Saito et al. (2008). In contrast, a pattern activation system conceptualisation of the visual cache entails more associative, long-term memory based representations which are not expected to reflect visual appearance so much as provide information for image reconstruction (Quinn, 2008, p 41). Logie (Logie & van der Meulen, 2009) points out that such a system may have problems in accounting for maintaining information about the appearance of novel or meaningless stimuli which have no long-term memory basis. It is possible some argument could be made that encoded visual information from the embedded-images DVN task performance may impact on stored information associated with visual images regardless of the extent to which representations are maintained pictorially or not. However, it is even less clear how a spatial tapping task would disrupt this proposed method of visual information representation. The underspecified nature of a claimed executive resource based spatial rehearsal prevents an adequate explanation of the disruptive effect of visual information on sequence as well as static array memory.

Observed interference effects could also be interpreted within a model which posits active maintenance of information is realised through a limited capacity focus of attention (Cowan, 2005). Cowan holds that all memory representations lie at different levels of activation and direction of said focus of attention determines both ongoing activation and retrieval from non-active states. While this model has not directly addressed fractionation of VSWM (though see Sauls, Cowan, Sher & Moreno, 2007) maintenance of visual arrays comprising four items or less is said to fall within the scope of the focus of attention (see e.g. Sauls et al., 2007; Cowan et al., 2005); greater numbers of items would require continual reactivation of items, and strategies to condense representational information. Removal of the ability to allocate attention to representations by a concurrent task which demands any level of sustained attention - such as a visual detection task or active navigation through a tapping pattern - would be considered detrimental to maintenance, as items beyond the focus of attention are subject to decay; encoding of visual items in the visual detection task as a result of activation from attributing focused attention could also create representation based interference. Though this model is largely unitary, and therefore limited for use in

investigation of fractionation or proposed multiple components of working memory, consideration of attention as a proposed mechanism of disruption does highlight the possibility of interference through amodal, cross domain resources.

It is possible that, due to statistically equivalent magnitude of disruption by tapping and by embedded-images DVN to simultaneous and sequential dot memory performance (Experiment 3), an argument could be made that completion of any second task would have disrupted performance – that is, an increase in demand reduced the ability of the system to efficiently perform the memory task. Though Pearson (2001; Pearson & Sahraie, 2003, for a review see Pearson, 2007) has argued that disruptive effects of spatial tapping are related to movement control interfering with maintenance of sequences of locations - which are considered as maintained using oculomotor planning -the model of Pearson (2001) also suggests executive resource use in the inner scribe and within the visual cache. Therefore, overall increased demand through use of any task could be suggested as detrimental; Quinn (2008) does not clarify the resources by which stored information about visual stimuli outside of conscious awareness would be maintained (i.e. the possible use of executive resources), leaving open the possibility that increased task demand could be deemed detrimental, moreover, Quinn advocates executively based spatial rehearsal. Previous studies on the ability to perform two tasks at once have indicated that task domain (e.g. Cocchini et al., 2002) and common task properties such as requirement to retain serial order (regardless of whether information is verbal or visuo-spatial; Depoorter & Vandierendonck, 2009), rather than overall dual task demand or difficulty, determine effects of performance impairment. A means to partial out possible common effects of executive resources, overall demand or involvement of controlled attention through use of an executively based, attentionally demanding secondary task to investigate this possibility is suggested in final discussion of the thesis. The next chapter considers performance on static array and sequence recall in the context of executive resource use.

The studies investigating memory for dot location (Experiments 1-3) have found no convincing evidence to indicate different resources are used to support performance when dots are presented simultaneously or are presented sequentially; it has been suggested that the same processes may be involved in supporting maintenance for recognition performance over a delay period regardless of presentation condition. It is also suggested that these processes may reflect the contribution of largely separable subsystems rather than a single subsystem. However,

two related points must be acknowledged: only a limited number of items were to be remembered in this task and participants were aware that this limited number of stimuli was consistent across trials. A limited number of items were used because previous studies had suggested that a difference between presentation conditions could be evident at this list length (e.g. Dent & Smyth, 2006, see also Boduroglu & Shah, 2006) and one of the main aims of the experiments was to assess presentation effects in as simple a paradigm as possible. It appears that, in this simple context, presentation effects are not exhibited. The study of Dent and Smyth (2006) employed positional reconstruction of dots presented against an otherwise uniform background. The results of Dent and Smyth (2006) suggested that it may not be possible to encode dot locations in a configural manner at a level of three items when presented sequentially (configural not necessarily referring to a single image, rather to associations between positions), emphasising a need to encode locations as individual items. The current study, however, employed a template array and in doing so provided an image and defined markers of location to which presented dots could be related. It is suggested that positional reconstruction of dot location in the study of Dent and Smyth (2006) may, therefore, be constrained by encoding restrictions not present in the current study. It is possible that differences in processes, or in relative contribution of processes, supporting memory for simultaneously and sequentially presented locations may be most evident at longer list lengths; for example, Parmentier and colleagues (2005; 2006) have provided evidence that presence or absence of path crossings and variation in distance traversed by a sequence can affect recall performance (measured by order reconstruction) in a way which indicates shorter, uncrossed sequences may enable static representations to be formed in support of sequence recall. There is less indication of static representation support at longer distances or in crossed sequences (see also Boduroglu & Shah, 2006). The use of any static image support may have been exacerbated in the current experiments due to the short sequences which, while unpredictable in appearance (i.e. did not follow left to right or top to bottom order), did not contain path crossing. As pointed out elsewhere (e.g. Ridgeway, 2006) participants use a variety of strategies to encode presented locations. While this adaptability and the current results of disruption by spatial tapping and visual detection suggest an interplay between visual representation and sequence maintenance processes, it is possible the contribution of static representation *processes* (e.g. the visual cache) may be reduced when participants encounter properties of sequences which reduce the ability to *form* a static image (e.g. Parmentier et al., 2005; Parmentier & Andres, 2006).

Experiments 1-4 provide evidence to support a conclusion that, with only three locations to remember, overlapping processes contribute to representation and maintenance of simultaneously and sequentially presented information. The following chapter looks at commonalities and differences in memory following simultaneous and sequential presentation when longer list lengths and recall procedures are employed.

Chapter Five

Experiment 5

Experiments 1-3 provided no evidence for variable performance on a task requiring memory for locations on the basis of simultaneous or sequential presentation conditions. There was also no evidence of more fragile representations on the basis of presentation condition – performance in each condition was equally affected by an extended delay, filled or unfilled – and no evidence for selective susceptibility to visual or spatial targeted interference. Such equivalence between presentation conditions is in contrast to previous reports of superior recognition performance following simultaneous presentation compared to sequential presentation of occupied cells within a matrix (e.g. Lecerf and de Ribaupierre, 2005; see also Dent & Smyth, 2006 for superior positional reconstruction following simultaneously rather than sequentially presented dot locations). As summarised in discussion of Experiments 1-4 with regards to effects of interference, this equivalence of recognition accuracy between presentation conditions could be due to the number of location stimuli involved in the task; with a small number of locations to remember it could be argued that representation of information involves considerable contribution from both proposed subsystems of visuo-spatial working memory, regardless of presentation. In the terms of Lecerf and de Ribaupierre (2005), with short list lengths participants may emphasise the path encoding available to simultaneously presented locations and also be able to form pattern encoding for the sequentially presented information (see e.g. Parmentier et al., 2005). Research into whether memory for simultaneously or sequentially presented locations is supported by largely separable subsystems was inspired by a variety of studies indicating that so called visual tasks such as matrix pattern (Phillips & Christie, 1977a,b) recognition or recall, and so called spatial tasks such as CBT (Milner, 1971) are not measuring a single, common ability (e.g. Logie & Pearson, 1997; Smyth & Scholey, 1996; Della Sala et al., 1999). It could be expected that operation of a subsystem upon which each of these tasks is proposed to be primarily reliant - a visual store and a spatial rehearsal mechanism respectively (e.g. Logie, 1995; Pearson, 2001, though see Baddeley, 2007) – will be most evident in performance on tasks with requirements which are similar to those of the frequently studied matrix pattern (or VPT) and CBT.

Experiment 5 was conducted to test the above proposal: memory was assessed in two conditions, using requirements derived from matrix pattern and Corsi blocks tasks respectively. Memory span for cells presented simultaneously within a structured array (i.e. $n \times n$ matrix structure), using a response method of recall of locations, was employed. Participants were required to identify each individual cell which had been occupied at presentation, in any order they wish (i.e. no top to bottom or left to right restrictions, after e.g. recall of matrix patterns Logie & Pearson, 1997; VPT of Della Sala et al., 1999). Memory span was also tested for a task with requirements similar to those of CBT: participants were presented with a series of cells and were required to reproduce these cells in the order in which they were shown. However, in contrast to the unstructured array used in CBT, a structured array (i.e. $n \times n$ matrix) was employed throughout presentation and test. Additionally, presentation of information was by illumination of cells rather than by the original CBT administration procedure of an experimenter physically pointing out each block; illumination of cells has, however, become a common method of presentation, especially when using computerised CBT (see e.g. Fischer, 2001 for an early review). Array structure and administration procedure was therefore identical between memory span conditions with the exception of presentation; physical response requirements at recall (i.e. pressing buttons to indicate cells occupied) were also identical between conditions with the exception of reproduction of sequence order in the sequentially presented condition. Previous studies (e.g. Logie & Pearson, 1997; Della Sala et al., 1999; Smyth & Scholey, 1996) have shown that for the different tasks of matrix pattern and CBT, the number of cells to which memory span refers differs significantly; Lecerf and de Ribaupierre (2005) have shown that, with an otherwise identical task, simultaneous presentation can lead to better recognition performance. It was therefore predicted that the presentation and associated response differences between conditions would lead to a significantly higher span (i.e. an ability to consistently recall more cells within a trial) in the simultaneous condition than in the sequential condition.

Method.

Participants.

Twelve participants were recruited through the University of Edinburgh careers website for a one off testing session of duration 30 minutes. All participants

were provided with a payment of £3.25. All participants (mean age 25.58 years, SD 1.93, median 26, range 23-28), of which two were male, were right handed.

Design.

All participants performed each task; a span procedure was employed therefore participants performed an individually determined number of trials, and for each participant the number of trials performed could differ between tasks. Order of completion of tasks was counterbalanced across participants.

Apparatus.

Apparatus consisting of two light-button boxes - an experimenter's box and a participant's box (see Figure 18) - was used to present patterns of increasing size/complexity in both the simultaneous and the sequential visuo-spatial recall tasks. These boxes allowed both presentation (by illuminating a series of buttons) and response (pressing of the button) to occur using the same display panel on the participant's box. Similar apparatus was employed by Rudkin et al. (2007) in order to manipulate presentation in a visuo-spatial recall task. Each box (24.5 x 24.5 cm) contained 25 light buttons in a 5 x 5 array (display area 15.8 x 15.8 cm) which were numbered 1 – 25 on the experimenter's box and were blank on the participant's box (button size 1.8 x 1.8 cm, spaced 1.7 cm apart). Sequences or patterns programmed into the experimenter's box were transferred to the participant's box where the specified buttons illuminated. A 40cm x 30cm screen separated the participant and experimenter boxes.

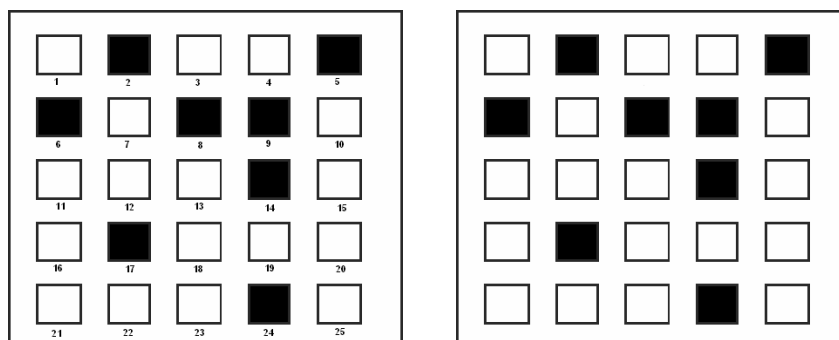


Figure 18: Experimenter's box (left) and participant's box (right). This shows completely correct recall by the participant.

Materials.

In order to minimise differences in content between the two presentation conditions of the button-box recall tasks two memory lists existed for the visuo-spatial information and these were counterbalanced between participants for the two versions of the task. Memory lists were created by a randomly generated sequence of numbers that corresponded to the numbers 1 to 25 on the button box. These lists (producing sequences of three items five times, four items five times, and so on to the maximum of twelve items five times) once generated were then fixed.

While 'sequence' indicates an ordered presentation, the simultaneous visuo-spatial task used the sequence of random numbers generated to dictate which stimuli (which of all the possible buttons on the button-box) would be shown at the same time for each trial.

Procedure.

In each task participants viewed the patterns or sequences presented on the 5 x 5 light-button box situated in front of them. As soon as the pattern (in the simultaneous presentation task) or last item in a sequence (in the sequential presentation task) disappeared participants were required to reproduce what they had seen by pressing the buttons which had been illuminated. When recalling information, whether in simultaneous or sequential presentation tasks, items which were touched by participants lit up, and remained illuminated, throughout recall.

At the start of each trial participants were reminded how many items were going to be presented - and therefore how many items were to be remembered.

During presentation of items participants were instructed to keep their hands on the table, at the sides of the light-button box in order to prevent them from 'hovering' over buttons. Instructions directed that recall could take place at any speed; however, participants were to use only one finger of their dominant hand. Additionally, the non-responding hand was to be kept away from the apparatus to prevent aiding recall by marking buttons.

Recall of simultaneous visuo-spatial information.

Patterns began at a size of three items and progressed to a maximum possible level of 12 items, with the patterns presented in a given trial according to the locations dictated by memory lists. Presentation of items in a trial entailed the experimenter typing the items to be displayed into the experimenter's box and then pressing a 'transfer' button which enabled all selected buttons to be illuminated at once on the participant's box (see Figure 18). The timing of presentation of simultaneous items was determined in part by how many items were in a trial. When three, four and five items were to be recalled, presentation time was 3000ms, 4000ms and 5000ms respectively. When more than five items were to be recalled presentation time remained at a maximum of 5000ms¹².

As soon as the presented pattern disappeared, at which point the experimenter voiced 'okay', the participant was required to press the buttons which had been illuminated in that trial. Participants were free to recall the items that constituted the pattern in any order they wished – that is, they were not restricted to top-down or left-right structured recall. To prevent experimenter influence on number of items recalled, end of each recall period was indicated by the participant; participants voiced 'finished' when they felt they had recalled all that they were able to. Participants were not able to assess their performance by any measure other than ability to produce or guess items involved in the patterns; feedback on accuracy was not provided.

Each level of list length difficulty was to be performed five times, however, when participants performed three out of five trials at a given list length correctly they were credited with achieving that level and progressed to the next level of difficulty without completing the remaining trials. Progression was announced to participants before beginning a trial at a larger list length. When participants failed to correctly recall three lists in succession, or failed to recall three lists at a given list length level,

¹² This corresponded to sequential presentation of one item per 1000ms for the first three levels (3, 4, 5 items), however, from the fourth level onwards the items were presented for less time than their sequential counterpart. Two reasons for this can be summarised: maximum presentation time possible using the light-button box was 5000ms. Furthermore, a maximum number of possible squares could be remembered using this apparatus (half of a 5 x 5 array, otherwise participants could encode which squares were *not* illuminated) and controlling presentation time was a measure to constrain performance; presentation of above 5000ms would likely result in ceiling performance.

testing terminated. Span was reported as the final level at which three trials were correctly recalled.

Recall of sequential visuo-spatial information.

Sequences to be recalled were presented beginning with list lengths of three items until a maximum of possible 12 items in a sequence. Testing progression, termination and span procedure were as detailed in simultaneous presentation.

Items to appear in sequence were programmed by the experimenter into the experimenter's box; as a button was pressed it would immediately illuminate on the participant's box. Each item in a sequence was presented for 1000ms, and as soon as one item disappeared another was presented. Participants were instructed to reproduce the sequence they had just seen as soon as the sequence had finished (indicated by the experimenter voicing 'okay'). It was stressed that it was necessary to reproduce the correct items in the correct sequence.

Again participants were instructed to use only one finger of one hand to reproduce the items, to do so at their own pace, and to keep away from the apparatus the hand that was not being used for responding. Participants again indicated when they had finished recalling the items, received no feedback on performance and were informed prior to beginning the next level of difficulty.

Results.

In each task, span scores for participants were determined as the last level of difficulty at which three trials were correctly recalled (see Table 34 for summary). In sequential presentation trials, correct recall corresponded to all items correctly recalled in the order in which they were presented. In simultaneous presentation correct recall of a trial corresponded to correct reproduction of all items shown.

	Mean	SD	Range
Sequential presentation	5.00	0.95	4.00 - 6.00
Simultaneous presentation	7.91	1.98	5.00 - 10.00

Table 34: Mean (in bold), SD and range statistics, based on span scores, for each task.

Span scores were not normally distributed for simultaneous, $D(12) = .25$, $p = .04$, or for sequential, $D(12) = .27$, $p = .02$, performance therefore a non-parametric, Wilcoxon Signed Ranks analysis was adopted. Simultaneous recall performance was found to produce higher span scores ($Mdn = 8.5$) than sequential recall performance ($Mdn = 5$), $T = 0$, $z = -2.82$, $p = .001$, $r = -.58$.

Discussion.

Consistent with indications from previous findings (e.g. Logie & Pearson, 1997; Della Sala et al., 1999; Smyth & Scholey, 1996) and proposed additional encoding opportunities available in simultaneous compared to sequential presentation (e.g. Lecerf and de Ribaupierre, 2005), span was significantly higher when recall was of simultaneously presented information than of sequences. Rudkin et al. (2007) also recently reported superior simultaneous compared to serial performance across single and dual task conditions using the same apparatus as the current experiment; however, performance in both single and dual conditions was described as a percentage of previously determined individual spans. Specifically, simultaneous performance was reported as being at a level closer to simultaneous span than serial recall was to serial span, during experimental trials – no absolute values of span or analysis on these values was provided. The results of Experiment 5 provide evidence to substantiate the idea that factors affect memory for sequentially presented, serially recalled cells within a matrix-like structured array which either do not affect memory for simultaneously presented cells or do not constrain performance to the same extent.

Kemps (1999) showed that both structure of an array (unstructured arrangement versus uniform organisation of cells) and number of cells within an array affects sequence recall; matrix style structure and less cells within an array were found to benefit sequence performance, however, when an array was as large as 25 cells, a benefit of structure was no longer present. It was proposed that the number of confusable locations at encoding, rehearsal or recall could lead to poorer performance. In the above study (Experiment 5) test conditions were the same between conditions except for the requirement to recall order of presentation in the sequence task: once items were recalled they remained lit for the duration of recall. It could be suggested that the detrimental effect of number of confusable items (Kemps, 1999) exacerbates any differences in encoding opportunities available for simultaneous and sequential

presentation (after Lecerf and de Ribaupierre, 2005). For example, it could be possible that poorer recall performance when items are presented one at a time rather than all at once reflects more a difference in locating items within an array than in representing target items with respect to each other. While this would not negate the indication that pattern and sequence recall requires different abilities or that the different presentation conditions entail different abilities at encoding, investigation of this hypothesis could add to understanding of sequence representation.

Experiment 6

Experiment 6 was conducted to investigate a hypothesis that locating single items within a quantitatively complex array contributes to differences in memory span for simultaneously presented cells and sequentially presented, serially recalled cells. As in Experiment 5, the same cell location information was to be maintained (counterbalanced across participants); however, in the sequential condition a mask was employed which limited the array presented to only the cells used throughout a single trial. In this comparison the emphasis was therefore on creating, representing and recalling sequences versus encoding, maintaining and recalling simultaneously presented displays. An extreme version of the hypothesis tested would predict that, with the presence of a mask and therefore removal of non-target items, sequence recall would be comparable to performance in the simultaneous condition. If simultaneous performance still provided better recall than sequence performance this would further indicate that poorer performance on sequence recall tasks reflected creation of associative spatio-temporal links between items rather than only locating items within an array.

Method.

Participants.

Twelve participants were recruited through the University of Edinburgh careers website for a one off testing session of proposed duration 30 minutes. All participants were provided with a payment of £3.25. All participants (mean age 19.92 years, SD 2.78, median 19, range 18-27), of which three were male, were right handed.

Design.

Each task was performed by all participants. A span procedure was employed therefore the number of trials completed differed between tasks and across participants. The order in which tasks were performed was counterbalanced across participants.

Apparatus and Materials.

The light-button box apparatus of Experiment 5 was used to present all visual information to be remembered.

Two memory lists were randomly generated, and then fixed, which dictated the locations to appear in a trial. In each memory list, sequences of three items through to sequences of twelve items were created and five sequences were created at each level of difficulty. Generated sequences corresponded to items which were displayed all at once in the simultaneous presentation and to both the order and items presented in the masked-sequential condition. Memory lists were counterbalanced for use with simultaneous and masked-sequential presentation between subjects.

Serial recall in a limited array necessitated the construction of 100 masks for use in the 50 trial sequences contained in each memory detailed above. Masks were made of cardboard and were cut to fit the dimensions of the light box; creation of a mask for each sequence involved removal of square (2.2 x 2.2 cm) sections of card above the areas in which the relevant buttons of the trial would light up. Sections were therefore cut from card so that, for each section, all that could be seen with the use of a mask was the buttons which would be present in a sequence. Masks were thin cardboard (180g/m², 200 microns) and when laid on top of the button box they rested on top of unseen buttons while the relevant buttons clearly showed through the section cut out to allow their presentation.

Procedure.

Procedure was that of Experiment 5, whereby patterns and sequences were presented to participants via experimenter controlled light box apparatus and participants were required to immediately reproduce the provided information via the same apparatus, by pressing the buttons which had been illuminated. Patterns were administered in the manner, and using timing, as detailed in Experiment 5.

Sequence presentation was administered as detailed in Experiment 5 and again with timings corresponding to a 1000ms display of each item in a sequence. In addition to the previous procedure, array masks were present throughout presentation and recall of a sequence (see Figure 19). This required that a new mask was laid on top of the button box at the beginning, and removed at the end of, each trial. Masks therefore not only limited items visible in the array at presentation, they maintained this display for recall purposes. Participants recalled items through button press in the same manner as Experiment 5 - presence of masks did not physically hinder recall processes in any way.

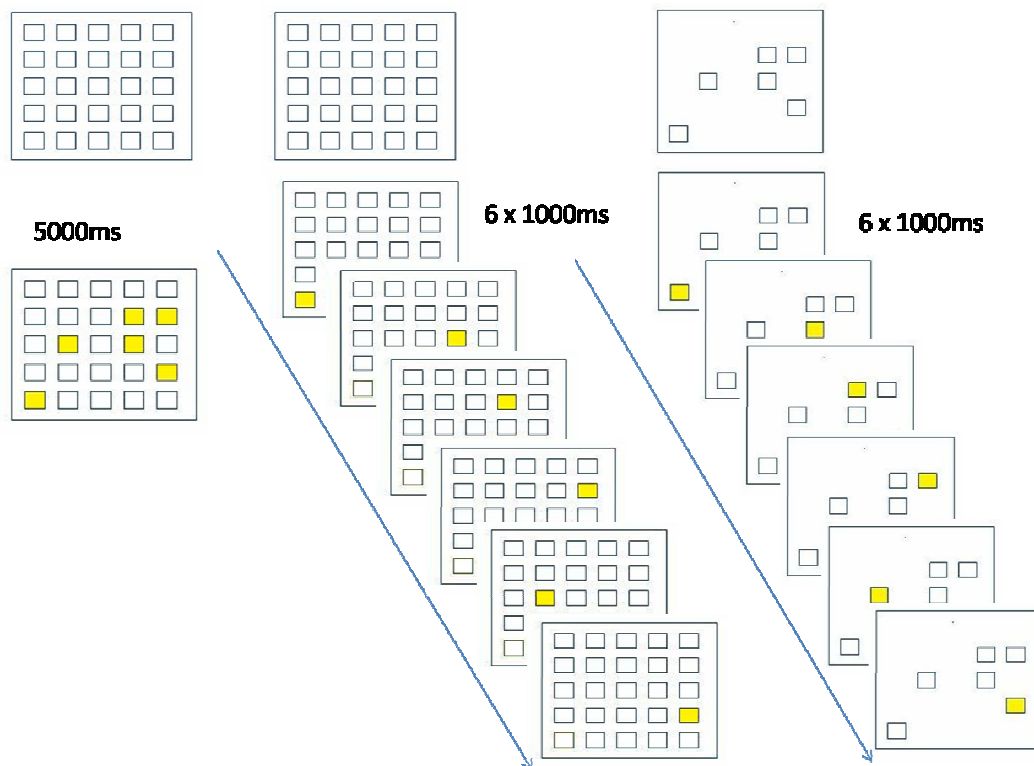


Figure 19: Panel A represents simultaneous presentation, B represents sequential presentation and C represents mask-sequential presentation. Comparison of panels A and B correspond to Experiment 5, panels A and C correspond to Experiment 6 and panels A,B and C correspond to Experiment 7.

