COMPARING THE IMMEDIATE FREE RECALL OF VERBAL AND VISUO-SPATIAL STIMULI: LIST LENGTH, CAPACITY AND OUTPUT ORDER EFFECTS IN SINGLE- AND DUAL-MODALITY TASKS

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For my Mother, who Taught me to Never Leave a Question Unanswered

"Il-Mistoqsija Oħt il-Għerf"

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ABSTRACT

When participants are presented with a list of words, and are asked to recall the items in any order (Immediate Free Recall; IFR), they tend to initiate their recall with the first list item when presented with short lists and with one of the last four items in longer lists. Chapter 2 examined whether this tendency necessitates a language-based retrieval mechanism by replicating and extending this finding in verbal and visuo-spatial IFR. The observed similarities between the two modalities are argued to be reflective of either a domain-general retrieval mechanism that operates on all stimuli at all timescales, or two domain-specific mechanisms that operate in quasi-identical ways. To distinguish between these two possibilities, Chapter 3 compared capacity and output order effects in both stimulus domains in single- and dual-modality IFR tasks. The number of items recalled in dual-modality IFR suggest partially independent capacities, but the output orders across the two modalities were greatly constrained; findings that cannot be fully explained through either a domain-general or domain-specific framework. Additionally, participants' tendency to alternate across modalities may be due to one-to-one associations of auditory words with the contemporaneous visuo-spatial locations. Consequently, Chapter 4 examined whether this alternating output strategy is still present when list structure is completely randomised and the items temporally off-set. I argue that this tendency is not entirely due to some form of binding but may, at least in part, reflect the most efficient way of outputting a mixed-modality list. Moreover, the asymmetry in the recall accuracy of the two modalities is due to increased number of to-be-recalled stimuli rather than increased output interference. I suggest that overall, a domain-general approach, such as the Embedded Processes model (Cowan, 2005), coupled with a forward-ordered retrieval mechanism based on temporal grouping (Farrell, 2012) is better placed to account for these novel findings.

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I confirm that the work presented in this thesis is my own original work and in my own words, except for quotations from published and unpublished sources which are clearly indicated and acknowledged as such, both in text and in the reference section.

PUBLICATIONS

Publications arising from this thesis:

Chapter 2

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Chapter 3

Cortis, C., Dent, K., & Ward, D. (in preparation). On the simultaneous immediate free recall of auditory-verbal and visuo-spatial stimuli: Evidence for separate capacities but constrained output orders.

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LIST OF ABBREVIATIONS

ACRONYM	PHRASE
ACT-R	adoptive character of thought rationale
ANOVA	analysis of variance
AP	alternating presentation
AS	articulatory suppression
AV	auditory verbal
CBT	Corsi blocks task
CDFR	continuous distractor free recall
CMR	context maintenance and retrieval
CQ	competitive queuing
DFR	distractor free recall
DNV	dynamic visual noise
EP	embedded processes
IFR	immediate free recall
ISR	immediate serial recall
LIST-PARSE	laminar integrated storage of temporal patterns for associative retrieval sequencing and execution
LL	list length
LTM	long-term memory
LTS	long-term store
MD	modality-dependent
MI	modality-independent
NRT	non-word repetition task
O-OER	object-oriented episodic record
PL	phonological loop
PM	primary memory
PP	parallel presentation
REM	retrieving effectively from memory
RoO	reconstruction of order
RP	randomised presentation
SIMPLE	scale-independent, perception and learning
SLI	specific language impairment
SM	secondary memory
SP	serial position
ST	spatial tapping
SPC	serial position curve
STM	short-term memory
STS	short-term store
TCM	temporal context model
TODAM	theory of distributed associative memory
VPT	visual pattern test
VS	visuo-spatial
VSSP	visuo-spatial sketch pad
WM	working memory

CHAPTER 1

CHAPTER 1

When participants are instructed to recall a short list of words *in any order,* such as: "bat, mouse, tea, stairs", they often recall the list *in the same order* it was presented (that is, they recall "bat, mouse, tea, stairs"), even though there is no forward order requirement of the task. Although this finding was first reported by Corballis (1967) and consequently by Neath and Crowder (1996), the first systematic examination into this finding was conducted by Ward, Tan, and Grenfell-Essam (2010). Ward *et al*. (2010) presented participants with lists of between 1 and 15 words, presented one at a time and at test required them to recall as many words as they could remember either in any preferred order (Immediate Free Recall; IFR) or in strict forward serial order (Immediate Serial Recall; ISR). The critical observation in their findings was that when participants are presented with short lists of words, they tend to initiate recall with the first item and proceed in an "ISR-like" manner; this tendency decreased with increasing list length.