Results and Discussion.

As in Experiment 5, span scores reflected the last difficulty level at which participants recalled three out of five trials correctly (see Table 35 for summary). In the simultaneous presentation task, recall was deemed correct if all items presented in a

trial were reproduced. In masked-sequential presentation task, recall was deemed correct if all items in a trial were reproduced in the order in which they were presented.

	Mean	SD	Range
Masked sequential presentation	7.25	0.75	6.00 - 8.00
Simultaneous presentation	10.25	1.76	7.00 - 12.00

Table 35: Mean (in bold), SD and range statistics, based on span scores, for each task.

Span scores were not normally distributed for simultaneous, $D(12) = .25$, $p = .04$, or for masked-sequential, $D(12) = .26$, $p = .03$, performance therefore a non-parametric, Wilcoxon Signed Ranks analysis was adopted. Simultaneous recall performance was found to produce higher span scores ($Mdn = 11$) than masked-sequential recall performance ($Mdn = 7$), $T = 0$, $z = -3.09$, $p = .01$, $r = -.63$. This result is in contrast to a hypothesis that the poorer sequence recall observed in Experiment 5, compared to recall of simultaneously presented items, was due only to a greater susceptibility of sequential presentation to a quantitatively complex display. Rather, superior recall of simultaneously presented items persists when a quantitatively complex array is used for simultaneous presentation while sequence recall employs a quantitatively limited (target-only) array. This indicates that the presentation format and subsequent presence or absence of ordered recall requirement creates performance differences in so-called pattern and sequence recall.

Comparison of Experiments 5 and 6.

As the same procedure and scoring method was employed in Experiments 5 and 6, a between subjects comparison can be made of performance in sequential presentation without presence of masks and performance in sequential presentation with presence of masks. This would enable evaluation of whether quantitative complexity affects sequence recall (after e.g. Kemps, 1999). As data was not normally distributed in any of the conditions of either experiment, non-parametric tests were employed for these analyses.

A Mann-Whitney U analysis found improved performance in the sequential condition with mask present, $U = 5.00$, $z = -3.97$, $p = .001$, $r = -.81$. Simultaneous performance, however, was also found to be better in Experiment 6 compared to Experiment 5, $U = 28.5$, $z = -2.54$, $p = .01$, $r = -.52$.

This improvement in simultaneous performance between Experiments 5 and 6 was not anticipated and suggests that differences in performance between the experiments could be due to a number of factors. Two factors - age of participants and memory lists - could be identified as possible contributors to this difference. Though the same recruitment of participants was carried out for both experiments, the differences observed in age groups, $U = 12$, $z = -.350$, $p < 0.01$, between the two experiments was significant. This could have occurred by chance or because of the time of year at which experiments were carried out; slight differences in timing within the university semester could lead to participants of a certain age group not volunteering to take part due to other commitments. Differences in age groups could potentially lead to differences in ability - for example Logie and Maylor (2009) revealed significant decline with age in visuo-spatial abilities across these age groups. Additionally, different memory lists were introduced for use in Experiment 6 and this could potentially lead to slight differences in performance if, for example, patterns dictated for creation in a trial by these lists formed more easily encoded or memorised shapes (e.g. Zoelch & Schumann-Hengsteler, 2006). A follow up experiment was therefore conducted in order to replicate the simultaneous versus masked sequential comparison of Experiment 6 and to extend the comparison to include unmasked sequence recall.

Experiment 7

Experiment 7 sought to compare, within the same subjects, the simultaneous presentation condition of Experiments 5 and 6, the sequential presentation condition of Experiment 5 and the masked-sequential presentation condition of Experiment 6.

Method.

Participants.

Twelve participants were recruited through a programme in which 1st year students of the psychology department at the University of Edinburgh obtain course credit for participation in research projects. Thirty minutes of course credit were

provided to all participants (mean age 20.17 years, SD 2.52, median 19.5, range 18-27) who took part. Four participants were male, and all participants were right handed.

Design.

All participants performed three tasks: recall of simultaneously presented information, recall of sequentially presented information and recall of information presented sequentially in a limited array. The order in which tasks were performed was counterbalanced across participants. A span procedure was employed for each task, therefore the number of trials completed on a given task differed across participants.

Apparatus, Materials and Procedure.

The apparatus and materials were those of Experiments 5 and 6. Three memory lists were used – the two lists used in Experiment 6 were employed and one list from Experiment 5. Only the two lists of Experiment 6 were used in the sequential-mask condition and these were counterbalanced for use in the mask condition between subjects. Simultaneous and sequential conditions for each participant used whichever Experiment 6 list was not in use for masked presentation, and the list of Experiment 5. The list of Experiment 5 was, with this constraint, counterbalanced for use with simultaneous and sequential conditions between subjects.

The experiment is represented by comparison of all three panels in Figure 19 above. Procedures for simultaneous and sequential presentation were as detailed in Experiment 5 and for masked-sequential as detailed in Experiment 6.

Results.

Achievement of correct recall of a trial was as in Experiment 5 for simultaneous and sequential presentation tasks, and as in Experiment 6 for masked sequential presentation. Span scores again reflected the last difficulty level at which participants recalled three out of five trials correctly (see Table 36 for summary).

	Mean	SD	Range
Sequential presentation	5.42	1.00	4.00 - 7.00
Masked sequential presentation	6.58	0.90	6.00 - 8.00
Simultaneous presentation	9.58	1.78	7.00 - 12.00

Table 36: Mean (in bold), SD and range statistics, based on span scores, for each task.

Sequential and masked sequential span scores were not normally distributed - $D(12) = .30, p = .01$ and $D(12) = .41, p = .001$ respectively - therefore a non-parametric analysis was adopted. A Friedman's Analysis of Variance (ANOVA) found span performance significantly changed with presentation between the three tasks, $\chi^2(2) = 21.84, p = .001$. Wilcoxon Signed-Rank tests, with a Bonferroni correction significance level of 0.0167, were used to compare performance between conditions. Simultaneous recall performance ($Mdn = 9.5$) was found to be higher than both sequential recall ($Mdn = 6$), $T = 0, z = -3.08, r = -.63$, and masked sequential performance ($Mdn = 6$) $T = 0, z = -2.96, r = -.60$. Masked sequential performance was also significantly higher than sequential recall performance when masks were not present, $T = 0, z = -2.57, r = -.52$.

Discussion.

As shown in Experiment 6, use of masks in sequence recall – employed with the aim of limiting quantitative complexity effects - did not enable span performance levels to reach recall of the same number of items as that achieved in the condition where items were simultaneously presented. Again, this would indicate that the primary manipulation of sequential presentation format and corresponding sequence recall requirements do indeed create recall ability differences as observed between the conditions of Experiment 5 (simultaneous/pattern and unmasked sequential) and subsequently replicated in the current experiment.

Additionally, it can be noted that memory span for simultaneously presented items was found to be closer to that of masked sequential performance than to sequential presentation with no mask present. As masks were employed to minimise the influence of identifying target from non-target stimuli within an array, the

remaining task requirement of encoding, maintaining and recalling information as a sequence could be considered the primary limiting factor in determining recall. It appears therefore, that emphasising the impact of order requirements on span achievement (masked sequential) does not exacerbate performance differences between simultaneous and sequence recall conditions and use of similar arrays (sequential condition) does not entail similar recall attainment. The finding of higher span performance in the masked-sequential condition compared to the sequential condition (as also shown in comparison of Experiments 5 and 6) does indicate, however, that increased quantitative complexity of surrounding array – that is, the number of items present but not used as presentation stimuli – negatively affects sequence recall (after e.g. Kemps, 1999). Moreover, it can be noted that this benefit of presence of masks to sequence recall performance exists despite the consequent change in display array from trial to trial in masked conditions.

The finding that array complexity affects sequence recall is consistent with previous research (e.g. Kemps, 1999; Smyth & Scholey, 1994 a; Logie & Vecchi, 2006). As previously reviewed in the general introduction, a number of factors have been shown to affect sequence recall – array complexity can be incorporated into path representation (e.g. De Lillo, 2004; De Lillo & Lesk, 2010; Parmentier et al., 2006) as can temporal properties of presented sequences (e.g. Bor et al., 2003; Parmentier et al., 2006), and path structure (e.g. Kemps, 2001; Imbo et al., in press) has also been demonstrated to affect performance. Influence of path complexity in the form of path crossing (e.g. Parmentier et al., 2005; Parmentier & Andres, 2006) has been shown to constrain performance. The influence of such varied factors led Parmentier et al. (2005, p425) to compare encoding and subsequent serial recall of locations to a problem-solving exercise; an extensive executive resource involvement was claimed to enable such a task. This view has been echoed elsewhere and contributes to consideration of spatial rehearsal as supplemented by (e.g. Pearson, 2001; 2007) or based on (e.g. Quinn, 2008) executive resources.

The two tasks in Experiment 5 were administered with presentation and recall requirements proposed as comparable to those of matrix pattern and Corsi block tasks. The use of the same apparatus for each condition enabled direct comparison of these presentation and recall requirements for the very same location information; recall differences were found between conditions and Experiments 6-7 provided evidence that recall differences found persist even when the same display is not used for each condition. On the basis of these findings, it was concluded that the tasks of Experiment

5 provided a suitable means to further investigate the possible different subsystems or processes that contribute to performance when information to be recalled is presented simultaneously or is in the form of a to-be-remembered sequence.

Experiment 8

In Experiment 8 an individual differences approach was adopted to look at the dissociation found for performance on tasks requiring memory of simultaneously presented 'pattern' information compared to sequence recall (e.g. Della Sala et al., 1999; Krikorian, et al., 1996; Logie & Pearson, 1997; Smyth & Scholey, 1996; Zoelch & Schumann-Hengsteler, 2006). The model of Logie (1995; 2003) proposed interlinked visual store and spatial rehearsal subsystems that differ in their relative contribution to supporting maintenance in each of these tasks; others have posited further separation between a store for visual or statically presented information and a rehearsal mechanism for sequences of locations (e.g. Pearson, 2001; see also Baddeley, 2007). Moreover, whereas Logie (1995; 2003) suggested executive resource involvement in task performance as limited to encoding information and implementing strategy use, proposed developments of the model have also changed the properties of the subsystems (e.g. Baddeley, 2007; Pearson, 2001; Quinn, 2008) including suggesting further involvement of executive resources in visual or spatial maintenance (e.g. Pearson, 2001; 2007), *requirement* of executive resources for maintenance (e.g. Barrouillet et al., 2004; Camos et al., 2009) and, more extremely, proposing spatial rehearsal as executive resource based (e.g. Quinn, 2008).

As reported in the literature review of Chapter 2, research employing working memory capacity tasks has influenced opinion on the role of executive resources – not least by implying more use of executive resources in visuo-spatial tasks overall than in supposedly comparative verbal tasks. However, as also reviewed over the course of Chapter 2, it has become increasingly apparent that some of the relevant studies are misapplied or misinterpreted. For example, previously WMC complex span tasks were thought to reflect primarily executive determined recall, due in no small way to seemingly better predictive power than simple span recall for higher order cognition (e.g. see meta-analysis of Daneman & Merikle, 1996) and theoretically taxing both processing and storage components of the WM system in a way which manifested in

recall score (e.g. Daneman & Carpenter, 1980). Indeed executive attention was proposed as the largest determinant of recall score (Engle, Kane et al., 1999). These conceptualisations did not fit with modern multiple component models of memory (e.g. Baddeley & Logie, 1999) and it has since been demonstrated that serial recall in complex span performance is near equivalent to simple span (e.g. Duff & Logie, 1999; 2001; Logie & Duff, 2007); moreover, predictive value of simple span has been shown as equivalent in magnitude to that of complex span (e.g. see meta-analysis of Unsworth & Engle, 2007a). An apparent asymmetry between verbal and visuo-spatial domains in simple and complex span relationships – specifically, in the verbal domain simple span and complex span recall performance constituted separate representation in latent variable analysis (Engle, Tuholski et al., 1999) while visuo-spatial spans did not (Miyake et al., 2001) - suggested that spatial simple spans already involved the executive resources supposedly present in complex span performance. However, the studies of this comparison (Engle, Tuholski et al., 1999; Miyake et al., 2001) used different scoring procedures, and such a difference between domains is no longer apparent once uniform scoring is adopted (Kane et al., 2004). That the spatial simple span measures of Miyake et al. (2001) correlated with executive tasks has also been cited (e.g. Quinn, 2008; Rudkin et al., 2007) as evidence of executive resource use; however, the total score measure upon which correlations were based represented supra-span retrieval; supra-span retrieval has also been shown in the verbal domain, through interference methodology, to require executive involvement (Vandierendonck et al., 1998 a,b). Nevertheless, interference methodology has provided evidence that executive resources are used in sequence encoding and recall (e.g. Fisk & Sharp, 2003; Rudkin et al., 2007; Vandierendonck et al., 2004) and possibly in performance of a simultaneous or pattern recall task too, though to a lesser extent (Hamilton et al., 2003; Phillips & Hamilton, 2001; Rudkin et al., 2007 Experiment 1, though see Experiments 2 & 3).

In the present study complex span tasks were considered an opportune way in which to explore the resources used in simultaneous (or pattern) and sequence memory; these simple recall tasks were measured using total score methods (after e.g. Miyake et al., 2001; Unsworth & Engle, 2007a). This follows recent acknowledgement that the serial recall measures of both simple and complex tasks “largely measure the same basic subcomponent processes (e.g. rehearsal, maintenance, updating, controlled search) but differ in the extent to which these processes operate in a particular task” (Unsworth & Engle, 2007a, abstract). Moreover, that the components constituting

performance in a complex span task – processing and recall - hold independent predictive value of higher order cognition (as do reaction time measures, e.g. Unsworth et al., 2009; Bayliss et al., 2003, 2005; Waters & Caplan, 1996) further substantiates the position that they reflect primarily the operations of different executive and storage components of a multiple component system (Duff & Logie, 1999; 2001; Daneman & Hannon, 2007; Logie & Duff, 2007; see Caplan & Waters, 1999 and ensuing discussion). A number of measures of a number of tasks were taken. Specifically – the present study was conducted in order to explore how much performance on pattern and sequence recall is related, and whether there is evidence of dissimilar resource use between performances on these tasks.

Method.

Participants.

Participants were 105 students of The University of Edinburgh who were tested in return for either course credit (38 participants were each given 75 minutes of course credit) or an honorarium (67 participants were provided with £6). Of these 105 participants, one participant's data were not used due to a failure to follow instructions on one task, two participants were not included in the study because they were dyslexic and two participants' data were excluded due to incomplete video recording of the box experiments. Of the remaining 100 participants (32 males, mean age 19.92 years, SD 1.44, median 20, range 18-23) 91 were right handed and nine reported using their left hand for most daily tasks. All were native English speakers, had normal or corrected-to-normal vision, and had no known reading or hearing problems.

Design.

This experiment used an individual differences approach to assess possible predictors of immediate memory for simultaneous and sequential presentation and recall of visual arrays. All participants performed the five tasks of this experiment. Verbal working memory capacity (WMC) was assessed using a modified *Sentence Span* task which required concurrent processing and storage (Baddeley et al., 1985), while spatial WMC was assessed using a *Letter rotation* task (Shah & Miyake, 1996) which had been designed to require concurrent processing and storage in an analogous manner. In most studies of WMC only the measure of memory is recorded and analysed. Following the general argument from Caplan and Waters (1999) and Duff and

Logie (1999, 2001), measures of processing accuracy, processing speed and of memory were recorded for the verbal WMC and spatial WMC tasks as measures of individual differences. Serial verbal recall was assessed using a *digit recall task*. Performance on *simultaneous and sequential* versions of a *visuo-spatial recall* task were measured separately following a similar procedure to that used in Experiment 5. The same test apparatus and materials were used for each presentation of the visuo-spatial recall task. Tasks were completed by all participants in a set order, corresponding to the descriptive order above; the order of the two box presentation visuo-spatial recall tasks was counterbalanced between participants.

Apparatus.

Presentation of WMC tasks employed the same testing computer which displayed all visual stimuli of previous experiments (Experiments 1, 2, 3 & 4); screen was located at a distance of 70cm from the participant. Stimuli were presented and processing responses were recorded using computer software E-prime (Version 1.1). Responses to the memory component of both WMC tasks were recorded by paper and pencil methods, using booklets created for each task (see procedure).

Presentation of digit recall task stimuli utilised .wav files which were created for each trial. These stimuli were presented using a Pentium 4 ® processor PC, Windows media player and Multi Media Speaker Systems speakers. Volume of sound files presentation was tailored to each participant's preference. Recall of digits was oral and recorded by the experimenter writing down participants' responses.

Two light-button boxes, as employed in Experiment 5, were used to present patterns of increasing size/complexity to be reproduced by the participant in both the simultaneous and the sequential visuo-spatial recall tasks.

A tripod mounted Panasonic S-VHS camera/recorder AG-DP200 was used to record participants' responses in the simultaneous and sequential visuo-spatial recall tasks. A Panasonic colour TV (screen dimensions 14.5 x 10.5 cm, 18cm diagonal), Model TC-801G, was used to monitor the recording process during testing. Video footage contained a view of only the response box and the participants' hands; no identifying information was recorded. Sound was recorded during testing, however, no identifying information was discussed at this time. Participants were informed before the experiment commenced that this recording procedure was necessary in these tasks, and were given the opportunity to withdraw from the experiment.

Recorded video footage of each participant was converted from VHS tapes to a digital VLC media file format after testing. Footage was subsequently viewed, using VLC media player, at a reduced speed in order to allow for accurate transcribing of participants' responses. Video footage was viewed only by the experimenter.

Materials.

Each task employed sequences of stimuli which were initially randomly generated and then fixed.

Sentence span task.

The *sentence span task* was an adapted version of the working memory verbal span measure (Baddeley et al., 1985; Duff & Logie, 2001) designed to assess concurrent verbal processing (through accuracy and reaction time) and verbal storage. This task required statements which would be judged on their 'truthfulness', with the last words of these statements serving as stimuli to be recalled at the end of a trial. All participants were tested on trials with two statements up to trials with five statements. The following statements: "Spaghetti is a food", "Sergeant Majors are mothers" would be an example of a two statement trial with a 'true' and then a 'false' statement. This example would require the memory response of 'food' and 'mothers' at the end of the trial. Each level of difficulty, as determined by number of statements in a trial, was to be performed five times by all participants. Twenty trials were performed in total by each participant.

A list of statements was therefore created (stimuli taken from Baddeley et al., 1985), using an equal number of 'true' and 'false' statements. These stimuli were randomly allocated to each trial, and then presented in a fixed random order for all participants. Sentences were presented in black, were centrally located on a white background and were of size 18 Courier New font. All stimuli were presented using E-Prime (Version 1.1) software.

Letter rotation task,

The letter rotation task was created adhering to the constraints of the task as it was originally designed (Shah & Miyake, 1996) and modified (Miyake et al., 2001). This task required that participants be tested on trials with two elements up to trials with

five elements. Each level was performed five times therefore each participant completed twenty trials in total.

Five letters were used throughout the task (J/ R/ L/ F/ G); each letter was shown an equal number of times in normal and mirror orientation and only one letter was employed per trial. Throughout the letter rotation task each letter was shown once in normal, and once in mirror image format, at each of the following angles: 45 degrees, 90 degrees, 135 degrees, 180 degrees, 225 degrees, 270 degrees, 315 degrees. Letters were never shown absolutely upright (0 degrees). Following these constraints, and the rule that no angles with 180 degrees of difference from each other should immediately follow one another in a sequence, one of every permutation of the items was randomly assigned to a trial and then fixed into this position. All participants therefore completed trials presented in the same order. See appendix for trial lists.

Letter stimuli were created as individual bitmap images using white letters of Arial bold font, in a capital format, presented on a black background (see Figure 20). Upright images of letters were of sizes ranging from 100 x 109 pixels (capital letter **G**) to 100 x 175 pixels (capital letter **F**). Upright letters were rotated around the central point to produce the required angles of presentation using GNU Image Manipulation Program software. This software was also used to make the 'mirror images' of all letter stimuli. Rotated images (normal and mirror image) were within the size of 184 x 184 pixels. These bitmap images were presented as stimuli for the task, run using E-Prime (Version 1.1) software.

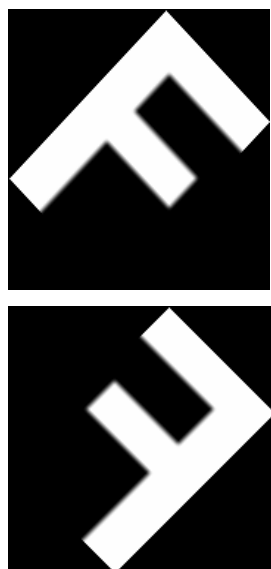


Figure 20: Normal and mirror image versions of capital letter **F** at orientation 45 degrees.

Digit recall task.

Digit strings began at the level of two digits to remember, performed five times, and then increased to three digits for recall to be performed five times. The task proceeded in this manner to the maximum level of eight items to remember, to be performed five times. There were thus 35 trials for each participant. Sequences used were created, using random number generation, and then fixed. One list of sequences was used for all participants. Sound stimuli, each individual trial recorded as a .wav file, were read by a neutral accented English speaker.

Simultaneous and sequential visuo-spatial recall tasks.

The two memory lists detailed in Experiment 6 were employed in order to determine the sequences and patterns presented for memory in each trial. Memory lists were counterbalanced for use with each presentation condition across participants. As previously stated these memory lists consisted of sequences of numbers which corresponded to the numbers 1 to 25 on the light-button box. Memory lists provided five sequences at each list length (five sequences of three items, five sequences of four items, five sequences of five items, and so on). On the basis of the range of span levels exhibited in Experiments 5 and 7 for each presentation condition, lists were administered up until twelve items for simultaneous presentation (thus 50 simultaneous trials in total) and up until eight items for sequential presentation (thus 30 sequential trials in total).

Procedure.

Sentence Span task.

Sentence span was visually presented, responded to via a computer keyboard press, and involved written recall. The procedure is illustrated in Figure 21. Participants were tested beginning with trials of two elements, proceeding up to trials with five elements. This limit was chosen on the basis of a review of the literature by Conway et al. (2005) which determined a range extending from two to five items as suitable for the target population, moreover, this administration corresponded to the five element administration of the letter rotation task (Shah & Miyake, 1996; Miyake et al., 2001). Each level of difficulty was performed five times, thus twenty trials were performed by each participant.

Participants were informed that there were two components to the task to perform: a processing and a memory component. It was emphasised that both aspects of the task were of equal importance.

The processing component of the task required reading and responding to sentences that appeared on the computer screen before them. Participants were instructed to respond true or false (by pressing standard keyboard number-pad keys '1' for True, '2' for False) and were informed that the study would involve looking at reaction times of these answers. Sentences appeared for up to a maximum presentation time of 3000ms each (with an inter-stimulus item, consisting of a fixation cross, of 250 ms) and were programmed to disappear on a participant's response. Examples of 'true' and 'false' sentences were verbally given to illustrate that while sentences must be read properly the decision process should not be extensive.