Ward *et al.* argued that this finding was important for a number of reasons. First, the finding encouraged greater theoretical integration between the otherwise divergent IFR and ISR literatures. Second, the finding is potentially difficult to explain by many theories of IFR that emphasize the importance of explaining recency effects (that is, the high accessibility of items presented toward the end of a list). Third, the finding adds to the growing body of evidence that suggests that forward-ordered recall may be a defining principle of episodic memory (Hurlstone, Hitch, & Baddeley, 2014)

Consequently, my thesis aims to address three main questions. First, it aims to address the question of whether this forward-ordered tendency observed in the IFR of word lists is restricted to the verbal domain. More specifically, is this finding underpinned by a language-specific mechanism or is it also present in the visuo-spatial domain? Second, it aims to further examine the functional similarities and differences between verbal and visuo-spatial immediate memory. This will be achieved through a direct comparison of IFR performance of verbal and visuo-spatial stimuli, using both single- (Experiment 1-3) and dual-modality tasks (Experiments 4-7). The third and final aim of the thesis is to help determine whether a domain-general or a domain-specific framework is better placed to explain list length, capacity and output order effects found in the IFR of single-and dual-modality tasks.

Although all empirical work in this thesis focuses on IFR, the significance of the findings and their implications can only be fully understood with knowledge of ISR. This is because recent investigations of the two tasks have shown that there are a great number of similarities between IFR and ISR, that imply that there may be common mechanisms underpinning both tasks (e.g. Beaman, 2006; Bhatarah, Ward & Tan, 2008; Bhatarah, Ward, Smith & Hayes, 2009; Farrell, 2012; Ward *et al.*, 2010). Therefore, it is beneficial to discuss both IFR and ISR literatures in both the verbal and visuo-spatial domains. Consequently, this chapter will first introduce verbal IFR and ISR tasks and their divergence, as well as introduce visuo-spatial tasks and their contribution to the divergence of verbal and visuo-spatial immediate memory. The present thesis requires a broad review of several literatures, as well as the theoretical relationships between them. Figure 1.1 depicts a 2 x 2 matrix representing the different literatures that fall within the scope of the thesis.

First, I will review the vast verbal IFR (a) literature and compare it to the much smaller visuo-spatial IFR (b) literature. Second, I will review both verbal ISR (c) and visuo-spatial ISR (d) literatures; these literatures have led to several studies investigating the functional similarities and differences between the two domains (3). Third, since the critical observation of the phenomenon of interest is the fact that participants tend to output short lists of words in IFR in an “ISR-like” manner, I will discuss research that is concerned with the similarities between the ISR and IFR literatures (1). Since I will be comparing verbal and visuo-spatial free recall, this thesis will shed light on the relationship between the two (2) and in turn, possibly elucidate the relationship between visuo-spatial IFR and visuo-spatial ISR (4).