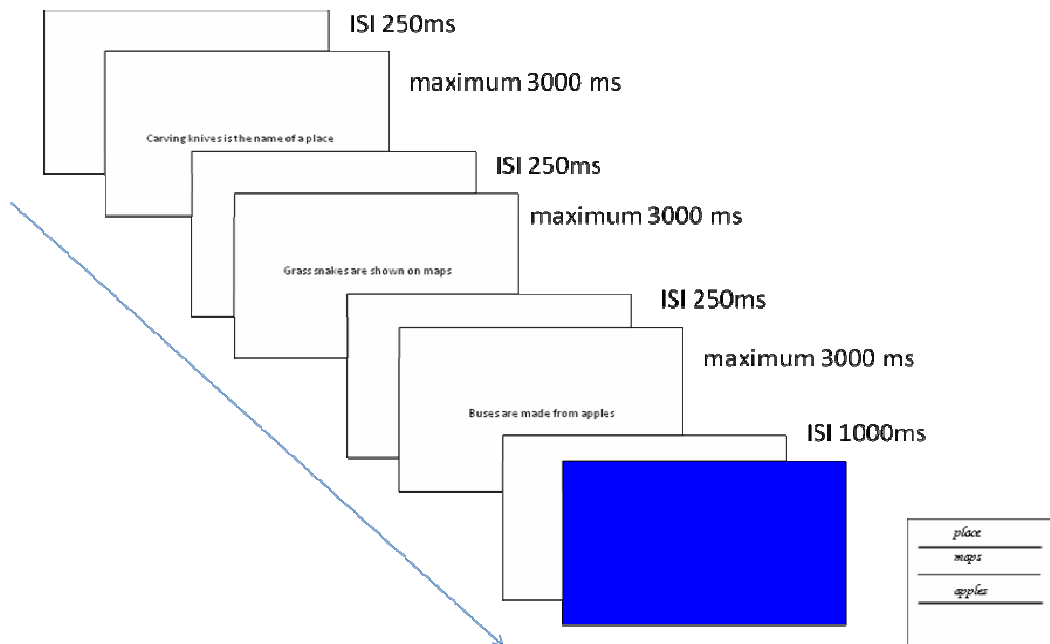


Figure 21: Example of sentence span trial at list length three with corresponding recall.

The memory portion of the trial required participants to produce responses when a blue screen appeared. This occurred 1000ms after the final sentence in the trial had either been responded to or reached maximum presentation time. When the blue screen appeared participants were to recall the last word of each sentence in that trial,

in the order in which they had appeared. Participants were provided with booklets, consisting of an individual page for each trial, with lines that corresponded to the number of items to be recalled and were instructed to place the words on appropriate lines (the last word of the first sentence on the first line, the last word of the second sentence on the second line and so on). Additionally, participants were informed that, when unable to recall a word, a position should be left blank and words which were remembered should be placed in the correct positions.

Letter rotation task.

The letter rotation task was visually presented, responded to via a computer keyboard press, and involved written recall. Participants were tested beginning with trials of two elements, proceeding up to trials with five elements. Each level of difficulty was performed five times, thus twenty trials were performed by each participant.

Participants were again informed that there were two components to the task they were about to perform: a processing and a memory component. It was again emphasised that both aspects of the task were of equal importance.

The letter rotation task involved viewing and responding to centrally presented letters that appeared on the computer screen before them. The processing component of the task required that participants decide whether images were presented in their normal format or were a mirror image representation of this format. Participants were instructed to respond, while the image was onscreen, 'normal' or 'mirror image' by pressing keys on the standard keyboard number-pad (keys '1' for Normal, '2' for Mirror Image). It was stated that the study would involve looking at reaction times for this decision. The requisite difficulty of this processing task was provided by the fact that letters were presented in a variety of orientations and never presented fully upright. Letters appeared for a maximum of 3000ms each, disappeared faster if responded to, and had an inter-stimulus interval of 250ms. Examples of 'normal' and 'mirror image' letters were hand-drawn for each participant; three different orientations were used in this example in order to fully familiarise the participants with the demands of the task (see Figure 22).

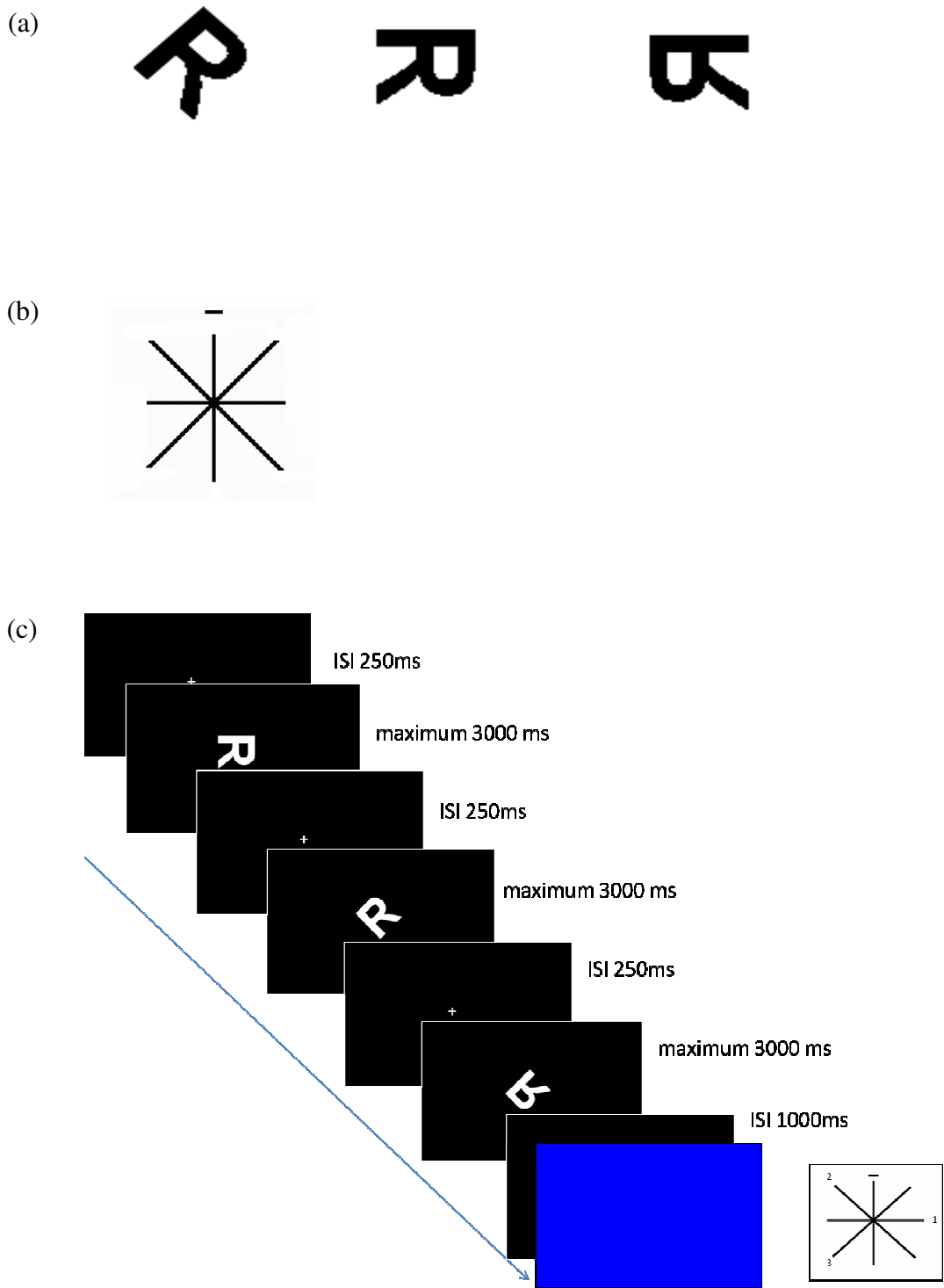


Figure 22: (a) Examples presented to participants. The third item was pointed out as mirror image (b) Example of single response sheet in recall booklet (c) Example of experimental procedure and corresponding recall response.

The memory portion of the trial involved recall at the appearance of a blue screen. This occurred 1000ms after the final letter in the trial had either been responded to or reached maximum presentation time. Participants were required to recall the orientation that each of the letters appeared in and the order in which these orientations had occurred. Instructions explicitly emphasised that this portion of the task did not require the recall of whether each letter was presented in normal or mirror image format.

Participants were provided with booklets consisting of an individual page per trial which contained a diagram to permit indication of orientations at recall. Orientation of presentation was described as the angle at which an upright letter has been moved to, or “where the top of each letter has been rotated to”. Participants were instructed to place a number at the top of each line to indicate where the first, second... (...third, fourth, fifth) letters were oriented (see Figure 22b). Instructions made clear that, if participants found themselves unable to recall the orientation of one of the letters but able to remember the orientation of the other letters, the number of the forgotten item should be left out and the true position in the sequence of the remembered items could be indicated by using the numbers that matched with order of appearance. A line at the top of the reproduction grid indicated that at no time should the answer be 0 degrees; this was pointed out and explained to participants prior to the first trial.

Digit recall task

The Digit recall task required participants to recall a string of digits as soon as the digits had finished being read aloud. Participants were informed that this was purely a memory task. Again, instructions reiterated that the task would proceed to a difficulty level presumed beyond participants’ capabilities and it was emphasised that they should continue to try their best and not get disheartened.

Participants were informed, before beginning the task, of the following set up: a voice recording (paced at one digit per 1000ms) on the computer would read out a series of numbers containing only digits between one and nine and as soon as the voice recording stopped the participant should repeat back the numbers in the order in which they were presented. Participants were instructed that, when unable to recall any numbers in the sequence, numbers which could be remembered should be stated – that is, the following style should be adopted: “nine, three, four, something, two,

something". Instructions informed participants that the task would begin with two numbers to remember, five times, and then the item load would increase to three, after five trials it would increase to four and so on, until a maximum. The maximum number of digits to be remembered was not divulged to participants until that level was reached.

Recall of simultaneous visuo-spatial information.

The procedure of assessing recall for simultaneously presented visuo-spatial information followed that of Experiments 5 - 7. Participants viewed a five by five matrix of buttons which would light up in a pattern determined by specific items programmed into the experimenter's box. Patterns began at a size of 3 items and progressed to levels with 12 items; each level was performed five times by all participants and items to be contained in each pattern were determined by use of above detailed memory lists. The number of items contained in a pattern to be reproduced was stated at the start of each trial.

Display of simultaneously presented items followed input of information into the experimenter's box and press of a button by the experimenter which caused this information to be illuminated on the participant's box at the corresponding locations. Participants were then required to reproduce the illuminated items as soon as the lights had disappeared and the experimenter had voiced 'okay' to indicate recall should begin.

As in previous experiments (Experiments 5,6,7), timing of simultaneously presented information was related to how many items were in a trial. When three, four and five items were to be recalled, presentation time was 3000ms, 4000ms and 5000ms respectively. When more than five items were to be recalled presentation time remained at a maximum of 5000ms.

Throughout presentation participants were required to rest their hands on the table at either side of the light box. At recall, participants used one finger of their dominant hand to reproduce items, while keeping their other hand resting on the table. Recall pace was not dictated and participants were free to reproduce the items which constituted the to-be-recalled pattern in any order (there were no direction or order restrictions). Participants indicated the end of a trial by vocally stating when they had finished recalling all items.

Participants were not provided with any means to assess their performance other than their ability to produce or guess items involved in the patterns; feedback on accuracy was not provided and, in contrast to Experiments 5- 7, buttons did not illuminate at the participants' touch as responses were produced. No items were illuminated at any point in the recall portion of the task.

Recall of sequential visuo-spatial information.

Participants were presented with sequences of increasing length to be reproduced, using the randomly generated, then fixed, sequences which were counterbalanced between participants for use in the simultaneous pattern recall task. Sequences began at the length of three items and proceeded to the difficulty of eight items. Each level of difficulty was performed five times. It was emphasised to participants that all items in a sequence had to be correctly recalled, in the order in which they were presented. A procedure as described in that of digit recall was adopted: if participants were aware that they had forgotten a location, but could remember other locations, they were allowed to maintain the absolute order of remembered items by indicating the position of the forgotten location through voicing "something".

Items in a sequence appeared displayed on the participant's box as they were programmed into the experimenter's box; each button was illuminated for 1000ms and as soon as one button in a sequence disappeared, the next would light up. Participants reproduced the sequence of buttons presented immediately after the light of the last button disappeared, and were prompted to do so by the experimenter voicing "okay".

As in simultaneous presentation, participants used one finger of one hand to reproduce items, were allowed to reproduce items at their own pace, and were instructed to rest their non-responding hand on the table in front of them or on their lap. End of a trial was determined by participants, who stated when they had finished recalling all items they were able to remember. Participants again received no feedback on performance and were informed prior to beginning the next level of difficulty.

Scoring

Total scores rather than span scores were calculated for each task. This scoring method was adopted in order to avoid a restricted range of values and the suggested lower reliability of measures observed when using span scores, with consequent reduced correlation findings, as demonstrated by Oberauer and Süß (2000) and Friedman and Miyake (2005).

Sentence span.

Two aspects of the sentence task were measured – processing and memory. Processing was assessed using accuracy responses and reaction time data for each of these responses. Memory was assessed using written recall of items at the end of each trial.

Sentence span processing.

Every correct response to a 'True' or 'False' judgment was allocated one point. Points for performance across all levels of difficulty of the task were summed to calculate a 'total score' for each participant. This 'total score' was then expressed as a percentage correct of all the items that the participant had seen. This latter step was taken due to accuracy data not being logged by the computer for the first trial of each level of difficulty for the first twenty four participants¹³.

Reaction times for each response were recorded. All reaction times below 300ms were not included in any further analysis because these were considered to be anticipatory responses and were too brief for a choice response time (see e.g. Woodworth & Schlosberg, 1954). Correct and Error reaction times were compared; sentence task error reaction times were not normally distributed ($D(100) = 0.12, p = .001$) therefore both sentence task correct and error reaction times were converted into Z scores before comparison. A significant difference was found ($t(99) = -2.65, p = .01$) between error and reaction times, thus for further analysis only correct reaction time was used.

Sentence span memory.

A point was allocated to every correctly recalled word in every trial. In order for a word to be correctly recalled, participants were required to remember the order in

¹³ A comparison between performance of these twenty four participants and a random sample of twenty four participants from those for whom all data was recorded yielded no significant differences ($t(46) = -0.66, p > .05$).

which the words had appeared in the trial (the item's position in sequence). Performance was scored at each level of difficulty of the task, and a 'total score' was used for each participant. This meant that the maximum for the memory portion of this task was a score of 70.

Letter rotation task.

Two aspects of the letter rotation task were measured – processing and memory. Processing was assessed using accuracy judgments of letter format and reaction time data for each of these judgements. Memory was assessed using written recall of angle of presentation of each item at the end of a trial.

Letter rotation processing.

Every correct response to a 'Normal' or 'Mirror image' judgment was allocated one point. Points for performance across all levels of difficulty of the task were summed to calculate a 'total score' for each participant. This 'total score' was then expressed as a percentage correct of all the items that the participant had seen. This step was taken due to accuracy data not being logged by the computer for the first trial of the first twenty four participants¹⁴.

Reaction times for each response were recorded. All reaction times below 300ms (a cut off choice reaction time minimum speed) were not included in any further analysis. Correct and Error reaction times were compared and a significant difference was found ($t(99) = -4.85, p < .001$). Therefore for further analysis only correct reaction time was used.

Letter rotation memory.

A point was allocated to every correctly recalled item in every trial. In order for an item to be correctly recalled, participants were required to remember both the angle of presentation of each item and the order in which the items occurred (the item's position in sequence). Points were counted up to a total for performance across all levels of difficulty of the task, and a 'total score' was used for each participant. A maximum score of 70 was therefore achievable.

¹⁴ A comparison between performance of these twenty four participants and a random sample of twenty four participants from those for whom all data was recorded yielded no significant differences ($t(46) = -1.03, p > .05$).

Digit recall task.

Digit recall was scored by allocating a point to every item which was reproduced accurately throughout the task: the correct digit in the correct position in the sequence. A maximum score of 175 was therefore possible.

Items were given a point if correct regardless of the accuracy of the rest of the items in a sequence. If provided with the presentation digit string '9,3,5,2' and participants reproduced "9, something, 5, 3" then two points would be awarded (for '9' and '5'), as correct items in the wrong position did not receive a point, and the use of 'something' was a valid indicator that the participant had remembered the positioning of the third item despite not recalling the identity of the item preceding it. If, in the above example, '9,5,2' had been the recall response, only one point would have been awarded (for '9') as the absolute correct position of '5' and '2' in the sequence had not been accurately maintained.

Simultaneous and Sequential visuo-spatial information.

Participants' scores were calculated, and transformed to percentages of the total number of items they had seen. This measure was necessary due to very infrequent instances in which the video recordings cut off the last response of the participant, in which participant's responses were obscured by the position of their hand, or in which - due to an error in programming - participants were not shown an item in the list.

Simultaneous/pattern recall task.

Participants were allocated a point for every item that they reproduced correctly throughout the test; there were no deductions for inaccurate responses. As order was not a requirement, 'correct' locations indicated subsequent to 'incorrect' locations were not affected by previous mistakes.

Participants' responses were only considered up to the number of items in a given trial - for example, if, in a condition containing 7 items, participants responded with eight items, the eighth item produced was not included in scoring.

Sequential/sequence recall task.

Participants were allocated a point for every correct item that they reproduced in the correct position in the sequence. As with all the above tasks, correct items reproduced following incorrect items were still marked as correct and there were no deductions for inaccurate responses - that is, there was no negative marking.

If a participant had been presented with a sequence corresponding to the buttons '3,5,14,6,25,21' and a sequence corresponding to buttons '3,5,13,8,25,21' was reproduced then four points would be scored for this trial (for items '3,5,25 and 21'). If participants reproduced '3,5,6,25,21' then only two points would be scored for this trial (for items '3' and '5') as the true position of items '6,25 and 21' was not indicated. If participants had indicated that an item of an unknown location should be inserted into the sequence and then correctly recalled the remaining items, these items would be scored as correct. For example, if when presented with items '17,15,6,24' a participant responded by pressing buttons '17 and 15' , stating "then a button that I cannot remember, then..." and subsequently pressing button '24', then the participant would score three points.

Results.

Descriptive statistics of all performance measures used are provided in summary in Table 37. A number of variables produced significantly negatively skewed data, with high performance levels observed on digit recall, sentence recall, sentence processing, letter rotation processing, visuo-spatial sequential and simultaneous recall (distribution tests available in appendix). No transformations of the data altered this finding.

<i>Measure</i>	<i>Observed score range</i>			
	<i>M</i>	<i>SE</i>	<i>Minimum</i>	<i>Maximum</i>
Sentence memory (total)	58.41	0.88	31.00	70.00
Sentence processing (% correct)	86.89	1.06	45.71	100.00
Sentence reaction time (mean of correct in milliseconds)	1729.62	27.16	1141.46	2240.35
Letter rotation memory (total)	34.52	1.20	9.00	64.00
Letter rotation processing (% correct)	72.95	1.17	41.18	92.86
Letter rotation reaction time (mean of correct in milliseconds)	1609.25	28.75	751.19	2285.95
Digit recall (total)	153.19	1.83	98.00	175.00
Simultaneous recall (% correct)	91.80	0.51	74.40	91.80
Sequential recall (% correct)	71.71	1.06	46.67	71.71

Table 37: Summary of Descriptive Statistics for all Measures
n=100

Correlation Data.

The regression analysis performed on the collected data “makes no assumption about the distribution of the independent or dependent variables” (Cohen, Cohen, West & Aiken, 2003, p110), rather, normality of residuals in the regression model must be established. The correlation data recounted below is therefore of parametric analysis - that is, the information which was the subject of the subsequent regression analyses. A supplementary nonparametric correlation analysis is available in the appendix.

Of note regarding the way in which participants performed the assigned tasks are the positive correlations between processing and storage measures within both the verbal and the visual working memory capacity tasks ($r_{(98)}=.59$ and $r_{(98)}=.26$ respectively, see Table 38). Such correlations indicate that participants were not focusing on one aspect of the task at the expense of the other.

	1	2	3	4	5	6	7	8	9
1. Sentence memory (total)	-	.59**	-.40**	.31**	.24**	.09	.65**	.22*	.22*
2. Sentence processing (% correct)		-	-.65**	.11	.40**	-.19*	.44**	.26**	.21*
3. Sentence reaction time (mean of correct)			-	-.05	-.27**	.36**	-.29**	-.21	.01
4. Letter rotation memory (total)				-	.26**	.26**	.19*	.34**	.51**
5. Letter rotation processing (% correct)					-	-.09	.19*	.56**	.50**
6. Letter rotation reaction time (mean of correct)						-	.16	.00	.10
7. Digit recall (total)							-	.22*	.33**
8. Simultaneous recall (% correct)								-	.63**
9. Sequential recall (% correct)									-

Table 38: Zero-order Pearson's Correlation

$n = 100.$

* $p < .05$ ** $p < .01$

Simultaneous and sequential recall correlated highly, $r_{(98)}=.63$, $p < .01$, and this correlation remained high and significant at each first order partial correlation when controlling for variance shared with any other variable (see Table 39). The largest change in simultaneous and sequential recall association was observed when letter rotation processing was held as a control variable in the partial correlation, $r_{(97)}=.48$, $p < .01$.

Control variable	<i>R between Simultaneous and Sequential</i>
Sentence memory	.61
Sentence processing	.61
Sentence reaction time	.63
Letter rotation memory	.56
Letter rotation processing	.48
Letter rotation reaction time	.63
Digit recall	.60

Table 39: Partial correlation statistics for simultaneous and sequential recall.

All correlations significant at $p < .001$

The correlation of Simultaneous recall with letter rotation processing, $r_{(98)}=.56$, $p < .01$, remained significant when the variance common to sequential recall was controlled for, $r_{(97)}=.36$, $p < .01$. Sequential recall correlated with letter rotation processing, $r_{(98)}=.50$, $p < .01$, and this too remained significant when variance shared with simultaneous recall was controlled for, $r_{(97)}=.23$, $p = .02$. Both simultaneous recall and sequential recall correlations with letter rotation processing remained significant when variance shared with sentence processing was controlled for ($r_{(97)}=.51$, $p < .01$ and $r_{(97)}=.46$, $p < .01$ respectively).

Simultaneous recall also correlated moderately highly with letter rotation memory, $r_{(98)}=.36$, $p < .01$, however, the correlation between these two measures was no longer significant when the variance associated with sequential recall was controlled for, $r_{(97)}=.02$, $p > .05$. Sequential recall correlated with letter rotation memory, $r_{(98)}=.51$, $p < .01$, and this remained a high and significant correlation when the common variance with simultaneous recall was partialled out, $r_{(97)}=.41$, $p < .01$.

Neither simultaneous nor sequential recall correlated at the zero-order level with Letter rotation reaction time.

The correlation between simultaneous recall and digit recall, though significant, was small, $r_{(98)}=.22$, $p = .03$, and when shared variance with other forms of serial memory was partialled out (sequential recall, letter rotation recall and sentence memory) this correlation became non-significant ($r_{(97)}=.01$, $p > .05$, $r_{(97)} = .17$, $p > .05$ and $r_{(97)}=.11$, $p > .05$ respectively). The correlations between simultaneous recall and both sequential recall and letter rotation recall, $r_{(98)}=.63$, $p < .01$ and $r_{(98)}=.34$, $p = .001$, however, remained significant when variance shared with digit span was partialled out: $r_{(97)}=.60$, $p < .01$ and $r_{(97)}=.31$, $p < .01$ respectively. Simultaneous recall and sentence memory recall, $r_{(98)}=.22$, $p = .03$, did not remain significantly correlated when variance associated with digit span was controlled for, $r_{(97)}=.10$, $p > .05$.

Sequential recall correlated with digit recall, $r_{(98)}=.33$, $p < .01$, however, when shared variance with other forms of serial memory was partialled out this correlation became non-significant : when variance associated with letter rotation recall was controlled for, $r_{(97)}=.28$, $p > .01$, and when variance associated with sentence memory was controlled for, $r_{(97)}=.26$, $p > .01$. The correlation between sequential and letter rotation recall, $r_{(98)}=.51$, $p < .01$, remained significant when common variance with digit span was controlled for, $r_{(97)}=.48$, $p < .01$. The correlation between sequential recall and sentence memory, $r_{(98)}=.22$, $p = .03$, however, was no longer significant when variance shared with digit span was partialled out, $r_{(97)}=.00$, $p > .05$.

Regression analysis.

Forward stepwise ordinary least squares, multiple regression analysis was employed in order to assess the variance in Simultaneous and Sequential recall accounted for by each variable measured.

Simultaneous recall performance.