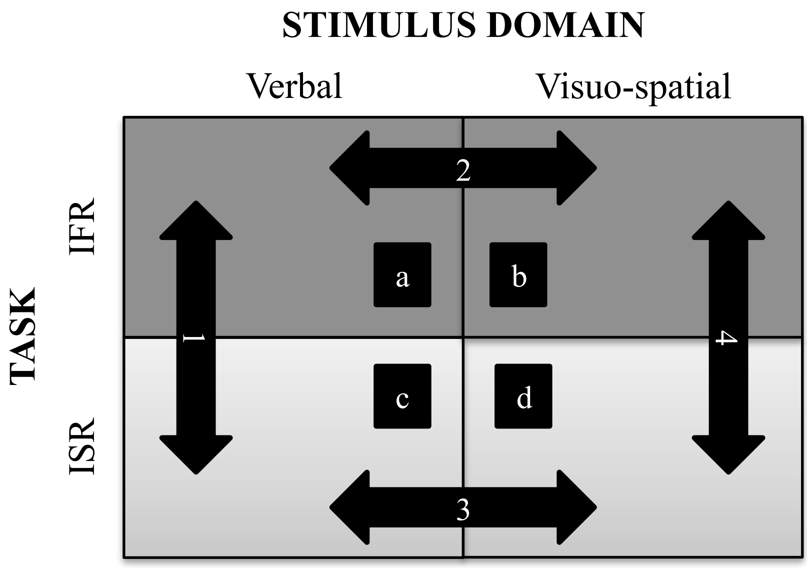

Figure 1.1. Scope of the Thesis. The darker shaded area reflects the tasks used in the present experimental work.

INTRODUCTION TO IFR AND ISR

IFR and ISR are probably the most widely used tasks within the field of immediate memory and are more commonly used with verbal rather than non-verbal stimuli. The typical IFR task presents participants with a relatively long list of verbal items (typically 10-20 words) that are presented one at a time. At test, the participants are required to recall as many items as they possibly can, in any order that they wish. Therefore, for a response to be considered correct in IFR, an item needs simply to have been presented during the stimulus presentation phase. Since no serial order information is required, the chosen order in which participants output their responses inform the study of the mechanisms of memory search and retrieval (Kahana, 2012).

The serial position curves (SPCs) in IFR tasks show a recall advantage for the first and last few items on the list, termed the *recency effect*. Many dual-store accounts of immediate memory (Atkinson & Shiffrin, 1968, 1971; Davelaar, Goshen-Gottstein, Ashkenazi, Haarman, & Usher, 2005; Farrell, 2010; Lehman & Malmberg, 2013; Raaijmakers & Shiffrin, 1981; Unsworth & Engle, 2007) state that the recency effect is the result of the last few presented items being stored in a short-term memory (STM) and at test these are outputted first.

In ISR, participants are presented with a short sequence of words (typically 5-7 items) and at test, asked to recall the items in strict forwards-order. Whereas in IFR only item information is required, in ISR, both item and order information are necessary, and therefore, for an item to be considered correct in ISR, it has to be recalled in the correct serial position. There are two important measures of ISR: (1) the maximum number of items that can be correctly recalled in order, which is termed the *memory span* (Guildford & Dallenbach, 1925) and (2) when memory span breaks down, the SPCs in ISR are characterized by the heightened graded advantage for the first few list items; this is termed the *primacy effect*. Models of ISR (Baddeley, 1986, 2000, 2007) postulate that memory span reflects the use of a limited-capacity STM, and that therefore a list greater than memory span exceeds STM capacity.

THE DIVERGENCE OF IFR AND ISR

Ward *et al*. (2010) note that IFR and ISR are very similar in methodology and both are thought to make use of a limited-capacity STM. Perhaps surprisingly, however, the main consensus within the field is that ISR and IFR require two separate types of theories and mechanisms. Indeed, until recently many theories of IFR could not explain ISR, and many theories of ISR could in turn, not explain IFR. Ward *et al*. identify three lines of evidence that initiated the theoretical separation of ISR and IFR.

The first line of evidence supporting the distinction between IFR and ISR came from the distinctive shapes of the serial position curves of each task. Whereas IFR yields a U-shaped curve with extended recency (Murdock, 1962), ISR yields an inverted tick-shaped curve with extended primacy and slight recency for the last item (Drewnowski & Murdock, 1980). Consequently, the majority of immediate memory models either sought to explain the primacy effects in ISR or the recency effects in IFR, potentially leading to the difficulty in some models to explain both patterns of data in both tasks.

The second line of evidence in support of separate mechanisms for IFR and ISR came from the dissociations between variables affecting ISR performance, but not recency in IFR. For example, ISR performance was strongly affected by variables such as phonological similarity and word length, which were taken as evidence for a speech-based STM (e.g. phonological loop; Baddeley, 1986); however these were found to not have an especially great effect on the recency in IFR (Baddeley, 1976).

The third and final line of evidence is related to the capacity difficulties of a single STM to account for recency in both IFR and ISR performance. Baddeley and Hitch (1974,1977) presented participants with lists of sixteen words, with and without a concurrent six-digit load for ISR. They found that the recency effect of IFR was still present despite the concurrent ISR task and this presented difficulties in explaining how a single limited-capacity STS can account for both recency and memory span. This finding has been replicated by Bhatarah, Ward, and Tan (2006) who used a more systematic approach, whereby six digits were presented and recalled between each and every word on the list, including after the last presented item. Therefore, theorists who use STS to explain either the recency in IFR or ISR memory span performance often limit their theories to one or the other of the two tasks.

VISUO-SPATIAL TASKS

Whereas the verbal domain was predominantly examined through the recall of familiar verbal items such as digits, letters and words, the earliest visuo-spatial tasks were based on recognition and were mostly same/different judgement tasks. In a typical early visuo-spatial task, the participants were presented with one or more matrices in which random cells were filled to create unnameable patterns. At test, another matrix pattern appeared and participants were asked to state whether the pattern was the same or different to the one that has been studied (Luck & Vogel, 1997; Phillips, 1974; Phillips & Baddeley, 1971; Phillips & Christie, 1977a, 1977b). These recognition-based tasks produced a relatively flat SPC with no primacy and a one-item recency (Phillips & Christie, 1977a, 1977b), as opposed to the primacy and recency found in the verbal domain. This difference in SPCs is one of the earliest main reasons why verbal and non-verbal memories were thought of as two functionally distinct systems. However, recent evidence showed that equating methodologies result in similar primacy and recency effects in various non-verbal domains (Jones, Farrand, Stuart, & Morris, 1995; Ward, Avons, & Melling, 2005), and these studies will be discussed in greater detail later on in this chapter.

One of the oldest and most widely used visuo-spatial tasks requiring serial order is the Corsi Blocks Task developed in an unpublished thesis by Corsi (1972) and publicised by Milner (1971). The original version utilised nine identical wooden blocks arranged in a fixed random configuration. During stimuli presentation, the experimenter taps some or all of the blocks in a sequence. The participant is then required to recall the sequence by tapping on the blocks in the identical sequential order. In the classic evaluation, the shortest sequence consists of three blocks, and testing follows the same staircase procedure as a span task, in that, if a sequence is correctly recalled, the number of blocks tapped in a sequence is increased by one until the performance breaks down with two out of three trials being recalled incorrectly. More recently, two-dimensional computerised versions of the task have been developed and these are now considered to be superior to the original task, since they enable (1) automatic scoring which has greater accuracy, (2) randomised spatial arrangements and (3) easier manipulation of other variables such as sequence length, number of blocks and block length as well as (4) enabling the recording of response latencies (Berch, Krikorian, & Huha, 1998; De Lillo, 2004).

Another variant of the Corsi Blocks Task is the Dots task, developed by Jones *et al.* (1995). In this task, participants are presented with a sequence of dots, each presented in a different spatial location on a computer screen. At test, all of the presented dots appear simultaneously on the screen and participants have to indicate the order in which each of the dots was presented. Such tasks are known as Reconstruction of Order (RoO) tasks and have been utilised with other stimuli such as unfamiliar faces (Ward *et al.*, 2005) and novel patterns (Avons, 1998). In the present work, a variant of the Dots task is used, such that at test, participants were required to click on the spatial locations where they had previously seen a visuo-spatial dots; this has therefore changed a RoO task into a recall-like task (see Chapter 2 for further discussion).

Another less common visuo-spatial task is the Visual Pattern Test (VPT) developed by Della Sala, Gray, Baddeley, Allamano, and Wilson (1999). In this task, participants are briefly presented with a matrix pattern produced by colouring half the cells in black. At test, participants are asked to identify which cells within the matrix were black. The aim of the task was to test visual memory without any sequential and spatial elements. However, this test can be considered to overlap with spatial memory, since indicating which cells were filled in, one at a time still entails some form of serial spatial recall (Vandierendonck & Szmalec, 2011).