The final model produced by regression found only two significant predictors, sequential recall performance, $t(97) = 5.44$, $p < .001$ and letter rotation processing performance, $t(97) = 3.83$, $p < .001$, which together accounted for 46% of the variation in simultaneous recall performance, $F(2,97) = 43.18$, $p < .001$. The greatest amount of predicted variance was accounted for by sequential recall performance (39%), while letter rotation was found to account for 8% of the variance in simultaneous recall

performance. The standardised regression coefficients establish that sequential recall performance is the strongest predictor of simultaneous performance (see Table 40). Sequential recall performance produced a final model regression coefficient of 0.22 (95% CI = 0.14 – 0.30) and letter rotation processing produced a final model regression coefficient of 0.14 (95% CI = 0.07-0.21); negative values were not encompassed in the confidence intervals of these predictors therefore it can be concluded that the population regression coefficients for performance on both tasks are positive.

Despite high zero-order correlation between simultaneous recall performance and letter rotation memory performance, as indicated by partial correlations letter rotation memory performance does not contribute significantly to simultaneous performance when contribution of letter rotation processing has already been taken into account.

	<i>Summary Statistics</i>			
	<i>B</i>	<i>SE B</i>	<i>β</i>	<i>p</i>
Step 1				
Constant	70.53	2.71		
Sequential recall (% correct)	0.30	0.04	.63	.001
Step 2				
Constant	65.78	2.83		
Sequential recall (% correct)	0.22	0.04	.46	.001
Letter rotation processing (% correct)	0.14	0.04	.33	.001

Table 40: Multiple Regression model for Simultaneous Recall Performance (% correct)

Note: $R^2 = .39$ for step 1: $\Delta R^2 = .08$ for Step2 ($p < .001$).

Simultaneous recall model assumptions.

The final model was assessed for outliers, influential cases, normality of distribution of residuals, homoscedasticity, multicollinearity, and assumption of independent errors.

Five cases were found to have standardised residuals beyond values of ± 2 which identifies these cases as the ones differing most from the main tendency of the data, indicating error in prediction from the model for these specific cases. Two cases were found to have a centred leverage value three times that of the average (value at which to investigate a case, Stevens, 1992 as cited in Field, 2005) indicating that the observed values for these cases were further than average from the mean of the

independent variables. These cases were therefore inspected for their influence on the model in general. No case was found to have a Cook's distance value greater than one, indicating no undue influence over the model, and no DFBETA statistics above a value of one indicated no undue influence over 'specific regression coefficients within the equation'. Summary statistics and values for cases described above are available in the appendix.

Following assessment of influential cases (established not to have undue influence over the model due to low Cook's distance values) further consideration was given to distribution of standardised residuals. As five cases with standardised residuals values ± 2 were identified, 95% of cases therefore had standardised residuals within these values, as would be expected for a conventionally accurate model. Two cases (2% of the participants) were found with standardised residual values ± 3 ; in an accurate model 99% of cases would be expected to fall within these limits, therefore it can be concluded that the number of cases found outside the expected limits was within 1% of the expected values. It was further established that the assumption of normally distributed residuals was met by inspection of graphic representation of the data (see appendix for normal distribution curve) and analysis by way of a Kolmogorov-Smirnov test on residuals showed distribution was not significantly different from normal, $D(100) = 0.08, p > .05$.

Graphic representation of standardised predicted values against standardised residuals indicated the assumptions of homoscedasticity and linearity were met. This also held for standardised residuals plotted against each individual predictor.

The assumption of no multicollinearity was met. The Variance Inflation Factor (VIF) of each variable was below cut-off value of 10, and corresponding Tolerance values were above cut-off value of .10 (Cohen et al., 2003). The variance proportions for each predictor in the final model was distributed across different dimensions (94% of sequential recall performance loading on one dimension, 92% of letter rotation processing loading on a different dimension). There was therefore no evidence for collinearity in the data.

The assumption of independent errors was assessed, producing a Durbin-Watson statistic of 1.426. While 'rule of thumb' boundaries of meeting assumption state values of 1 and 3 (Field, 2005), the acceptable values stated by Durbin and Watson (1951) show that for a model with two predictors and 100 observations, lower limit and upper limit values 1.63 and 1.72 should be adopted. By this measure, the statistic produced by the model is lower than the lower limit value and would indicate positive

autocorrelation at lag 1 in the data. While this would indicate a violation of assumption of independent errors, there is little in the sampling method or measures of the study that would indicate reasons to predict autocorrelation of errors.

Sequential recall performance.

The final model produced by regression found five significant predictors, simultaneous recall performance, $t(94) = 4.49$, $p < .001$, letter rotation memory performance, $t(94) = 4.10$, $p < .001$, digit recall, $t(94) = 2.82$, $p < .01$, letter rotation processing performance, $t(94) = 2.61$, $p = 0.01$, and sentence reaction time, $t(94) = 2.52$, $p = 0.01$, which together accounted for 55% of the variation in sequential recall performance, $F(5,94) = 24.86$, $p < .001$. The greatest amount of predicted variance was accounted for by simultaneous recall performance (39%), while letter rotation memory performance was found to account for 10% of the variance in sequential recall performance. Digit recall, letter rotation processing and sentence reaction time were found to account for, respectively, 3%, 2% and 3% of the variation in sequential performance. The standardised regression coefficients establish that simultaneous recall performance is the strongest predictor of sequential recall performance (see Table 41). Simultaneous recall performance produced a final model regression coefficient of 0.80 (95% CI = 0.45 – 1.15) and letter rotation memory performance produced a final model regression coefficient of 0.27 (95% CI = 0.14 – 0.39), while digit recall produced a coefficient of 0.12 (95% CI = 0.04 – 0.20), letter rotation processing produced a coefficient of 0.20 (95% CI = 0.05 – 0.35) and sentence reaction time produced a coefficient of 0.01 (95% CI = 0.00 – 0.01). Negative values were not encompassed in the confidence intervals of these predictors therefore it can be concluded that the population regression coefficients for performance on both tasks are positive. The confidence intervals of sentence reaction time are, however, lying on zero and therefore do not indicate a robust positive relationship.

<i>Summary Statistics</i>				
	B	SE	β	p
Step 1				
Constant	-49.23	15.27		
Simultaneous recall (% correct)	1.32	0.17	.63	.001
Step 2				
Constant	-37.60	14.24		
Simultaneous recall (% correct)	1.08	0.16	.51	.001
Letter rotation memory (total)	0.30	0.07	.34	.001
Step 3				
Constant	-46.24	14.43		
Simultaneous recall (% correct)	1.02	0.16	.48	.001
Letter rotation memory (total)	0.28	0.07	.32	.001
Digit recall (total)	0.10	0.04	.17	.024
Step 4				
Constant	-39.09	14.63		
Simultaneous recall (% correct)	0.83	0.18	.39	.001
Letter rotation memory (total)	0.27	0.07	.31	.001
Digit recall (total)	0.09	0.04	.16	.031
Letter rotation processing (%correct)	0.16	0.08	.17	.045
Step 5				
Constant	-56.30	15.78		
Simultaneous recall (% correct)	0.80	0.18	.38	.001
Letter rotation memory (total)	0.27	0.07	.30	.001
Digit recall (total)	0.12	0.04	.21	.006
Letter rotation processing (%correct)	0.20	0.08	.22	.010
Sentence reaction time (mean)	0.01	0.00	.18	.013

Table 41: Multiple Regression model for Sequential Recall Performance (% correct):
Note: $R^2 = .39$ for step 1: $\Delta R^2 = .10$ for Step2 ($p < .001$): $\Delta R^2 = .03$ for Step 3 ($p < .05$): $\Delta R^2 = .02$ for Step 4 ($p = .05$): $\Delta R^2 = .03$ for Step 5 ($p < .05$).

On the basis of the above coefficient and confidence interval findings, the role of sentence reaction time in the final model could be considered questionable. A nested

models comparison of the following equation was therefore carried out to assess the inclusion of this measure in the final regression model:

$$F = ([SS1-SS2]/p) / (SS2/[n-(k+p+1)])$$

$$\text{Degrees of freedom: } v1, v2 : v1 = p \quad v2 = n - (k+p+1)$$

Where k = number of predictors in model 1, p = number of additional predictors in model 2, n = number of participants.

The final model was found to be a significant improvement in explaining the variation in sequential recall performance (significant reduction in error) as compared to model 4, $F(1,94) = 6.37, p = .01$. Examination of variance proportions for each predictor in this model, however, indicated that the final model was not clearly distributed across different dimensions. Simultaneous recall loaded on dimension six (89%) and letter rotation memory loaded on dimension two quite cleanly. Digit recall performance loaded on dimensions four and five (42% and 53% respectively), letter rotation processing loaded unequally on dimensions three, four, five and six (17%, 42%, 28% and 13%) and sentence reaction time loaded on dimensions three (38%) and five (48%), indicating a problem of collinearity in the final model. Zero-order correlation for sequential recall performance and sentence reaction times indicated a poor, non-significant relationship. It therefore seems practical, on the basis of these above findings, to reject sentence reaction time as a predictor in a model of sequential recall performance in order to improve the reliability of the chosen model.

Model 4 of the forward stepwise regression sequence is a satisfactory model of sequential recall performance. In this chosen model (see Table 41) remain four significant predictors: simultaneous recall performance, $t(95) = 4.53, p < .001$, letter rotation memory performance, $t(95) = 4.10, p < .001$, digit recall, $t(95) = 2.19, p = .03$ and letter rotation processing performance, $t(95) = 2.02, p = .05$, which together account for 52% of the variation in sequential recall performance, $F(4,95) = 27.90, p < .001$. The greatest amount of predicted variance was accounted for by simultaneous recall performance (39%), while letter rotation memory performance was found to account for 10% of the variance in sequential recall performance. Digit recall was found to account for 3% of the variance and letter rotation processing 2%. Simultaneous recall performance produced a final model regression coefficient of 0.83 (95% CI = 0.47 - 1.19) and letter rotation memory performance produced a final model regression coefficient of 0.27 (95% CI = 0.14 - 0.40), while digit recall produced a

coefficient of .10 (95% CI = 0.08 – 0.18), letter rotation processing produced a coefficient of 0.15 (95% CI = 0.03 – 0.31). Negative values were not encompassed in the confidence intervals of these predictors therefore it can be concluded that the population regression coefficients for performance on tasks are positive. While these confidence intervals of digit span and letter rotation processing performance are wide and lie very close to zero, these predictors indicate cleaner variance proportion loadings and this model satisfies assumptions required for regression.

Sequential recall model assumptions.

The final model was assessed for outliers, influential cases, normality of distribution of residuals, homoscedasticity, multicollinearity, and assumption of independent errors.

Four cases were found to have standardised residuals beyond values of ± 2 which identifies these cases as the ones differing most from the main tendency of the data, indicating error in prediction from the model for these specific cases. Three cases were found to have a centred leverage value three times that of the average (value at which to investigate a case, Stevens 1992 as cited in Field, 2005) indicating that the observed values for these cases were further than average from the mean of the independent variables. These cases were therefore inspected for their influence on the model in general. No case was found to have a Cook's distance value greater than one, indicating no undue influence over the model, and no DFBETA statistics above a value of one indicated no undue influence over 'specific regression coefficients within the equation'. Summary statistics and values for cases described above are available in the appendix.

Following assessment of influential cases (established not to have undue influence over the model due to low Cook's distance values) further consideration was given to distribution of standardised residuals. As for cases with standardised residuals values ± 2 were identified, 96% of cases therefore had standardised residuals within these values, as would be expected for a conventionally accurate model. One case (1% of the participants) was found with a standardised residual value ± 3 ; in an accurate model 99% of cases would be expected to fall within these limits. It was further established that the assumption of normally distributed residuals was met by inspection of graphic representation of the data (see appendix for normal distribution

curve) and analysis by way of a Kolmogorov-Smirnov test on residuals showed distribution was not significantly different from normal, $D(100) = 0.07, p > .05$.

Graphic representation of standardised predicted values against standardised residuals indicated the assumptions of homoscedasticity and linearity were met. This also held for standardised residuals plotted against each individual predictor.

The assumption of no multicollinearity was met. The Variance Inflation Factor (VIF) of each variable was below cut-off value of 10, and corresponding Tolerance values were above cut-off value of .10 (Cohen et al., 2003). The variance proportions for each predictor in the final model was distributed across different dimensions (96% of simultaneous recall performance loading on dimension five, 94% of letter rotation memory loading on dimension two, 81% of digit recall loading on dimension four and 70% letter rotation processing loading on dimension three). There was therefore no evidence for collinearity in the data.

The assumption of independent errors was assessed, producing a Durbin-Watson statistic of 2.04. While 'rule of thumb' boundaries of meeting assumption state values of 1 and 3 (Field, 2005), the acceptable values stated by Durbin and Watson (1951) show that for a model with four predictors and 100 observations, lower limit and upper limit values 1.59 and 1.76 should be adopted. By this measure, the statistic produced by the model is higher than the higher limit value and would indicate negative autocorrelation at lag 1 in the data. While this would indicate a violation of assumption of independent errors, there is little in the sampling method or measures of the study that would indicate reasons to predict autocorrelation of errors.

Rank transformation regression.

While distribution of residuals in both regression analyses is clearly normal (and Kolmogorov-Smirnov tests support this), interpretation of homoscedasticity by graphic representation of standardised predicted values against standardised residuals (and standardised residuals plotted against each individual predictor) is more subjective. In order to strengthen the claims of the models, rank transformation of data can be employed (for example, Cohen et al., 2003; Conover, 1999, though see Headrick & Rotou, 2001, for arguments of inflated Type 1 errors and power loss). Using this method, ranks were subject to the same least squares stepwise regression analyses as the untransformed data, as detailed above.

Stepwise regression with rank transformed simultaneous recall as dependent variable produced a model with two significant predictors, $R^2 = .47$, $F(2, 97) = 43.31$, $p < .01$. Rank transformed sequential recall, $\beta = .52$, $t(97) = 6.19$, $p < .01$, and rank transformed letter rotation processing, $\beta = .26$, $t(97) = 3.10$, $p < .01$, were both significant predictors. Backward regression employed to corroborate findings from forward stepwise methods produced an equivalent finding.

Stepwise regression with rank transformed sequential recall as dependent variable produced only two final model predictors, $R^2 = .51$, $F(2, 97) = 49.45$, $p < .01$. The predictors in this final model were rank transformed simultaneous recall, $\beta = .55$, $t(97) = 7.20$, $p < .01$, and rank transformed letter rotation memory, $\beta = .31$, $t(97) = 4.09$, $p < .01$. Backward regression, however, produced a final model with five predictors, $R^2 = .55$, $F_{(5, 94)} = 23.37$, $p < 0.01$. The predictors in this final model are rank transformed digit recall, $\beta = .15$, $t(94) = 2.04$, $p = .04$, letter rotation memory, $\beta = .27$, $t(94) = 3.70$, $p < .01$, letter rotation processing, $\beta = .19$, $t(94) = 2.24$, $p < .03$, and simultaneous recall, $\beta = .45$, $t(94) = 5.37$, $p < .01$. Sentence memory reaction time was also included as a predictor in this final model, however, the contribution of this variable does not reach significance, $\beta = .14$, $t(94) = 1.89$, $p > .05$.

Discussion.

Simple and partial correlations and subsequent regression analyses all indicated a substantial relationship between performance in the simultaneous and sequential conditions of the simple recall tasks. This was supported by rank transformed regression analysis of the same data. As shown in partial correlations, a relationship between simultaneous task and sequence recall is still evident when controlling for any other measure; when variance shared with letter rotation processing is controlled there is a more noticeable change, however, the correlation is still considerable.

A substantial portion of simultaneous performance (46%) was explained by performance in only two tasks - sequence recall and letter rotation processing. While a relationship with letter rotation recall was also indicated in simple correlations, as indicated in partial correlations this was not more explanatory than variance shared with sequence recall; sequence recall, however, retained a relationship with simultaneous recall beyond variance shared with letter rotation recall. Sequence recall provided a more complex final model than did simultaneous recall, however, a

considerable portion of variance was explained (52%). Regression analyses revealed letter rotation memory recall as the second most important predictor of performance, following simultaneous recall. This corroborated an indication of such a relationship in simple and partial correlations, which showed letter rotation memory and sequence recall were still correlated when variance shared with simultaneous performance was controlled. Letter rotation processing contribution to explaining sequence variance was, while present, less prominent than in the simultaneous regression analyses; digit recall accounted for a similar proportion of the variance in the final sequential regression model as did letter rotation processing.

Of note, in neither of the primary regression analyses did sentence processing measures hold predictive value. This followed indications from partial correlations where sentence processing measures did not correlate with simultaneous or sequence recall once variance shared with the visuo-spatial processing measure was removed; in contrast, a relationship of visuo-spatial processing with both simultaneous and sequence recall measures remained when the verbal domain processing performance was controlled. Moreover, sentence recall did not emerge as a predictor in either of the final regression models. This followed indications in partial correlations that a relationship of sentence recall with either simultaneous or sequential performance did not remain significant when controlling for the visuo-spatial complex span recall (while the letter rotation recall correlations with the primary tasks did remain significant when controlling for sentence recall). Digit recall proved similarly non-predictive for simultaneous recall.

The use of measured processing responses is in its infancy; processing components - by very definition of their use in complex span tasks - are considered to require executive resources, however, processing performance measures have yet to be fully investigated. Thus far development has centred on distinguishing executive resources as distinct from those required to perform the storage aspect of a complex span task - through evaluation of concurrent processing and storage performances (e.g. Duff & Logie, 1999; 2001; Waters & Caplan, 1996; Logie & Duff, 2007), predictive value of processing for complex storage measures (Bayliss et al., 2003; 2005) and unique predictive value for higher order cognition (Unsworth et al., 2009). In the current experiment the letter rotation aspect of the task implies imagery, manipulation (execution of rotation) and decision making processes could all be tapped by the performance measure which contributed to prediction of simultaneous recall and, to a lesser extent, sequence recall. In contrast, sentence processing - requiring judgement

of legitimacy of a written statement - did not demonstrate predictive value. It could be argued that the letter rotation processing measure exhibits domain specific executive resource use; however, a more cautious suggestion would be that possibly domain general executive processes are, when employed in hosting, manipulating and evaluating visuo-spatial material, predictive of visuo-spatial simple recall measures.

Letter rotation complex span recall appears to represent an aspect of recall performance which is shared with sequence recall beyond that which sequence recall shares with simultaneous recall, while this is not true for letter rotation recall and simultaneous recall. The storage component of WMC tasks has variously been interpreted as representative of controlled attention ability (Engle, Kane et al., 1999), short term storage or slave system performance (e.g. Duff & Logie, 1999; 2001; Logie & Duff, 2007) and retrieval from LTM - in addition to, or in place of, active maintenance (e.g. Healy & Miyake, 2009 see also e.g. Unsworth, Brewer et al., 2009). The use of a total score measure (after e.g. Oberauer & Süß, 2000; Friedman & Miyake, 2005; Conway et al., 2005; Unsworth & Engle, 2007a), as utilised in simple and complex tasks of the current experiment, entails representation of supra-span retrieval and could be expected to make more equivalent, between simple and complex recall, any contribution of executive resources in the form of retrieval from memory beyond representations actively maintained. It is possible that specific aspects of serial encoding and recall, or supra-span executive resource involvement underlie the unique shared variance between sequence and letter rotation recall.

Due to stepwise methods employed, it remained possible that sentence recall may possess explanatory variance which was of a lesser magnitude to rotation recall – specifically, letter rotation recall may have accounted for the variance that sentence recall had potential to also explain. While this was not suggested in simple or partial correlations, it remained a possibility thus a supplementary hierarchical forced entry regression carried out to test this idea; when entered in place of letter rotation recall (i.e. subsequent to entry of simultaneous recall) the sentence memory measure did not contribute significantly to explanation of sequence recall. It must be noted, however, that sentence recall materials on any given trial were derived from a much larger pool of stimuli than those used in any of the other serial recall tasks; it is possible that a sentence memory recall measure with a closed pool of stimuli could produce variance predictive of sequence recall.

The magnitude of variance accounted for by digit recall in the final sequence regression model was also determined subsequent to letter rotation recall. A further

supplementary hierarchical forced entry regression was therefore conducted: when digit recall was entered as a predictor after simultaneous performance (which accounts for 39%) digit span accounts for a further 4% of the variance in sequence recall (as compared to the 3% contributed in the final model detailed in results section). After this, entry of letter rotation memory performance still accounted for a further 9% of the variance. Interpretation of these demonstrations of unique predictive value for sequence performance variance is unclear: it is possible that variance shared with digit recall represents processes specific to performance in a simple storage task while variance shared with letter rotation memory represents domain specific serial memory. It could possibly be argued that sequence recall and letter rotation recall share variance independently from a verbal simple task due to unspecified shared executive resources in sequence and complex span recall, however, digit recall was also reported as a total score and thus would also demonstrate executively demanding retrieval processes.

Finally, it should be noted that though there is little indication of a single, domain-general mechanism underlying retention of order in performance of visuo-spatial sequential recall -as evidenced by poor predictive value of digit span in the regression analysis and lack of predictive contribution of sentence recall measures - in light of issues discussed above and due to the nature of correlation studies, the present results do not necessarily argue for domain specific order mechanisms. For example, the present results could not distinguish between alternative proposals of separate order systems for each of the domains (see e.g. Saito et al., 2008), domain specific systems that work in similar ways (see e.g. Smyth, Hay, Hitch & Horton, 2005), or a single system which retains order – such as general timing mechanism which retains pointers to representations of specific stimuli (for discussion on these possibilities with regards to visuo-spatial recall see e.g. Avons, 1998; Avons & Mason, 1999; Avons, Ward & Melling, 2004; Depoorter & Vandierendonck, 2009; Jones et al., 1995).

General Discussion: Experiments 5-8

The clearest indication from the results of the exploratory analysis of Experiment 8 is that simultaneous and sequence recall are best predicted by each other, and then by different measures. While simultaneous performance shares

variance with letter rotation processing independent of that shared with sequence recall, sequence recall shares little independent variance with letter processing beyond that also shared with simultaneous performance. Sequence and simultaneous performance remain highly correlated when letter rotation processing is controlled. Sequence recall is next best predicted, after simultaneous recall, by another visuo-spatial serial recall task, and subsequently by a simple verbal serial recall task and visuo-spatial processing. Variance common to the serial recall tasks may reflect executive retrieval processes or may reflect operation of one or more rehearsal mechanisms. It must be noted however, that indicated relationships between variables cannot be localised as referring specifically to encoding, maintenance or recall processes - or processes used in all three actions - in simultaneous or sequence recall task performance.

The correlation obtained between simultaneous and sequence recall in Experiment 8 is within the range demonstrated throughout the literature for VPT and CBT correlations - for example, when measured at span level, Della Sala et al. (1999) showed only small to moderate correlations (.27 and .35 with two alternate versions of VPT) in a group comprising a wide age range (16-65 year olds). Miyake et al. (2001), using a total score measure, showed a correlation of .48 between CBT and dot matrix in a group of students, and Smyth and Scholey (1996), in computerised versions of VPT and CBT tasks administered to 19-36 year olds, found spans produced a .71 correlation (note, it is not clear whether items remained selected once pressed at recall). A subsequent regression analysis (Smyth & Scholey, 1996) revealed combined results of recognition and recall versions of VPT accounted for 55% of CBT performance variance. It should be noted that in each of these above studies (as opposed to studies with children e.g. Logie & Pearson, 1997, though see Mammarella et al., 2008), a relationship between performance on the two tasks exists (see also Krikorian et al., 1996; Thompson et al., 2006; Lecerf et al., 2004). As has previously been argued in discussion of developmental fractionation (see e.g. Logie & Pearson, 1997; Pickering et al., 2001; Rudkin et al., 2007), it is possible VPT and CBT tasks differentially exhibit performance increase with age; experience and strategy development in childhood are found to effect sequence recall (e.g. Imbo et al., in press). Differences may also be apparent between the two tasks in performance decrease as a result of increasing age beyond young adulthood (see e.g. Phillips & Hamilton, 2001; Logie & Maylor, 2009). Moreover, array properties (after e.g. Kemps, 1999, see also current Experiment 7) can affect sequence performance and method of scoring recall performance has also been

shown to affect correlations (see e.g. Oberauer & Süß, 2000; Friedman & Miyake, 2005; Conway et al., 2005; Unsworth & Engle, 2007a). Experiment 8 employed the same apparatus and visual array between tasks, a tight age group and total score methodology – it is therefore not directly comparable to any of the above studies; the current results consequently may also only pertain to a specific population and task administration procedure. Nevertheless, the indication from current results is that pattern and sequence recall performance, in a young adult population, share variance; this not contradicted by previous studies.

Importantly, Experiment 8 reveals simultaneous and sequence recall are correlated when controlling for any other measure tested. This shared variance was found for simultaneous and sequence tasks which – as suggested in Experiments 5-7 – are performed in a manner akin to visual pattern and Corsi blocks tasks respectively. Such a relationship seems hard to reconcile with the structure of visuo-spatial working memory as proposed by Pearson (2001), Quinn (2008) or Baddeley (2007) which, as discussed at length in the previous chapter, posit separate subsystems support performance in a visual storage task and a spatio-temporal task requiring memory for a sequence of locations. These models do not explicitly propose processes or resources common to a visual store (Pearson, 2001; Quinn, 2008) and a spatial rehearsal system (Pearson, 2001; Quinn, 2008) outside of conscious visual imagery or common executive contributions. This is also true of the model of Baddeley (2007) in which a visual store plus rehearsal subsystem (Baddeley, 2007) is said to support visual matrix performance and a separate spatial store plus rehearsal mechanism is considered to support Corsi block like tasks. Baddeley's episodic buffer may allow for cross subsystem predictive ability, however, if cross subsystem predictive ability exists from a buffer which employs multi-code representations this would entail currently unanswerable questions of why simultaneous and sequential recall are best predicted by each other rather than, for example, digit recall as a prominent predictor of sequence recall. In contrast, the model of Logie (1995; 2003; Logie & van der Meulen, 2009) suggests that both a visual store and a spatial rehearsal mechanism are employed in tasks requiring encoding, maintenance and recall of either pattern or sequence recall; these interact to support performance on a task, however, they would differ in their relative contributions to performance at the sequence lengths employed in the current experiment (e.g. at or above span). Shared and independent variance in simultaneous and sequence recall could therefore be accommodated within this model.

The independent variance demonstrated in each task in Experiment 8 would not necessarily contradict any of the proposed divisions of VSWM (Logie, 1995; Pearson, 2001; Quinn, 2008; Baddeley, 2007). As noted above, sequence recall appears to be subject to determinants of performance common to other serial recall tasks; as also noted, the current study cannot distinguish between proposed means by which serial order is maintained with respect to domain specific material (see e.g. Avons, 1998; Avons & Mason, 1999; Avons et al., 2004; Depoorter & Vandierendonck, 2009; Jones et al., 1995, Smyth et al., 2005; Saito et al., 2008). Therefore, while each suggested VSWM structure (Logie, 1995; Pearson, 2001; Quinn, 2008; Baddeley, 2007) was formed within the multiple component tradition (after Baddeley & Hitch, 1974; Baddeley, 1986) and would imply division between resources on the basis of verbal or visuo-spatial material, the current finding that digit recall variance predicts sequence recall is ambiguous. Similarly, the predictive value for sequence recall from letter rotation recall is also somewhat unclear – in addition to a possible amodal timing mechanism, visuo-spatial complex span recall could possibly represent a contribution of controlled attention ability (Engle, Kane et al., 1999), visuo-spatial slave system rehearsal of a series of locations (after e.g. Duff & Logie, 1999; 2001; Logie & Duff, 2007) and retrieval from LTM - in addition to, or in place of, active maintenance (e.g. Healy & Miyake, 2009 see also e.g. Unsworth, Brewer et al., 2009). Baddeley has also stated complex span recall as dependent on the episodic buffer (2007). While these factors cannot be disambiguated in the current study, the difference in predictive value of serial recall tasks for sequence recall compared to simultaneous recall indicates different processes contribute to encoding, maintenance and recall of the same information when presented as simultaneous array or a sequence to be remembered.

Use of executive resources in encoding and recalling visuo-spatial sequences at long list lengths, as demonstrated through interference methodology (e.g. Rudkin et al., 2007; Rossi-Arnaud et al., 2006; Vandierendonck et al., 2004), is also suggested in the results of Experiment 8 ; in addition to the possibility of executive resources in the form of controlled attention or LTM retrieval in serial recall measures, executive resource use was also suggested through correlation with the visuo-spatial processing measure which also, in the regression analysis, contributed beyond any variance shared with simultaneous recall. As is also true for indication of executive resource involvement in simultaneous performance – as demonstrated through predictive value of letter rotation processing – these results are not contradictory to any of the proposed structures of VSWM considered; correlations could reflect executive resource

involvement in encoding, maintenance or recall of the task. For example, the models of Logie (1995) and Baddeley (2007) suggest executive involvement in strategy formation and, additionally, Pearson (2001) suggests executive involvement in support of maintenance; the involvement of executive resources in visual maintenance as conceptualised by Quinn (2008) is not clear, though executive resource use in sequence recall is claimed. The indication of executive resource use in performance of the simultaneous task is, however, somewhat in contrast to a previous demonstration of absence of interference effects when an RNG or RIR task was employed throughout presentation and recall stages of a simultaneous span task (Rudkin et al., 2007; Experiments 2 & 3). Executive resource use in pattern memory performance has been shown before through different interference tasks (verbal fluency; Hamilton et al., 2003) or with use of different array structures (VPT rather than uniform matrix, Rudkin et al., 2007 Experiment 1) and was attributed to interference with strategy formation (see also Phillips & Hamilton, 2001). The present results suggest that further investigation of executive resource use in simultaneous recall performance is warranted; it may be the case that, though a second predictor in the regression, executive resource use as measured through the letter processing task may not determine whether participants can reach a consistent span level of performance. Experiment 8 employed a total score measure which represented supra-span recall ability – it is possible that the executive resource use indicated was employed as a strategy at encoding or recall to deal with arrays beyond capacity limits.

Chapter Six

General discussion, limitations and future directions

The development and use of a novel visual detection paradigm has both benefits and limitations. In the present experiments (Experiments 3-4) it proved a successful way in which to disrupt visuo-spatial retention which had otherwise proven largely resistant to interference (Experiments 1-2c of the current thesis; also e.g. Andrade et al., 2002; Avons & Sestieri, 2005; Baddeley & Andrade, 2000; Dean et al., 2008; Dent, 2010; van der Meulen et al., 2009). The current results indicate that engaging with visual stimuli beyond passive viewing - that is, following a requirement to actively encode visual information - can disrupt storage of visually presented stimuli in working memory. Previous research demonstrating interference effects of passively viewed stimuli to imagery task performance (Andrade et al., 2002; McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1996a,b, 1999, 2006; Smyth & Waller, 1998) has produced claims of direct access of perceptual information to a visual buffer (e.g. Pearson, 2001; Quinn, 2008) or creation of competition at the level of activation from long term memory (e.g. Logie, 1995, 2003; Logie & van der Meulen, 2009) while lack of effects of passively viewed visual images on storage of visually presented information (e.g. Andrade et al., 2002; Avons & Sestieri, 2005; Baddeley & Andrade, 2000; Dean et al., 2008; Dent, 2010; van der Meulen et al., 2009) has led to assertions of lack of direct access to stored representations (e.g. Logie, 1995; 2003; Logie & van der Meulen, 2009; Quinn, 2008). The present evidence indicates the next step for this literature should be to thoroughly investigate the underlying mechanisms by which encoded information disrupts short-term storage. Performance on the embedded-images DVN task generated interference in two memory tasks (Experiments 3 & 4); it is possible that not all detection tasks may produce this effect and specific properties of the current stimuli, and task, may affect prospect or magnitude of interference. Further investigation through varying detection requirements of the current task could provide an avenue to determine the means by which this encoded information disrupts storage. For example, it would be of interest whether detected images have to be suggested as identifiable and meaningful in order to gain access to the cache or whether disruption would be evident when participants are tasked only with detection of any visual irregularity in an otherwise uniform or regulated display- specifically, it may be the case that

participants are less likely to encode information in a manner which appears to permit access to the visual cache if they are not primed to be detecting something resembling images. Current task performance could be construed as participants attempting to encode visually presented images into working memory in order to evaluate them for similarity to known forms. Emphasis in instructions to participants that performance on all tasks completed was strictly monitored could have encouraged this; participants were not told that there would not be any penalty for guessing or pressing the response button when no image was present. If a visual detection task using stimuli with no inherent or imbued meaning produced disruption to information considered as stored functionally separate (Logie, 1995; 2003; Logie & van der Meulen, 2009) from long term memory and impervious to perceptual information, this could place constraints on theories of mechanisms of access. Future experiments should vary the detection requirements of the task and examine whether, if there is no need to encode information beyond a degree pertaining solely to perceptual differences - for example, if participants were tasked with pressing a button whenever a sizable section of DVN turned completely black - there would be an effect of visual detection. This also leads to obvious further manipulations of level of difficulty of detection and quantitative and structural complexity (after e.g. Ichikawa, 1985) of visual interference stimuli (e.g. as adopted by McConnell & Quinn, 2004 in investigating disruption to imagery) which would be necessary to fully understand mechanisms of visual detection effects on storage.

It could potentially be argued that the embedded images-DVN visual detection task employed executive resources in the form of sustained or controlled attention (e.g. Cowan, 2005) and that this aspect, rather than the visual material, produced the observed disruption to storage tasks (though see e.g. Duff & Logie, 1999). Klauer and Zhao (2004), in a series of experiments, sought to establish that the visual and spatial properties of their chosen interference tasks were producing selective interference effects to memory for Chinese ideographs and dot locations, respectively; in doing so, they employed a controlled attention task - random interval repetition (RIR, Vandierendonck et al., 1998b) to assess comparative effects. The visual interference task of Klauer and Zhao (2004) required participants to make classifications as to whether a number of colour screens presented throughout a retention interval were more blue or more red; it was found that performance of this task disrupted memory for the appearance of a Chinese ideograph more than did a spatial tapping task. The processing - that is, the possible executive component to this judgment - was

determined not to be the main source of interference found, as colour judgement affected memory for ideographs more than did RIR (while RIR affected an executive primary task of mental arithmetic more than did colour judgment). In the present experiments, no binary decisions were necessary, implying even less requirement in the interference task for executive resource involvement than that of colour judgements. It would be constructive, however, to clarify the interference effect found as visually based. This could be achieved in the manner adopted by Klauer and Zhao: a comparison of embedded-images DVN interference on visuo-spatial storage with an executive primary interference task which does not engage a visuo-spatial system (e.g. Random interval generation, RIG, Vandierendonck et al., 1998a; or RIR, Vandierendonck et al., 1998b). Equally, a relative lack of effect of embedded-images DVN performance on an executively demanding primary task (e.g. mental arithmetic) in comparison to the effect of, for example, RIR would aid in evaluating any executive contribution to the visual detection task.

Interference methodology was employed with short sequences of items to be retained and their simultaneous counterparts (Experiments 1-3); a different methodology was employed for investigating common resources at longer list lengths, with the additional requirement of retention of order. Future studies, informed by these experiments and the limitations detailed above, could be considered which would further elucidate the nature of representation and maintenance for pattern and sequence information and, moreover, the organisation of the visuo-spatial system. A comparison of embedded-images DVN, spatial tapping and RIR or RIG interference during the retention period of either simultaneously or sequentially presented location tasks could potentially allow for distinguishing the primary contributing components and processes to visuo-spatial maintenance; moreover it could provide a way of determining whether these processes differ following each of the presentation conditions. Given the implication of overlapping processes observed in the current experiments (1-3) it would be of interest whether, performed at a range of list lengths (e.g. from three items up until span), differences in magnitude of interference appear and increase as span is approached. As discussed, it is possible that the sequences in the current interference experiments were of a length that participants may create representations which employ both static and sequence properties – something which may not be possible at longer list lengths for a variety of reasons including possibly metric path length (Parmentier et al. 2005) and path crossing (Parmentier et al., 2005; Parmentier & Andres, 2006). Additionally an ordered presentation (left to right, top to

bottom) may enable an encoding more dependent on a visual storage subsystem while lack of presentation organisation may restrict encoding (e.g. Lecerf & de Ribaupierre, 2005) to depend more heavily on a spatial subsystem. A three way comparison of the effects of the interference tasks listed above on retention of simultaneous, disorganised sequential (including naturally occurring path crossing) and ordered sequential presentation conditions, at a variety of list lengths, would go a long way to providing answers to the question of how presentation affects the representation and maintenance of the same location information. Further progress could be made with manipulation of means of response – for example, examining whether, when recall of the order of item presentation is required in sequential presentation conditions, the rehearsal process is engaged to a greater extent; such a difference could be evidenced by a greater effect of spatial tapping than observed in a maintenance period of either a sequential condition with no requirement to remember order or in simultaneous presentation conditions where no order information is dictated. Equally, a reduction in effect of embedded-images DVN between these conditions with introduction of a requirement of order would indicate less reliance on a visual store.

As demonstrated in the final experiments (5-8), and consistent with the model of Logie (1995; 2003; Logie & van der Meulen, 2009), the requirement to remember order does not remove all commonalities between simultaneous and sequential task performance, rather, even at long list lengths performance in these conditions share a great deal of their resources: performance limitations in one task best predicts performance limitations in the other. Despite recent focus on executive resource involvement in sequential or serial visuo-spatial recall, these resources proved to be less explanatory than simultaneous performance; controlling for executive resource involvement – either in the form of visuo-spatial complex span recall or visuo-spatial processing performance - did not negate the relationship between simultaneous and sequential performance. There is the potential, however, for different deployment of resources between rehearsal and storage in a visuo-spatial system with separable yet interacting subsystems; interference methodology in the manner described above could provide further insight on any necessary difference in resource use between the conditions (e.g. increased reliance on a rehearsal loop with increased sequence information for properties which a storage system may not be able to maintain). The model proposed by Logie (1995; 2003; Logie & van der Meulen, 2009) allows for this flexibility in storage and rehearsal loop interaction in the form of the visual cache and the inner scribe, and findings of increased use of the scribe in some conditions and the

cache in other conditions would provide no conflict to the model, rather they would serve to provide detail and enhance understanding of functionality. As detailed throughout the discussions of current findings, however, proposed alternatives to this model (e.g. Pearson, 2001; Baddeley, 2007; Quinn, 2008) appear unable to fully account for a relationship between performance derived largely from a spatial rehearsal mechanism and that based on visual storage, outside of executive involvement. Moreover, flexible contribution of more or less (theoretically labelled) visual storage or spatial rehearsal processes as determined by demands of a memory task would not seem feasible within current descriptions of these models which currently provide little opportunity for these processes to interact outside of conscious awareness (Pearson, 2001) or at all (Baddeley, 2007; Quinn, 2008).

The current thesis found evidence of shared resources and processes used in memory for location information within a visual array whether information is presented simultaneously or sequentially. These findings can be taken as support for one prominent model of visuo-spatial working memory (Logie, 1995; 2003; Logie & van der Meulen, 2009), and provide a challenge to other existing interpretations (e.g. Baddeley, 2007; Pearson, 2001; Quinn, 2008). A novel means of disrupting visual storage was also developed in the course of investigation; moreover, consideration of use of this task, current experimental findings and recent literature converge to indicate a number of potentially fruitful directions in which to take future research into the effect of presentation on representation and maintenance in visuo-spatial working memory.

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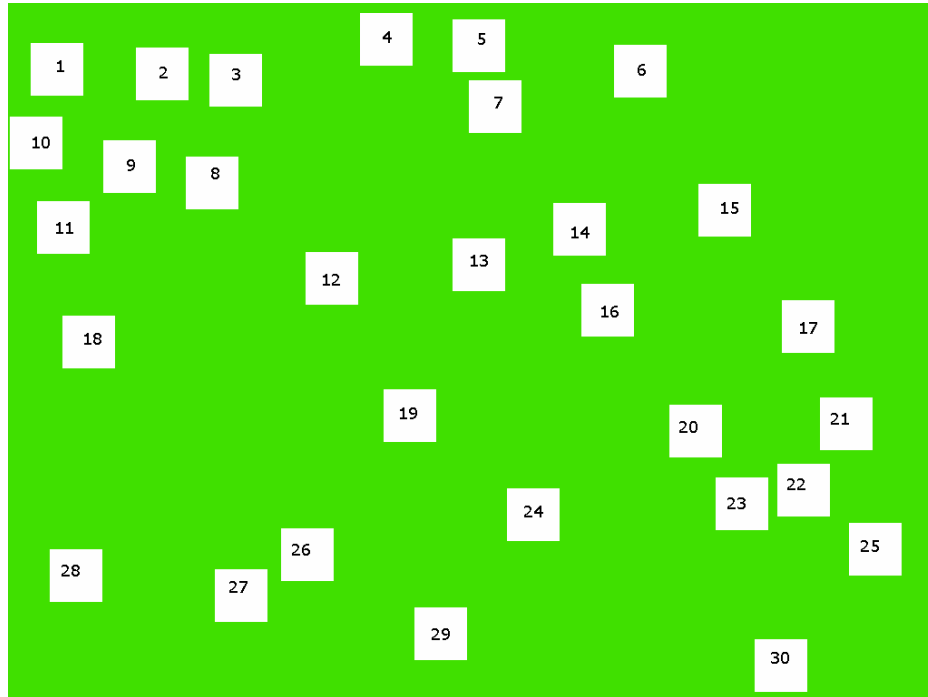
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APPENDIX

APPENDIX A

Location specifics for memory lists 1,2 & 3 used throughout Experiments 1-3; numbers correspond to template labels as shown in Figure below. Example presentation and test stimuli follow.

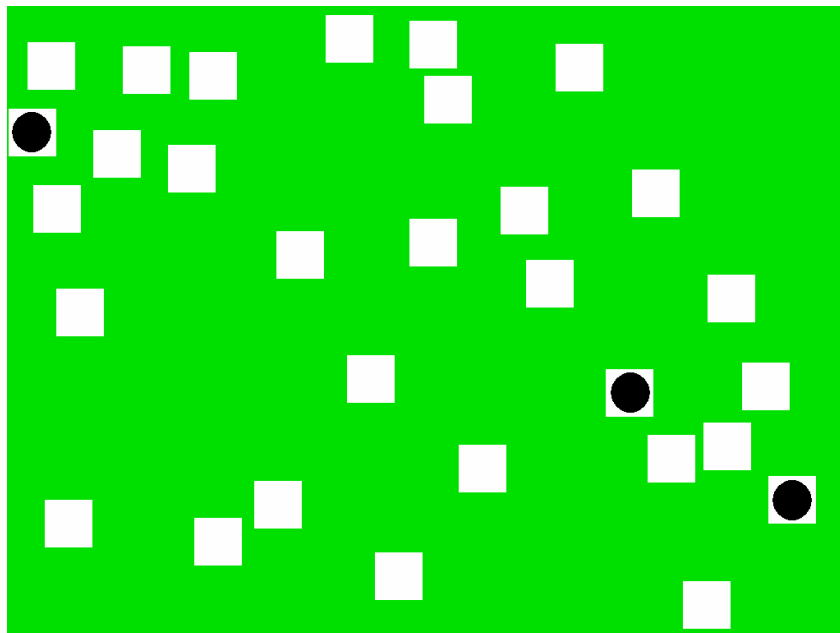


original sequences of list 1			Changes made in 'incorrect' recall		
7	11	4			
29	13	18			
8	4	3			
17	16	25			
11	10	13			
5	30	11			
18	2	28			
5	13	10			
22	12	27			

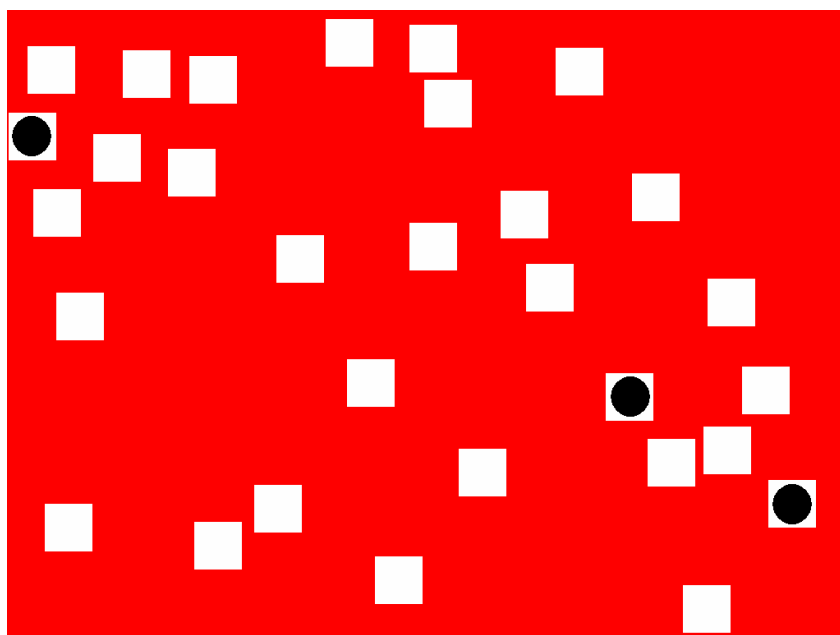
18	19	29			
25	10	20			
19	18	17			
30	8	5	23	8	5
17	16	3	17	13	3
1	14	24	1	14	19
5	12	21	6	12	21
23	25	19	23	22	19
18	20	19	18	20	24
29	26	12	30	26	12
19	11	9	19	10	9
10	15	3	10	15	7
1	14	6	2	14	6
13	25	1	13	30	1
23	19	8	23	19	12
original sequences list 2					
14	2	27			
19	8	29			
28	8	1			
9	19	13			
27	20	8			
30	4	5			
11	1	14			
21	26	8			
22	16	27			
4	14	17			
6	19	16			
25	9	5			
8	30	20	9	30	20
12	1	4	12	2	4
28	3	25	28	3	22
3	16	25	8	16	25

21	2	28	21	9	28
27	18	7	27	18	6
14	19	2	6	19	2
22	5	28	22	6	28
26	4	25	26	4	22
7	15	8	6	15	8
17	16	30	17	13	30
19	1	13	19	1	12
original sequences list 3					
13	25	30			
20	7	8			
8	9	3			
25	24	6			
19	22	15			
23	28	19			
14	6	18			
16	24	23			
5	30	13			
8	4	18			
17	21	27			
20	19	22			
23	29	8	30	29	8
30	3	14	30	8	14
28	10	7	28	10	5
10	11	28	9	11	28
12	24	16	12	29	16
5	17	6	5	17	15
11	6	28	18	6	28
1	18	16	1	12	16
7	8	11	7	8	10
29	24	23	26	24	23
26	9	14	26	2	14
19	2	10	19	2	8

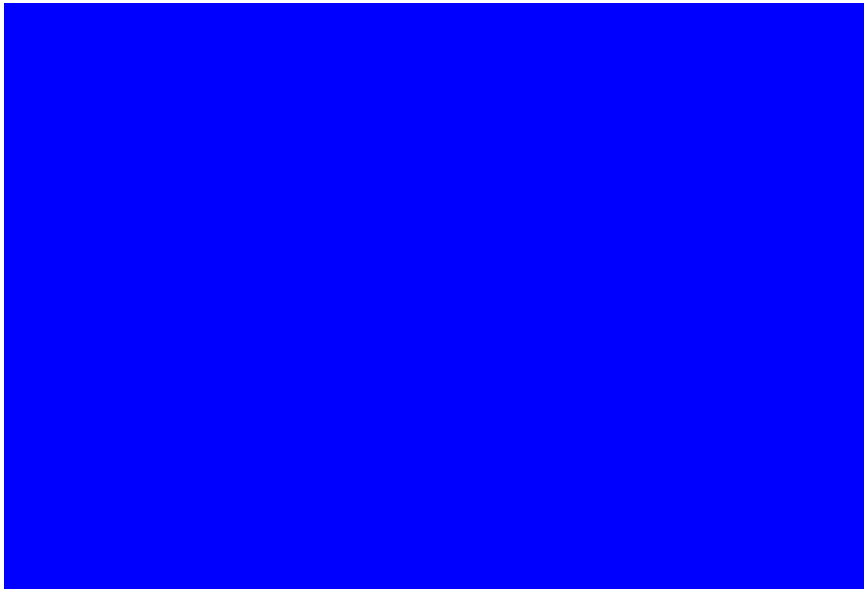
Example template stimuli and specifics of colours used for templates and recall screen in Experiments 1 through 3:



Green template: Luminance 108; red 0; green 230; blue 0; saturation 240; hue 80.



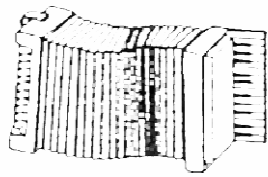
Red template: Luminance 113; red 240; green 0; blue 0; saturation 240; hue 0.



Blue template: Luminance 117; red 0; green 0; blue 248; saturation 240; hue 160.

APPENDIX B

Images (post-erosion) used within embedded-images DVN trials (note order of trial presentation was randomised) Difficulty category provided. Trial 1:



Easy



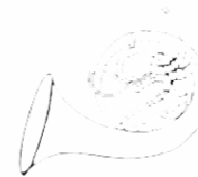
Hard



Medium



Hard



Hard



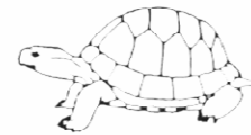
Medium



Hard



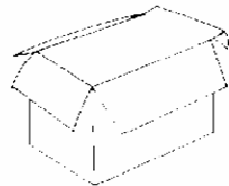
Hard



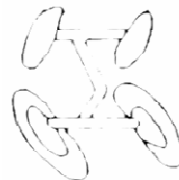
Easy



Easy



Easy



Easy

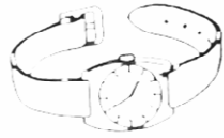


Easy



Easy

Trial 2:



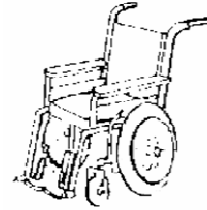
Easy



Easy



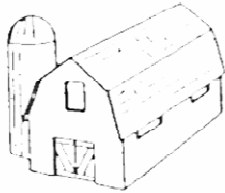
Hard



Easy



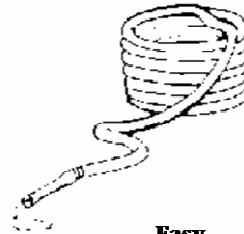
Hard



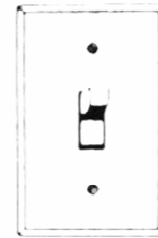
Medium



Hard



Easy



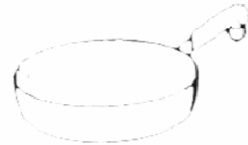
Medium



Easy



Easy



Hard

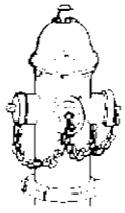


Hard



Easy

Trial 3:



Easy



Easy



Hard



Easy



Hard



Easy



Hard



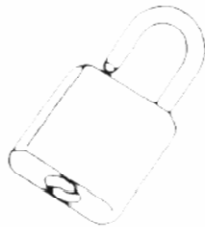
Easy



Hard



Medium



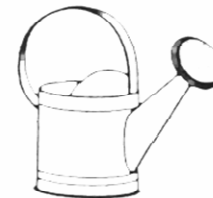
Hard



Hard



Medium



Easy

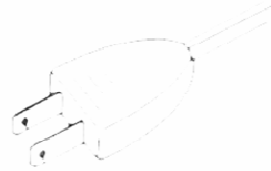
Trial 4:



Easy



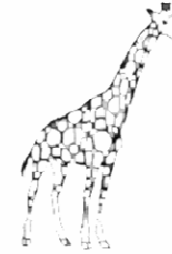
Hard



Hard



Easy



Hard



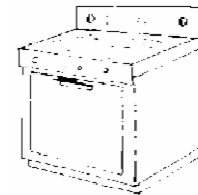
Hard



Easy



Hard



Easy



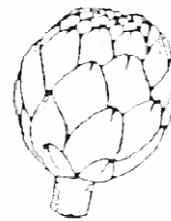
Easy



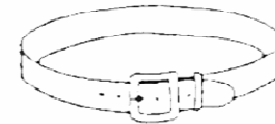
Medium



Hard

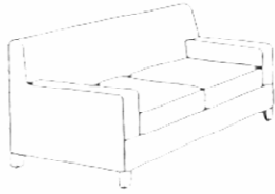


Easy



Medium

Trial 5:



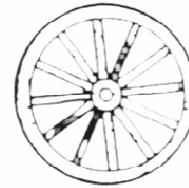
Hard



Hard



Medium



Easy



Medium



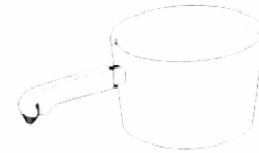
Hard



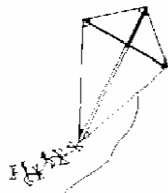
Easy



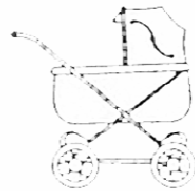
Easy



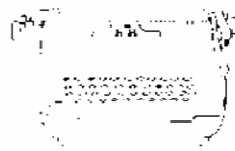
Hard



Easy



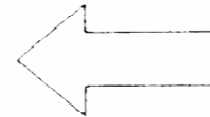
Easy



Medium



Easy

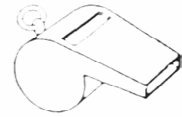


Hard

Trial 6:



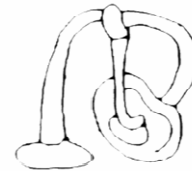
Hard



Easy



Hard



Easy



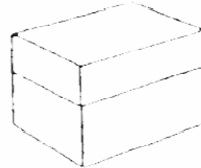
Medium



Easy



Easy



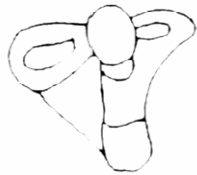
Medium



Hard



Easy



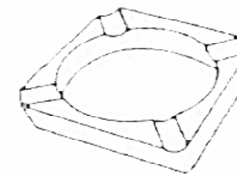
Easy



Hard



Easy



Hard

Trial 7:



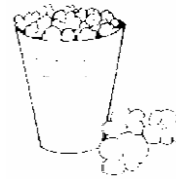
Easy



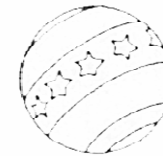
Easy



Medium



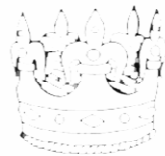
Easy



Hard



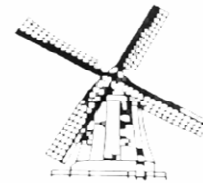
Hard



Hard



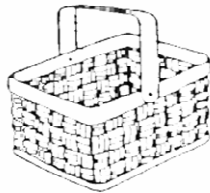
Hard



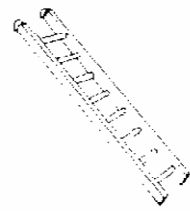
Easy



Hard



Easy



Easy



Medium



Hard

Trial 8:



Easy



Easy



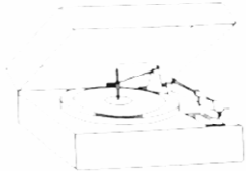
Hard



Hard



Easy



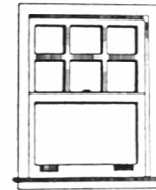
Hard



Easy



Easy



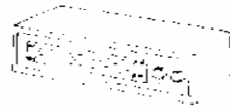
Easy



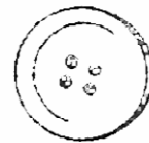
Hard



Hard



Easy

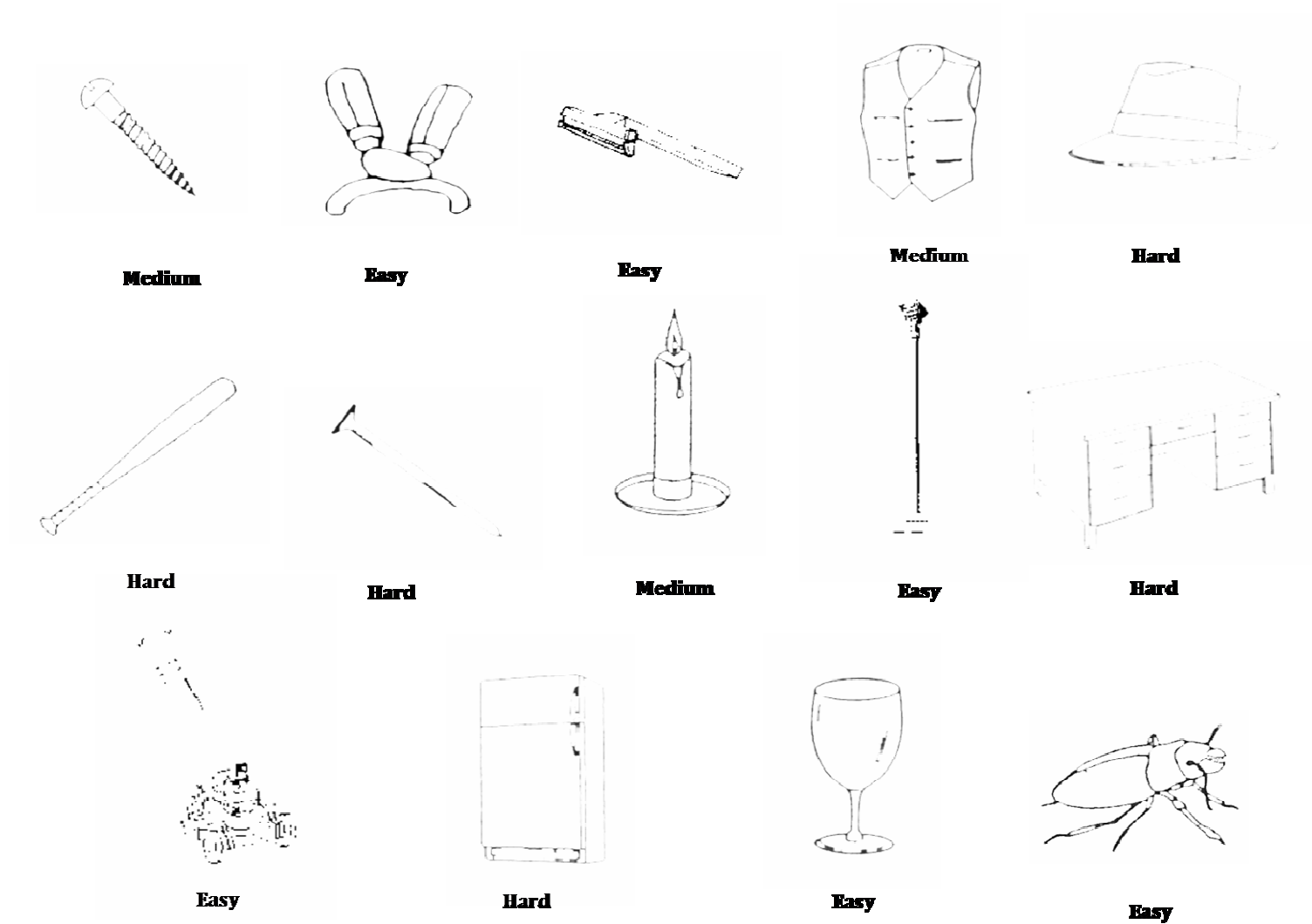


Medium



Medium

Trial 9:



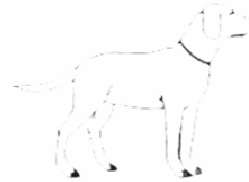
Trial 10:



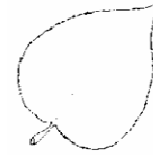
Easy



Hard



Hard



Easy



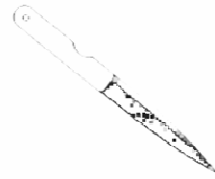
Easy



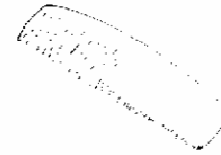
Easy



Medium



Hard



Easy



Hard



Easy



Hard



Easy

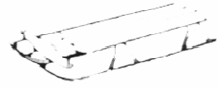


Medium

Trial 11:



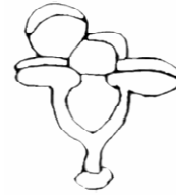
Easy



Medium



Hard



Easy



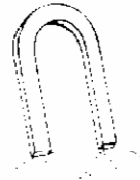
Easy



Hard



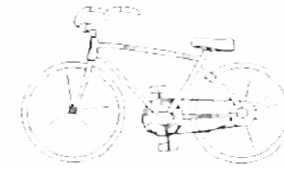
Hard



Easy



Medium



Hard



Easy



Hard



Hard



Easy

Trial 12:



Easy



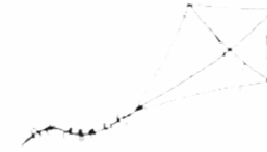
Easy



Hard



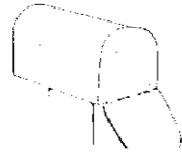
Easy



Hard



Easy



Easy



Hard



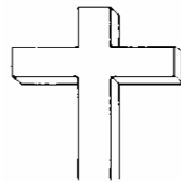
Easy



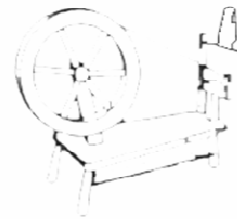
Medium



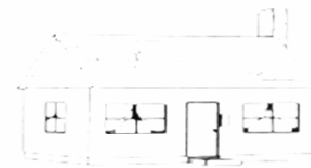
Hard



Easy



Medium



Hard

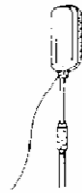
Trial 13:



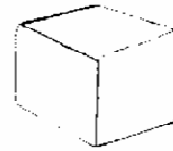
Easy



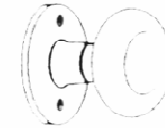
Easy



Easy



Easy



Hard



Hard



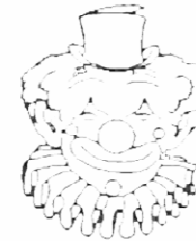
Hard



Easy



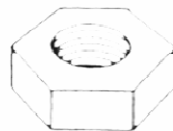
Medium



Easy



Hard



Hard



Hard



Medium

Trial 14:



Medium



Easy



Hard



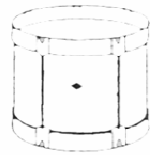
Hard



Hard



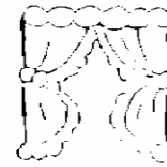
Medium



Easy



Hard



Easy



Hard



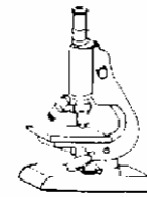
Easy



Hard



Easy



Easy

Trial 15:



Hard



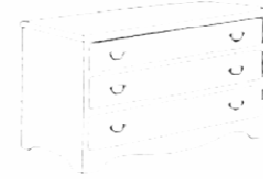
Hard



Medium



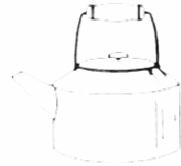
Medium



Hard



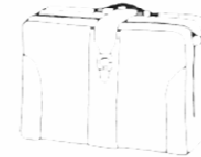
Easy



Hard



Easy



Hard



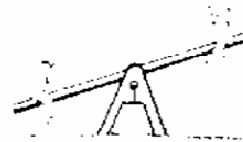
Easy



Easy



Hard

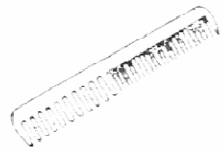


Easy

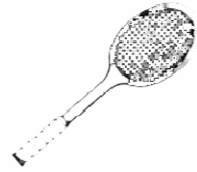


Easy

Trial 16:



Medium



Easy



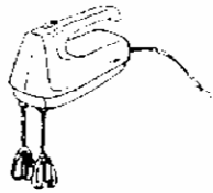
Easy



Hard



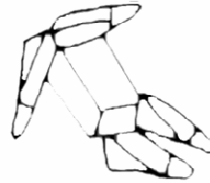
Hard



Easy



Hard



Easy



Hard



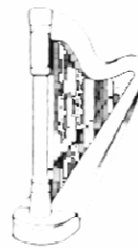
Hard



Medium



Easy



Easy



Easy

Trial 17:



Easy



Easy



Hard



Medium



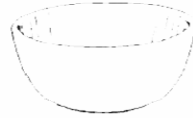
Easy



Hard



Easy



Hard



Easy



Hard



Easy



Hard

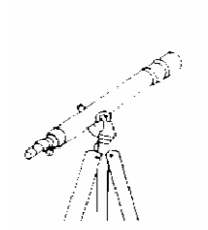


Medium



Easy

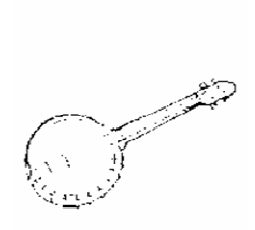
Trial 18:



Easy



Hard



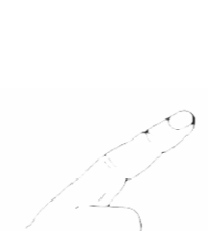
Easy



Easy



Easy



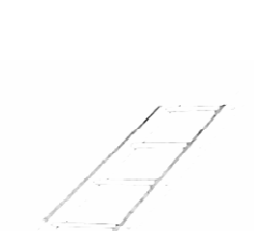
Hard



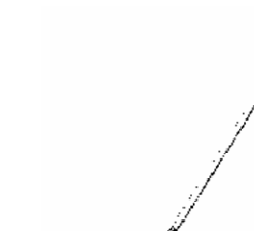
Easy



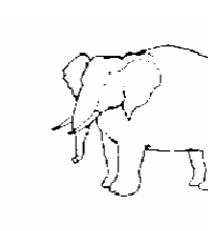
Medium



Hard



Easy



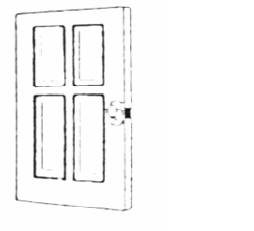
Easy



Hard

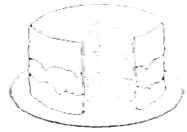


Hard

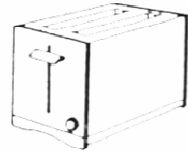


Medium

Trial 19:



Hard



Medium



Hard



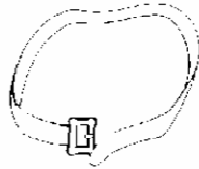
Medium



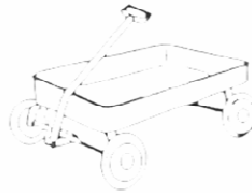
Easy



Hard



Easy



Hard



Hard



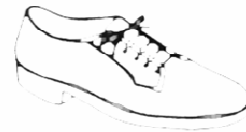
Easy



Easy



Hard



Easy



Easy

Trial 20:



Easy



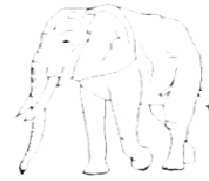
Hard



Hard



Hard



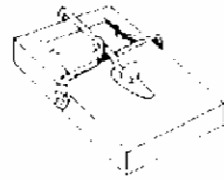
Medium



Hard



Easy



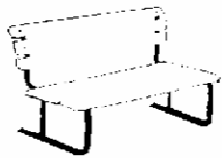
Easy



Medium



Easy



Easy



Easy



Hard



Easy

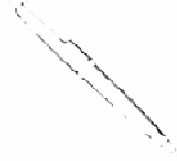
Trial 21:



Easy



Hard



Hard



Easy



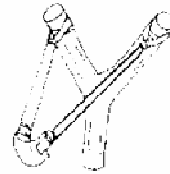
Easy



Medium



Easy



Easy



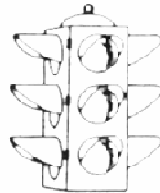
Hard



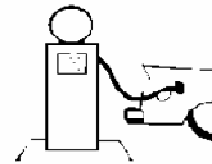
Hard



Hard



Medium



Easy



Easy

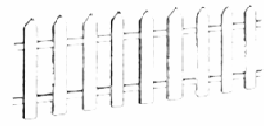
Trial 22:



Easy



Easy



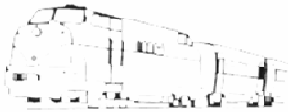
Medium



Hard



Easy



Medium



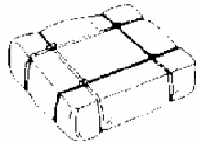
Easy



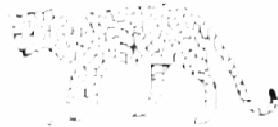
Hard



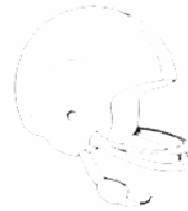
Hard



Easy



Hard



Hard

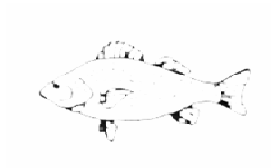


Easy



Easy

Trial 23:



Medium



Easy



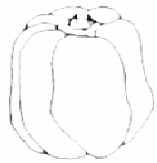
Hard



Hard



Easy



Hard



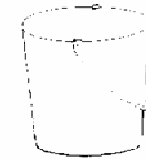
Hard



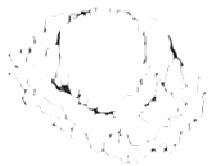
Medium



Easy



Easy



Hard



Easy

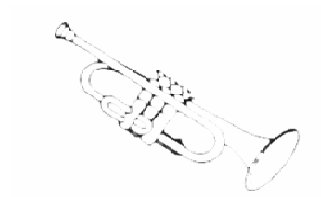


Easy



Easy

Trial 24:



Easy



Hard



Hard



Easy



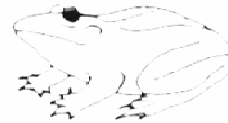
Easy



Hard



Hard



Medium



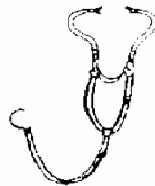
Easy



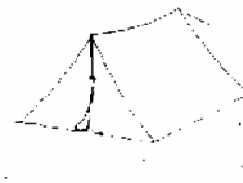
Medium



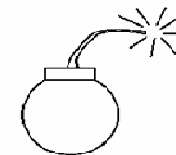
Hard



Easy



Easy



Easy

APPENDIX C

Stimuli used in memory recall task Experiment 4

Trial:	List 1					List 2			
practice	Q	r	l	H		d	Q	n	R
practice	n	q	D	h		R	L	N	d
1	l	h	n	r		D	n	l	h
2	H	n	L	D		l	H	r	q
3	L	d	h	R		Q	D	n	r
4	d	Q	r	N		N	R	h	d
5	N	R	D	l		L	q	R	H
6	R	N	l	H		q	r	N	L
7	q	l	r	n		H	N	q	d
8	H	q	L	d		r	L	D	q
9	R	d	n	Q		d	l	H	Q
10	h	L	N	q		R	n	q	h
11	q	H	D	r		r	h	L	D
12	Q	n	R	H		N	D	h	l
13	r	Q	l	d		l	H	r	Q
14	L	D	h	R		R	d	Q	N
15	D	r	q	L		n	Q	l	R
16	N	q	d	h		n	L	d	H
17	D	N	Q	h		h	N	L	D
18	n	l	H	Q		d	R	Q	n

APPENDIX D

Stimuli specifics of Imagery task, Experiment 4: Criterion judgment and explanations (after van der Muelen, 2008; van der Muelen et al., 2009) with stimuli lists. Physical experimental set up diagram provided.

Criteria on which to judge letters	Explanations of judgement criteria
<i>Similar upper and lower case forms</i>	Do the upper-case form and lower-case form of the letter look roughly similar in shape?
<i>Vertical Symmetry (left-right)</i>	Are the letters symmetrical on the vertical axis? Are the left and right halves mirror images?
<i>Horizontal Symmetry (upper-lower half)</i>	Are the letters symmetrical on the horizontal axis? Are the upper and lower halves mirror images?
<i>Enclosed spatial areas</i>	Are there any spaces in the letter that are completely surrounded by lines?
<i>Parallel lines</i>	Are there any sets of straight parallel lines in the letter? These lines do not have to be the same length, and only straight lines count.
<i>Curved lines</i>	Are there any curves in the letter?
<i>Straight lines</i>	Are there any straight lines in the letter? These are lines that are completely without curve, so straight parts of lines do not count.
<i>Single line</i>	Does the letter consist of one continuous line? Would you be able to write the letter without taking your pen off the paper?
<i>Right angle</i>	Does the letter contain any right angles (of 90 degrees)? Curves count, so there can be a right angle where a straight line and a curve meet.

List 1: Trial number, associated judgement criteria, stimuli order and correct response:

Trial 1	Enclosed areas	Trial 2	Vertical symmetry.	Trial 3	Similar cases	Trial 4	Horizontal symmetry
D	yes	O	yes	H	no	S	no
L	no	V	yes	K	yes	W	no
E	no	Y	yes	E	no	Q	no
A	yes	N	no	J	yes	Z	no
K	no	S	no	M	yes	X	yes
M	no	X	yes	F	yes	U	no
C	no	T	yes	A	no	Y	no
G	no	Z	no	G	no	P	no
B	yes	R	no	I	yes	V	no
I	no	W	yes	B	no	T	no
F	no	U	yes	L	no	O	yes
H	no	Q	no	D	no	R	no
J	no	P	no	C	yes	N	no

Trial 5	Parallel lines	Trial 6	Curve present	Trial 7	Right angle present	Trial 8	Consist of single line
J	no	Q	yes	E	yes	S	yes
C	no	X	no	I	no	W	yes
M	yes	R	yes	L	yes	O	yes
B	no	P	yes	F	yes	Z	yes
H	yes	W	no	A	no	N	yes
A	no	S	yes	K	no	V	yes
I	no	N	no	C	no	T	no
D	no	Y	no	J	no	Y	no
L	no	Z	no	G	yes	R	no
G	no	O	yes	M	no	Q	no
K	no	T	no	B	yes	P	no
F	yes	V	no	H	yes	U	yes
E	yes	U	yes	D	yes	X	no

Trial 9	Straight line present	
E	yes	
I	yes	
L	yes	
F	yes	
A	yes	
B	yes	
H	yes	
M	yes	
D	yes	
C	no	
J	no	
G	yes	
K	yes	

List 2: Trial number, associated judgement criteria, stimuli order and correct response:

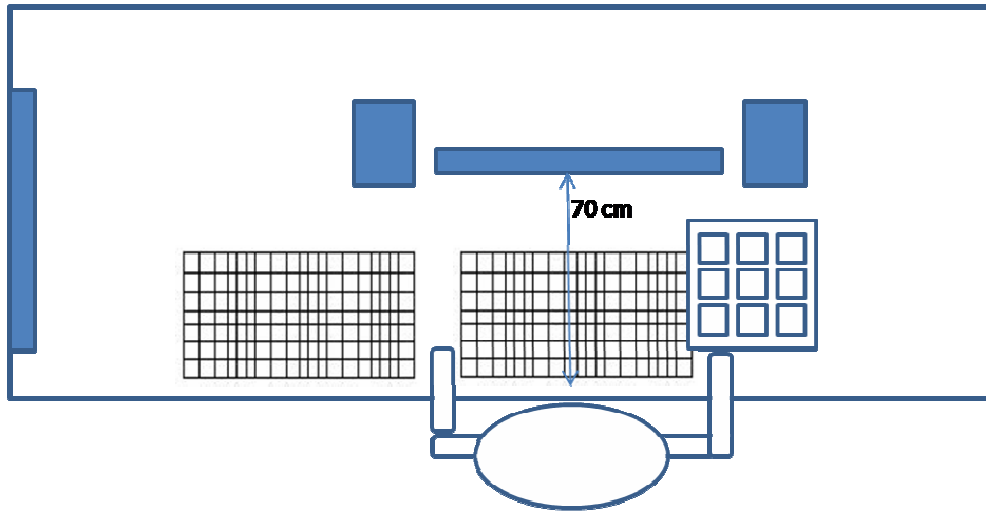
Trial 1	Right angle present		Trial 2	Curve present		Trial 3	Similar cases		Trial 4	Horizontal symmetry
R	yes		D	yes		R	no		E	yes
N	no		K	no		N	no		M	no
T	yes		F	no		W	yes		A	no
V	no		I	no		X	yes		H	yes
X	no		E	no		Q	no		D	yes
P	yes		L	no		V	yes		C	yes
Z	no		G	yes		O	yes		G	no
Y	no		J	yes		Y	no		I	yes
O	no		B	yes		S	yes		B	yes
U	no		C	yes		Z	yes		J	no
S	no		H	no		P	yes		F	no
Q	no		M	no		U	yes		L	no
W	no		A	no		T	no		K	yes

Trial 5	Parallel lines		Trial 6	Vertical symmetry		Trial 7	Enclosed areas		Trial 8	Consist of single line
X	no		C	no		W	no		D	no
W	yes		K	no		T	no		F	no
N	yes		B	no		U	no		H	no
T	no		A	yes		N	no		J	yes
P	no		M	yes		X	no		A	no
V	no		D	no		V	no		L	yes
O	no		L	no		O	yes		C	yes
U	no		E	no		S	no		M	yes
Q	no		H	yes		P	yes		B	no
Z	yes		J	no		Y	no		K	no
R	no		G	no		R	yes		E	no
S	no		F	no		Q	yes		G	yes
Y	no		I	yes		Z	no		I	yes

Trial 9	Straight line present	
U	no	
Q	no	
X	yes	
T	yes	
N	yes	
Z	yes	
R	yes	
V	yes	
O	no	
Y	yes	
S	no	
W	yes	
P	yes	

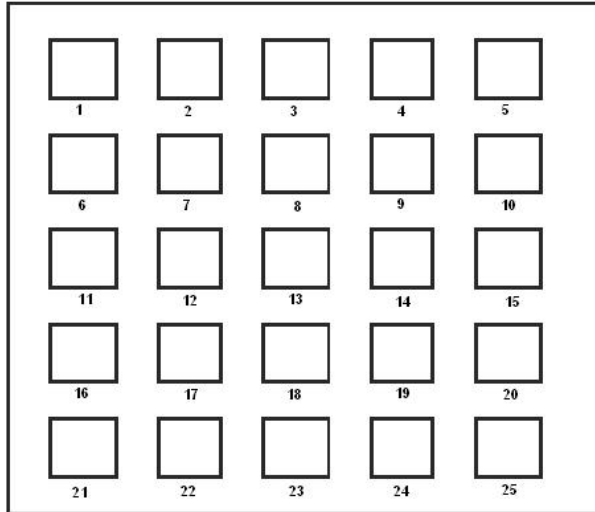
Diagram of physical set up of Experiment 4:

Visual displays on Computer screen shown directly in front of participant; speakers either side. Primary response keyboard shown in front of participant with tapping pad to the right. Keyboard to left of participant used to initiate imagery task .wav files run on unseen computer.



APPENDIX E

Experiments 5-8 Light-button box stimuli lists (only lists 1 & 2 used in Experiments 6 & 8) corresponding to array labels as demonstrated on box image below:



	list 1	list 2	list 3
3 items	21,4,10	25,3,17	24, 4, 14
	24,9,1	9,2,19	22, 13, 2
	17,8,15	22,12,10	18, 15, 14
	13,22,19	21,13,6	16, 25, 4
	11,20,3	4,16,15	9, 11, 25
4 items	22,9,25,3	13,16,25,18	11, 17, 22, 12
	7,15,10,1	4,25,5,23	23, 3, 9, 25
	13,10,1,18	21,13,5,9	12, 22, 4, 7
	16,14,24,19	13,15,19,2	19, 21, 11, 15
	20,1,7,3	3,7,14,6	15, 6, 21, 3
5 items	3,21,4,15,19	1,22,11,14,24	5, 23, 16, 15, 20
	16,3,9,19,20	7,12,18,21,13	2, 3, 15, 10, 13
	18,9,25,22,8	4,18,7,9,25	11, 4, 25, 19, 5
	9,11,10,20,4	1,14,7,11,5	1, 7, 8, 4, 6
	8,18,24,6,2	5,15,19,16,8	16, 11, 23, 12, 22
6 items	16,17,14,19,11,8	19,25,11,22,17,9	18, 7, 13, 16, 8, 4
	23,17,6,5,4,13	23,6,4,8,19,12	19, 11, 8, 5, 6, 21
	21,14,9,10,20,12	4,2,7,18,16,14	8, 5, 24, 12, 2, 9
	14,9,6,17,4,21	1,3,8,16,11,25	25, 10, 12, 16, 11, 18
	19,21,4,24,7,11	23,6,13,14,8,16	23, 13, 3, 2, 8, 9
7 items	21,22,19,16,8,5,23	12,20,16,15,2,23,14	1, 2, 17, 7, 10, 25, 18
	9,22,18,14,16,25,4	7,1,10,9,14,11,18	4, 11, 6, 13, 21, 8, 5
	11,25,3,13,16,17,10	17,9,14,12,6,23,2	23, 21, 5, 4, 9, 18, 11
	2,15,19,7,10,22,9	4,25,13,21,10,18,6	12, 23, 5, 18, 11, 13, 19

	10,16,24,14,13,22,6	16,19,12,3,8,6,22	14, 16, 22, 6, 24, 20, 19
8 items	24,3,11,19,16,13,4,10	12,11,1,18,8,25,6,22	14, 21, 18, 7, 22, 25, 1, 8
	21,22,15,2,1,12,18,9	23,14,11,5,16,25,8,9	19, 20, 7, 8, 6, 18, 11, 17
	9,23,16,7,19,11,3,15	1,16,15,21,22,20,4,3	21, 13, 23, 11, 3, 10, 17, 24
	23,6,17,16,24,3,15,5	5,11,24,18,19,22,7,2	19, 10, 9, 15, 5, 24, 6, 7
	11,16,12,4,5,7,24,1	25,20,16,7,9,18,10,1	2, 11, 21, 3, 4, 15, 13, 1
9 items	10,12,25,16,6,3,5,18,2	6,5,16,22,4,25,17,14,1	14, 8, 24, 7, 25, 18, 12, 16, 17
	18,23,14,2,25,22,20,6,3	9,21,15,10,20,17,7,23,13	20, 14, 16, 6, 10, 7, 4, 25, 22
	5,9,3,1,21,12,20,10,19	21,18,23,15,5,1,16,17,2	17, 21, 9, 24, 10, 2, 4, 3, 11
	8,16,11,21,20,7,24,2,13	25,10,15,21,7,14,18,24,2	16, 18, 24, 9, 5, 14, 1, 22, 17
	4,24,8,3,25,1,10,19,17	2,7,22,18,5,3,17,16,9	9, 1, 4, 5, 25, 6, 12, 24, 17
10 items	23, 2, 7, 8, 18, 1, 19, 4, 20, 9	15, 5, 1, 7, 11, 4, 17, 14, 18, 21	10, 9, 11, 5, 22, 14, 16, 3, 13, 25
	17, 23, 15, 9, 1, 25, 4, 24, 6, 13	12, 20, 15, 13, 24, 2, 21, 4, 23, 5	13, 16, 12, 8, 20, 24, 3, 21, 2, 6
	19, 14, 13, 4, 5, 17, 16, 8, 1, 24	2, 22, 25, 20, 4, 9, 18, 7, 3, 6	2, 15, 20, 22, 14, 1, 12, 5, 24, 11
	18, 6, 4, 19, 14, 22, 7, 10, 21, 17	22, 10, 14, 15, 8, 23, 16, 25, 13, 12	4, 23, 24, 22, 10, 14, 17, 5, 16, 12
	22, 3, 19, 20, 16, 5, 17, 9, 24, 12	19, 22, 16, 6, 20, 9, 8, 25, 21, 12	21, 6, 11, 1, 12, 22, 15, 5, 24, 2
11 items	5, 6, 15, 8, 12, 4, 3, 10, 20, 1, 22	11, 17, 5, 1, 2, 24, 20, 14, 18, 8, 13	18, 2, 15, 17, 23, 3, 5, 7, 21, 24, 1
	1, 14, 25, 19, 6, 12, 23, 3, 17, 8, 7	25, 21, 22, 14, 17, 15, 7, 24, 8, 2, 11	14, 18, 23, 15, 17, 2, 25, 7, 3, 21, 9
	16, 4, 7, 8, 19, 18, 20, 5, 12, 9, 21	14, 17, 11, 18, 6, 15, 10, 3, 5, 12, 16	21, 19, 7, 5, 22, 6, 16, 9, 15, 25, 2
	24, 19, 9, 10, 8, 3, 16, 14, 1, 15, 20	10, 16, 23, 17, 5, 18, 9, 21, 8, 1, 11	17, 15, 16, 18, 6, 5, 7, 12, 4, 19, 11
	19, 11, 14, 21, 12, 13, 7, 4, 1, 9, 18	17, 25, 1, 14, 5, 24, 8, 18, 12, 10, 3	4, 9, 12, 14, 16, 21, 18, 13, 24, 6, 5
12 items	7, 21, 20, 11, 23, 5, 3, 1, 18, 10, 24, 8	5, 19, 21, 17, 4, 9, 1, 8, 22, 20, 24, 12	21, 7, 17, 25, 13, 16, 19, 6, 23, 4, 5, 18
	13, 21, 14, 25, 11, 16, 15, 8, 24, 22, 5, 9	9, 7, 15, 3, 18, 8, 14, 20, 21, 23, 5, 4	3, 13, 4, 8, 9, 10, 7, 25, 15, 11, 14, 22
	20, 2, 4, 25, 24, 21, 6, 16, 10, 14, 18, 7	3, 13, 24, 17, 11, 8, 21, 1, 7, 22, 23, 5	18, 21, 3, 13, 4, 5, 24, 19, 12, 2, 9, 17
	21, 22, 25, 10, 15, 23, 16, 19, 7, 6, 18, 4	3, 23, 18, 8, 17, 22, 1, 2, 15, 10, 14, 11	4, 10, 17, 23, 22, 21, 19, 20, 3, 1, 12, 7
	15, 23, 11, 4, 16, 9, 7, 2, 10, 19, 1, 8	23, 16, 10, 2, 3, 19, 1, 6, 14, 9, 17, 25	25, 22, 2, 19, 16, 6, 8, 1, 20, 9, 23, 24

APPENDIX F

Digit recall stimuli of Experiment 8:

2 items	67
	17
	27
	91
	87
3 items	829
	428
	871
	251
	915
4 items	6342
	2651
	5316
	4815
	1872
5 items	94287
	85319
	16542
	92543
	84132
6 items	487652
	328967
	632147
	429735
	641357
7 items	4769128
	7419652
	5784216
	9865312
	2941378
8 items	37518426
	42785921
	74529638
	76921358
	57419628

APPENDIX G:

Sentence span stimuli of Experiment 8 with correct judgment answer and correct recall item:

Items per trial	Sentences stimuli	True or false	last words {to be recalled}
2 Items	Lions are living creatures	T	<u>creatures</u>
	Carving knives is the name of a place	F	<u>place</u>
	Trout move around searching for food	T	<u>food</u>
	Hawaii has palm trees	T	<u>trees</u>
	Buses are made in factories	T	<u>factories</u>
	Bananas are often made by carpenters	F	<u>carpenters</u>
	Doctors have a profession	T	<u>profession</u>
	Carving knives are meats	F	<u>meats</u>
	Sergeant-major is a dish	F	<u>dish</u>
	Aunts are relatives	T	<u>relatives</u>
3 Items	Hawaii is edible	F	<u>edible</u>
	Rattlers are poisonous	T	<u>poisonous</u>
	Saws are members of the Armed Forces	F	<u>forces</u>
	Trout are carpenters' tools	F	<u>tools</u>
	Robins have feathers	T	<u>feathers</u>
	Lions are eaten in salads	F	<u>salads</u>
	Aunts are people	T	<u>people</u>
	Flies are insects	T	<u>insects</u>
	Priests are made in factories	F	<u>factories</u>
	Buses are made from apples	F	<u>apples</u>
	Saws cut wood	T	<u>wood</u>
	Buses are manufactured goods	T	<u>goods</u>
	Asia is edible	F	<u>edible</u>
	Rattlers are manufactured goods	F	<u>goods</u>
	London is shown on maps	T	<u>maps</u>
4 Items	California is frothy	F	<u>frothy</u>
	Peas grow in pods	T	<u>Pods</u>
	Priests deliver sermons	T	<u>sermons</u>
	Sergeant-majors are members of the Armed Forces	T	<u>forces</u>
	Aunts are fried	F	<u>fried</u>
	Flies attend religious services	F	<u>services</u>

	Pork chops are sold by butchers	T	<u>butchers</u>
	Mayors are birds	F	<u>birds</u>
	Sergeant-majors can be bought in shops	F	<u>shops</u>
	London is a living creature	F	<u>creature</u>
	Carving knives are often used in preparing meals	T	<u>meals</u>
	Saws are carpenters' tools	T	<u>tools</u>
	Rattlers are shown on maps	F	<u>maps</u>
	Brothers-in-law are people	T	<u>people</u>
	Europe is a continent	T	<u>continent</u>
	Peas move around searching for food	F	<u>food</u>
	Peas are people	F	<u>people</u>
	London is a person with a religious faith	F	<u>faith</u>
	Carving knives are made in factories	T	<u>factories</u>
	Pork chops are edible	T	<u>edible</u>
5 Items	Bananas are fruit	T	<u>fruit</u>
	Asia undergoes a long training	F	<u>training</u>
	Pork chops are people	F	<u>people</u>
	Spaghetti can be bought in shops	T	<u>shops</u>
	Spaghetti is red	F	<u>red</u>
	Buses are insects	F	<u>insects</u>
	Shoes are often made of leather	T	<u>leather</u>
	Chairs are liquid	F	<u>liquid</u>
	Beer is a 4-legged animal	F	<u>animal</u>
	Doctors are often used in preparing meals	F	<u>meals</u>
	Shoes wear clothes	F	<u>clothes</u>
	California is the name of a place	T	<u>place</u>
	Robins are manufactured goods	F	<u>goods</u>
	Russia is shown on maps	T	<u>maps</u>
	London houses many people	T	<u>people</u>
	Beer can be bought in shops	T	<u>shops</u>
	Lions have wings	F	<u>wings</u>
	Priests attend religious services	T	<u>services</u>
	Asia has high mountains	T	<u>mountains</u>
	Beer has pips	F	<u>pips</u>
	Trout are clear	F	<u>clear</u>
	Spaghetti is part of the family	F	<u>family</u>
	California is a state of America	T	<u>America</u>
	Robins are fruit	F	<u>fruit</u>
	Shoes are always sold in pairs	T	<u>pairs</u>

APPENDIX H

Letter Rotation stimuli of Experiment 8 with correct judgment and correct recall answers:

	Letter stimuli	Format of presentation Normal/Mirror image	Angle to be recalled
2 Items	F mirror 225	M	225°
	F 135	N	135°
	J mirror 180	M	180°
	J 315	N	315°
	G mirror 180	M	180°
	G 90	N	90°
	L 45	N	45°
	L mirror 180	M	180°
	R mirror 135	M	135°
	R mirror 270	M	270°
3 items	F mirror 270	M	270°
	F 180	N	180°
	F 45	N	45°
	L mirror 225	M	225°
	L 315	N	315°
	L 90	N	90°
	R mirror 45	M	45°
	R 270	N	270°
	R 225	N	225°
	G mirror 315	M	315°
	G mirror 45	M	45°
	G 270	N	270°
	J 225	N	225°
	J mirror 270	M	270°
	J 180	N	180°
4 Items	L mirror 270	M	270°
	L 135	N	135°
	L mirror 45	M	45°
	L 180	N	180°

	J mirror 225	M	225°
	J 135	N	135°
	J mirror 45	M	45°
	J 90	N	90°
	G mirror 90	M	90°
	G mirror 225	M	225°
	G 180	N	180°
	G 135	N	135°
	R 45	N	45°
	R mirror 90	M	90°
	R mirror 315	M	315°
	R 180	M	180°
	F 315	N	315°
	F mirror 180	M	180°
	F mirror 90	M	90°
	F 270	N	270°
5 Items	R 315	N	315°
	R mirror 225	M	225°
	R 90	N	90°
	R mirror 180	M	180°
	R 135	N	135°
	L 225	N	225°
	L mirror 90	M	90°
	L mirror 315	M	315°
	L 270	N	270°
	L mirror 135	M	135°
	J 45	N	45°
	J 270	N	270°
	J mirror 135	M	135°
	J mirror 90	M	90°
	J mirror 315	M	315°
	F mirror 135	M	135°
	F 225	N	225°
	F mirror 315	M	315°
	F 90	N	90°
	F mirror 45	M	45°
	G 315	N	315°
	G 45	N	45°
	G mirror 135	M	135°
	G 225	N	225°
	G mirror 270	M	270°

APPENDIX 1

Supplementary data information:

Summary table of squared variance values for timing analysis of Experiment 3c

	Condition					
	Unfilled delay		DVN		Tapping	
	Mean	SD	Mean	SD	Mean	SD
Simultaneous Presentation	67412.6	17211.8	74783.8	34331.4	83631.7	22079.5
Sequential Presentation	54410.8	28135.8	80980.0	38245.3	77859.4	45805.8

Mean SD (in bold) and SD of the mean SD of memory task reaction time performance (shown in milliseconds). Displayed according to presentation condition. Mean provided in Bold.

APPENDIX 2

Experiment 8: Distribution tests of all variables :

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Digit recall	.154	100	.000	.890	100	.000
Letter rotation reaction time	.056	100	.200	.990	100	.671
Letter rotation recall	.067	100	.200	.988	100	.502
Letter rotation processing	.100	100	.015	.965	100	.009
Sentence span reaction time	.059	100	.200	.981	100	.153
Sentence span recall	.149	100	.000	.906	100	.000
Sentence span processing	.173	100	.000	.832	100	.000
Sequential recall	.088	100	.053	.977	100	.079
Simultaneous recall	.125	100	.001	.920	100	.000

Experiment 8: Spearman's Zero-order Correlations for performances on all tasks

	1	2	3	4	5	6	7	8	9
1. Sentence memory (total)	-	.59**	-.39**	.26**	.26**	.09	.56**	.19	.21*
2. Sentence processing (% correct)		-	-.67**	.13	.39**	-.17	.32**	.21*	.19
3. Sentence reaction time (mean of correct)			-	-.07	-.27**	.31**	-.25*	-.10	-.01
4. Letter rotation memory (total)				-	.27**	.25*	.18	.33**	.49**
5. Letter rotation processing (% correct)					-	-.11	.19	.51**	.48**
6. Letter rotation reaction time (mean of correct)						-	.14	-.02	0.6
7. Digit recall (total)							-	.19	.29**
8. Simultaneous recall (% correct)								-	.65**
9. Sequential recall (% correct)									-

n = 100.

* $p < .05$. ** $p < .01$.

APPENDIX 3

Experiment 8: Information regarding assumptions of final model: Dependent variable Simultaneous recall performance.

a) Outliers and influential cases

Summary of residual statistics

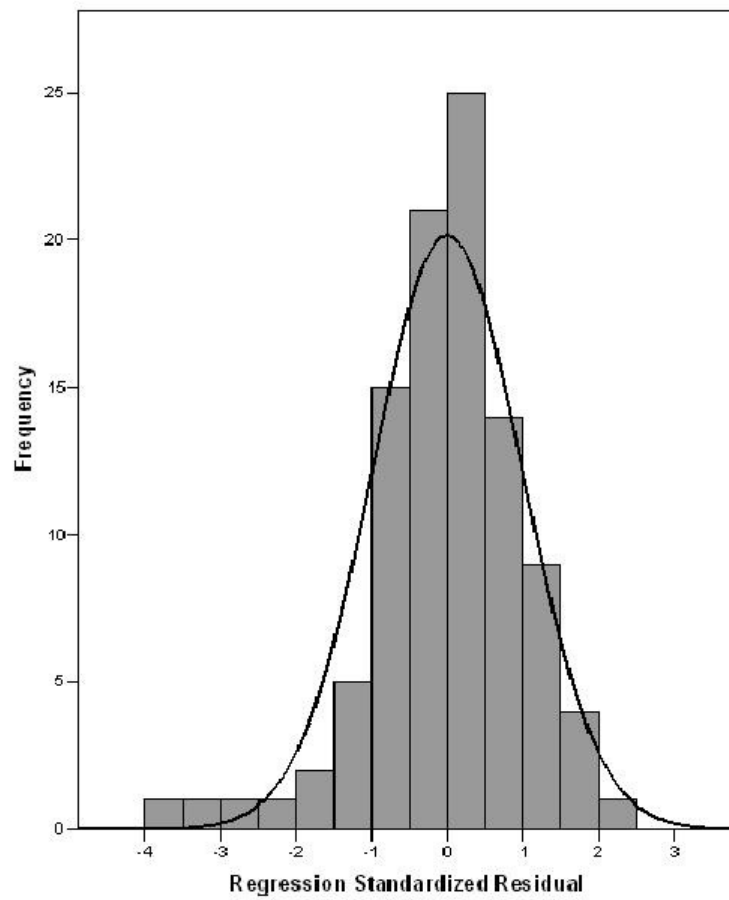
	Minimum	Maximum	Mean	Std. Deviation	N
Residual	-13.2158	8.9370	.000	3.6734	100
Std. Residual	-3.561	2.408	.000	.990	100
Cook's Distance	.000	.230	.013	.033	100
Centred Leverage Value	.001	.094	.020	.018	100

Summary of identified cases

Case Number	Std. Residual	Centred Leverage Value	Cook's Distance	Std. DFBETA Intercep t	Std. DFBETA sequenti al recall	Std. DFBETA letter rotation processing
23	-3.561	.03909	.22951	.27141	-.78213	.50368
44	-3.121	.02848	.13516	-.61516	.34213	.23154
49	-2.377	.03148	.08501	-.25863	.45066	-.24966
68	0.717	.09432	.02232	.07234	.23821	-.17013
73	2.408	.06127	.15972	.61317	-.06883	-.53517
83	-2.626	.00976	.04726	-.30515	.17981	.08907

b) Normality of distribution of residuals

Graph of distribution of residuals for dependent variable simultaneous recall performance:



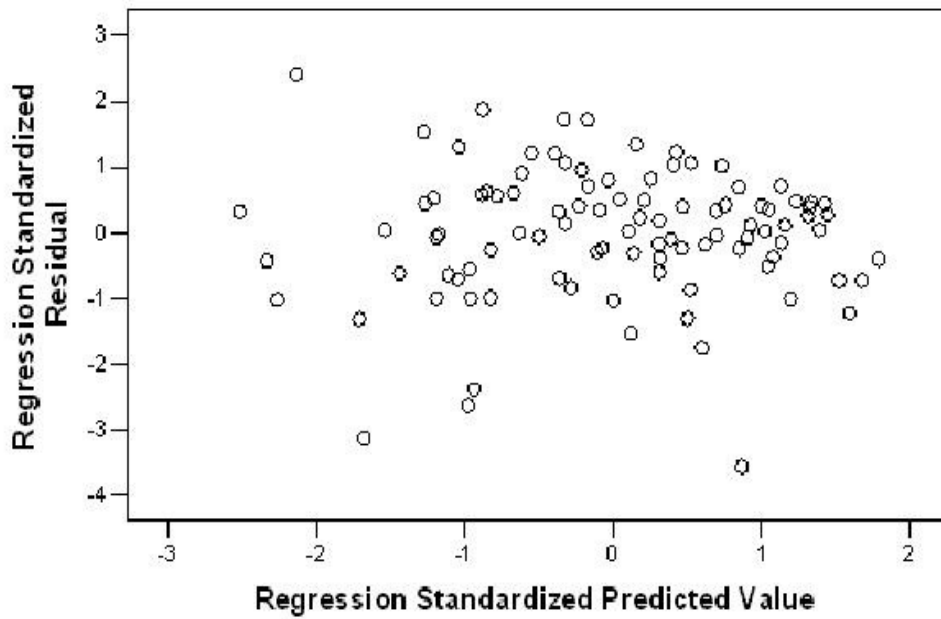
Kolmogorov-Smirnov test on residuals:

Tests of Normality

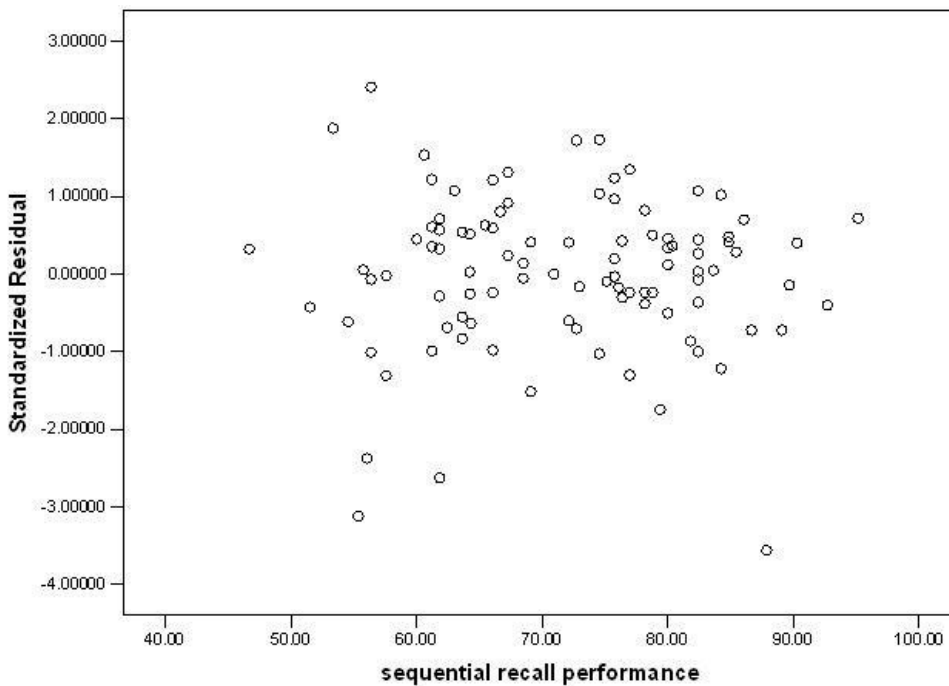
	Kolmogorov-Smirnov		
	Statistic	df	Sig.
Standardized Residual	.079	100	.129

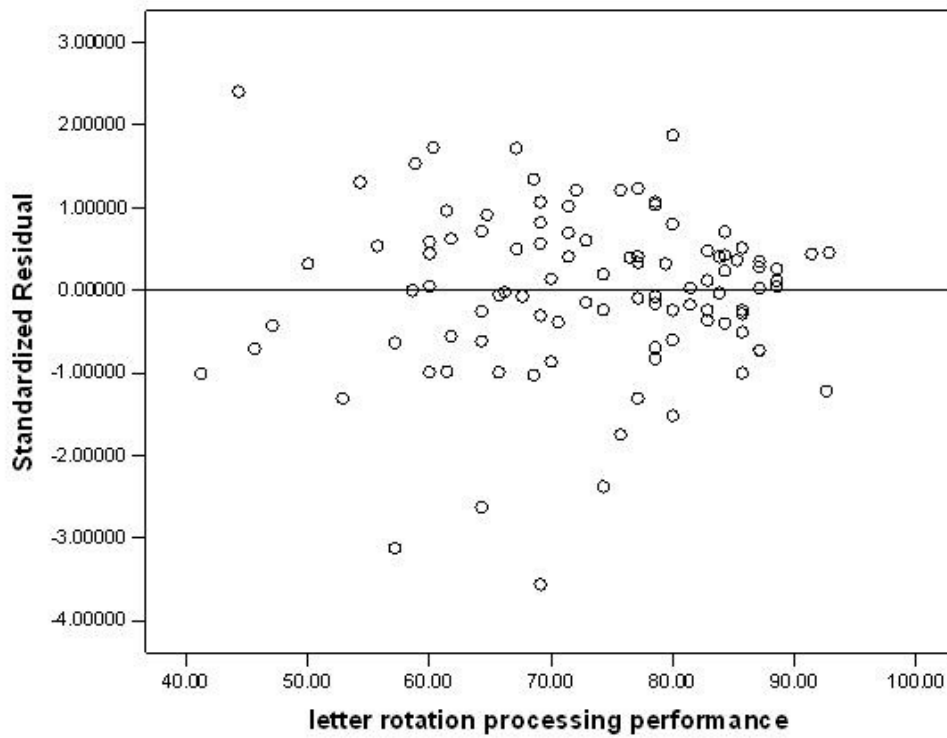
c) Linearity and homoscedasticity:

Scatterplot of standardised residuals versus standardised predicted values:



Scatterplots of residuals versus predictors:





d) Multicollinearity

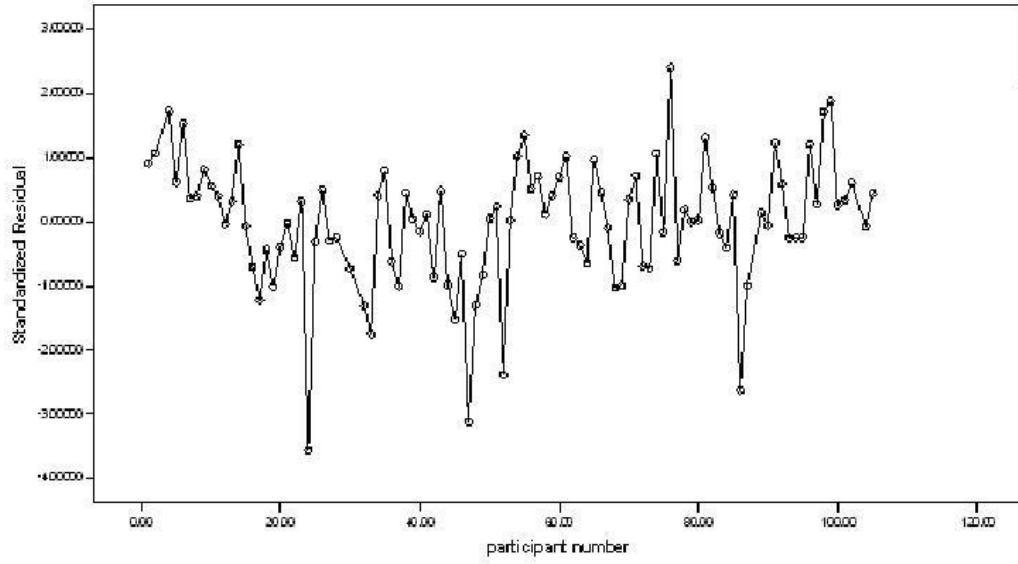
<i>Collinearity statistics</i>		
Variable	Tolerance	VIF
Sequential recall performance	.752	1.329
Letter rotation processing performance	.752	1.329

Collinearity diagnostics:

Model	Dimension	Eigenvalue	Variance Proportions		
			(Constant)	sequential recall performance	letter rotation processing
1	1	1.989	.01	.01	
	2	1.07E-002	.99	.99	
2	1	2.977	.00	.00	.00
	2	1.26E-002	.45	.06	.92
	3	1.06E-002	.55	.94	.07

e) Assumption of independent errors

Plot of standardised residuals versus participant



APPENDIX 4

Experiment 8: Information regarding assumptions of final chosen model: Dependent variable Sequential recall performance.

a) Outliers and influential cases

Summary of residual statistics

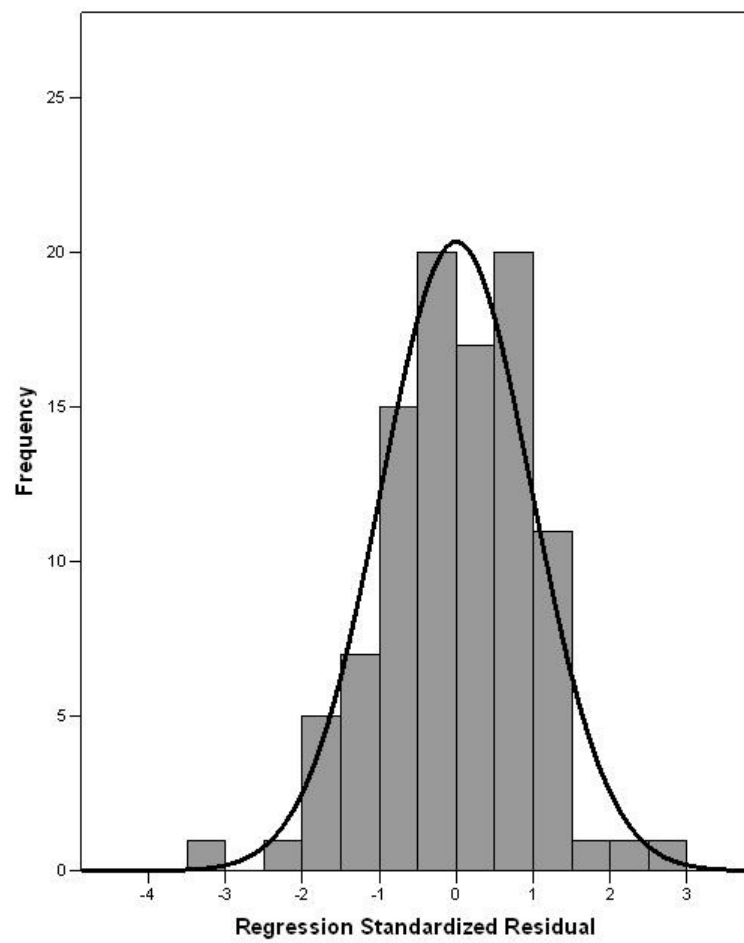
	Minimum	Maximum	Mean	Std. Deviation	N
Residual	-22.30322	20.82098	.00000	7.21593	100
Std. Residual	-3.028	2.827	.000	.980	100
Cook's Distance	.000	.191	.011	.024	100
Centred Leverage Value	.002	.128	.040	.029	100

Summary of identified cases

Case Number	Std. Residual	Centred Leverage Value	Cook's Distance	Std. DFBETA intercept	Std. DFBETA simultaneous recall	Std. DFBETA letter rotation memory	Std. DFBETA A digit recall	Std. DFBETA letter rotation processing
1	.76554	.12124	.02038	.01131	.12656	-.10546	-.25741	-.50844
18	-.53437	.12518	.01032	-.10097	.08796	-.08526	.08139	.12073
23	2.82653	.08747	.19121	.72041	-.86671	.53917	.25536	.24446
44	.98011	.12760	.03554	.38572	-.34157	-.05091	.02842	.08445
68	2.27478	.05154	.07232	-.41838	.47409	.02900	.12479	-.45093
92	2.19866	.00762	.01765	.11424	-.06303	-.09729	.11455	.03181
95	3.02775	.02005	.02855	.31363	-.21119	.31634	.24807	-.07414

b) Normality of distribution of residuals:

Graph of distribution of residuals for dependent variable sequential recall performance:

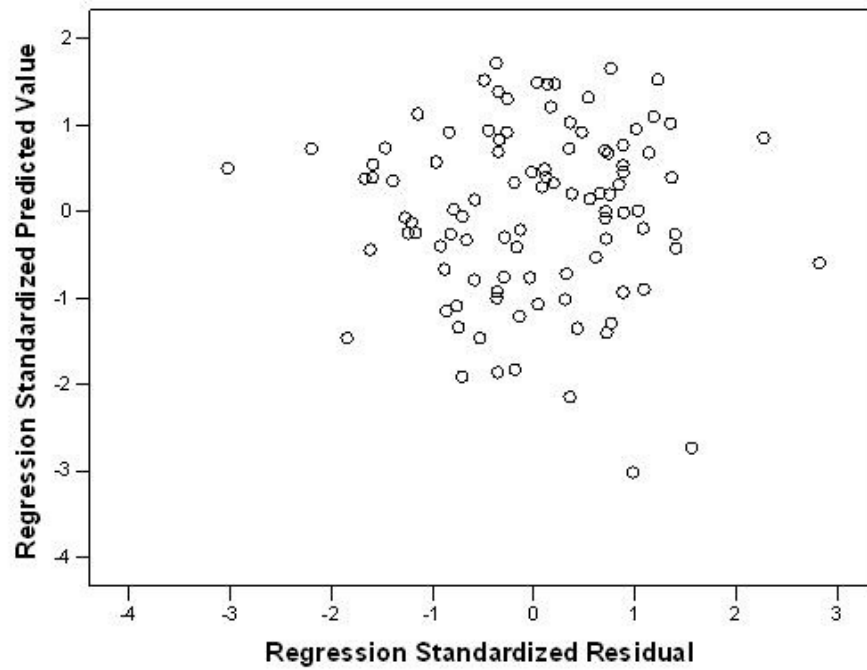


Kolmogorov-Smirnov test on residuals:

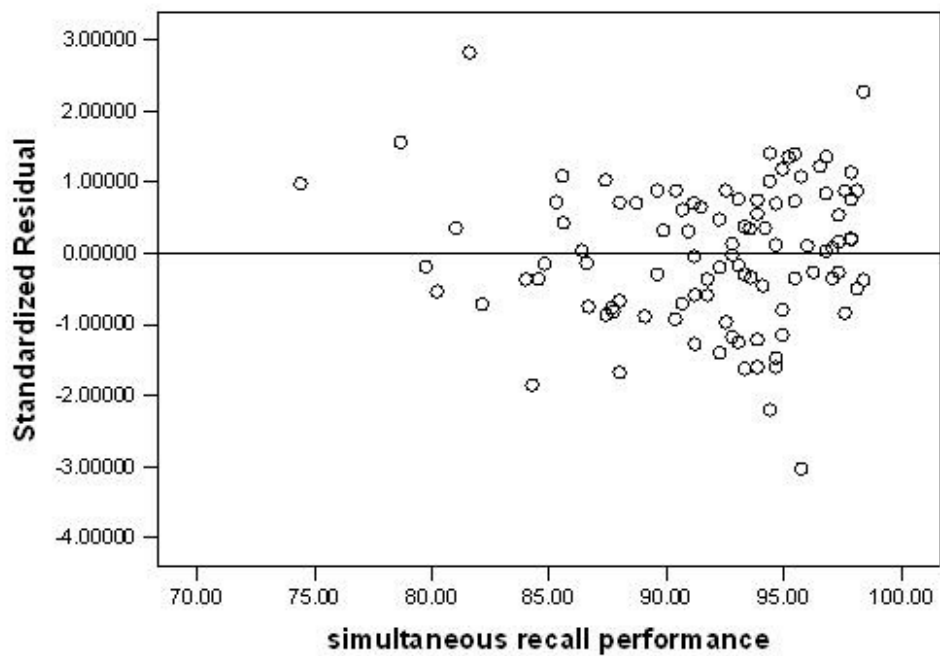
	Kolmogorov-Smirnov		
	Statistic	df	Sig.
Standardized Residual	.064	100	.200

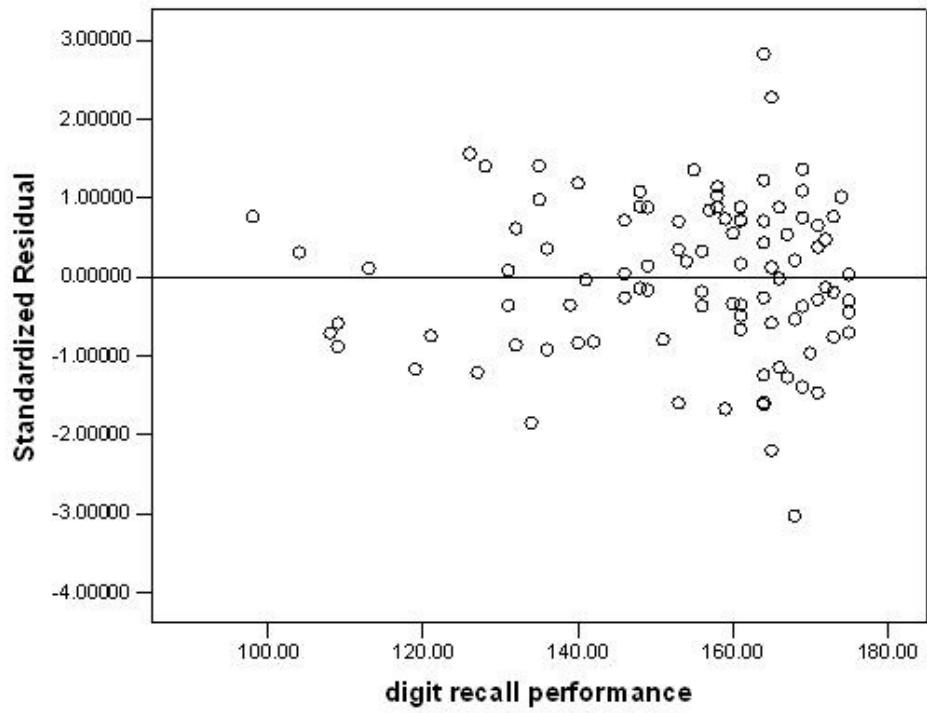
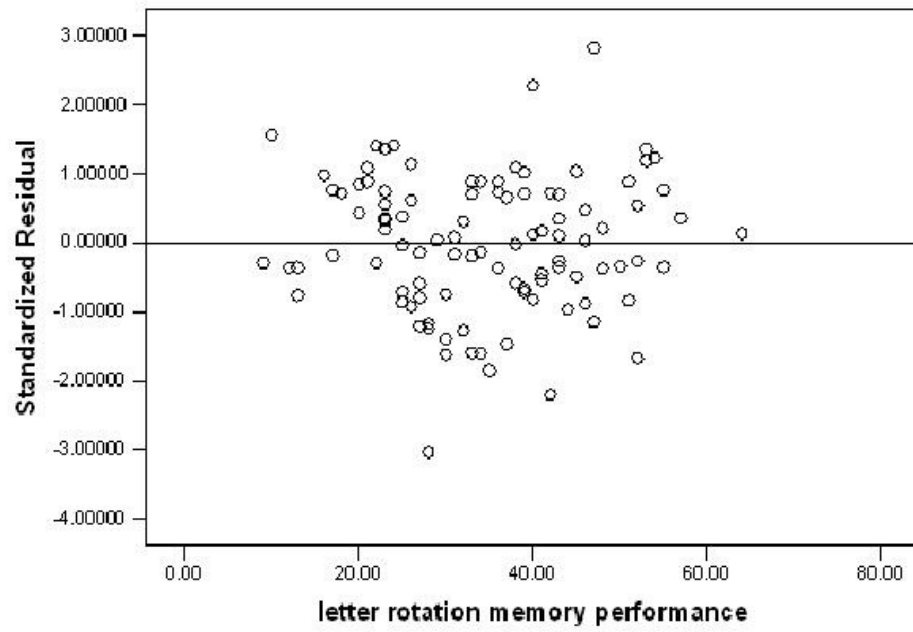
c) Linearity and homoscedasticity

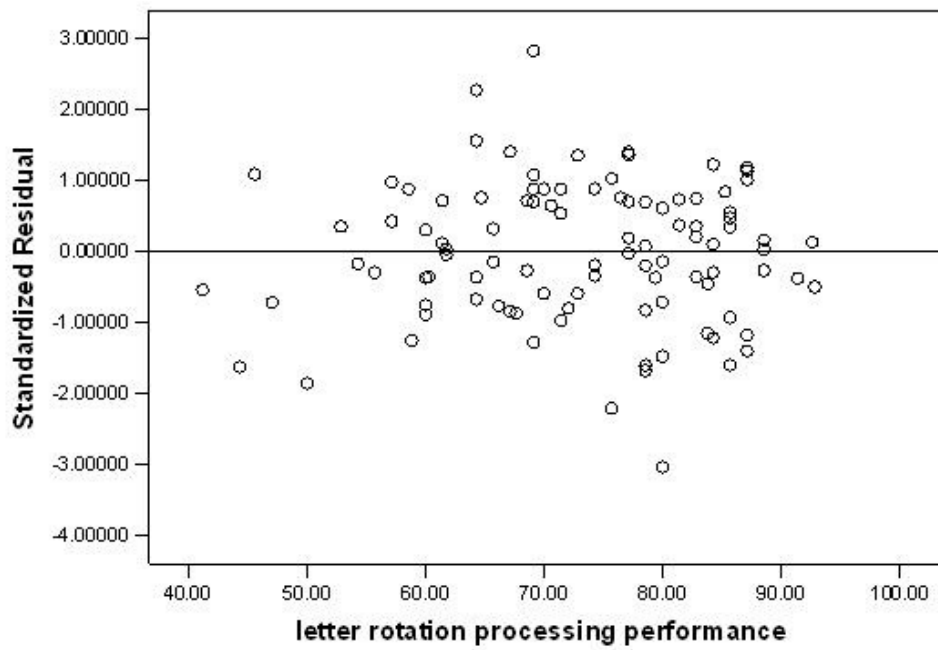
Scatterplot of standardised residuals versus standardised predicted values:



Scatterplot of residuals versus predictors:







d) Multicollinearity

<i>Collinearity statistics</i>		
Variable	Tolerance	VIF
Simultaneous recall performance	.643	1.556
Letter rotation memory performance	.686	1.152
Digit recall	.931	1.074
Letter rotation processing performance	.681	1.468

Collinearity diagnostics:

Dimension	Eigenvalue	Variance Proportions				
		(Constant)	simultaneous recall performance	letter rotation memory	digit recall	letter rotation processing
1	4.895	.00	.00	.00	.00	.00
2	7.91E-002	.00	.00	.94	.01	.01
3	1.70E-002	.01	.00	.01	.18	.70
4	8.19E-003	.08	.04	.00	.81	.11
5	1.15E-003	.91	.96	.04	.00	.18

e) Assumption of independent errors

Plot of standardised residuals versus participant