A REVIEW OF THE VERBAL IFR LITERATURE

Immediate free recall tasks have been central to our understanding of the mechanisms underpinning immediate memory. The first published study using an IFR task was published by Kirkpatrick (1894), who presented primary school and college students with lists of ten common words either visually or orally and then asked them to write down as many words as they could remember without requiring order and then again after three days. This study was pedagogical in nature and exclusively concerned with the average number of words recalled and although its technique was initially met with criticism for its simplicity and lack of structure (Ebbinghaus, 1908), the IFR task gained popularity in the 1950s and 1960s – the main empirical findings and theories will be discussed in subsequent sections.

EXPLAINING THE PRIMACY AND RECENCY EFFECTS IN IFR

Greene (1992) states that most research expounding on the importance of serial position effects have focused more on recency effects than primacy effects. This is due to the fact that the primacy effect can be satisfactorily explained as the result of rehearsal, whereby the first items on the list are remembered more readily due to the number of rehearsals attributed to them. By contrast, recency effects have captured the interest of memory researchers since, the last few list items are remembered as well as, if not better than, the earlier ones despite having little or no rehearsal. Furthermore, it has been shown that a number of variables during material presentation affect the primacy and recency portion of the SPCs in different ways.

PRIMACY AND REHEARSAL

One of the earliest experimental studies conducted to try to explain primacy and recency effects was conducted by Welch and Burnett (1924). In their first experiment they presented participants with unpronounceable trigrams (e.g. ‘YJV’ and ‘QWH’) and specifically instructed them to exclusively focus their attention on a particular trigram only during its presentation. The results showed no primacy effect, whereas performance on the later items, especially for the last item was considerably higher, leading to a one-item recency.

Welch and Burnett's second and third experiments differed from the first in that, the trigrams used were pronounceable (e.g. “MOF” and “TUV”) and participants were merely instructed to remember as many syllables as possible. In both these experiments, the serial position curves showed primacy and recency. Welch and Burnett attributed the primacy to the difference in encoding between the first experiment and the other two, whereby when not instructed to focus only on the present item, participants availed themselves of the opportunity to rehearse previous list items. Several consequent studies have shown an elimination or reduction of the primacy effect when participants were only allowed to rehearse a particular item while it was being presented (Fischler, Rundus, & Atkinson, 1970; Glanzer & Meinzer, 1967).

Studies of incidental learning (Glenberg *et al*., 1980; Seamon & Murray, 1976) have also shown support for the rehearsal account of the primacy effect. In incidental learning tasks, such as in Experiment 2 of Glenberg *et al.*, participants are presented with lists of words without being made aware that they will be asked to recall them later. Participants are then asked to perform unrelated tasks such as mental arithmetic and object-size judgement tasks, followed by an unexpected recall test at the end of the experimental session. Glenberg *et al.* showed that there was no primacy in such tasks and they attributed this to the fact that because participants did not know they would be subsequently asked to recall, they simply had no motivation to rehearse the earlier items on the list, and these were consequently forgotten.

Other researchers have tackled the idea that primacy is a result of rehearsals attributed to each list item by asking participants to rehearse the list items out loud, i.e. the overt rehearsal method (Rundus & Atkinson, 1970). When tallying the number of rehearsals for each list item, the first few items on the list were repeatedly rehearsed much more than the rest of the list items (Rundus, 1971; Rundus & Atkinson, 1970; Tan & Ward, 2000). Additionally, Craik and Lockhart (1972) note that the first items on a presented list are rehearsed qualitatively differently to the later ones, since at the beginning of the list participants have less items to divide their attention between and this may lead to more elaborative rehearsal, whereby mnemonic strategies are devised to aid recall. By contrast, items toward the end of the list are rehearsed shallowly (Craik, 1970). Recently however, it has been shown that although rehearsal contributes to primacy, especially at slower presentation rates, primacy is still found in the absence of rehearsal (Grenfell-Essam, Ward, & Tan, 2013).

Dissociations between Primacy and Recency

The pre-recency and recency portion of the serial position curve have also been shown to be distinct through dissociations, whereby different variables have shown to affect one portion but not on the other. More specifically, whereas variables such as word frequency, presentation rate and list length have been shown to affect the primacy portion, the use of filled delay tasks and final free recall have been shown to affect recency.

Variables affecting Primacy

(1) Word Frequency. When presenting participants with lists of either high or low frequency words, Sumby (1963) found that IFR performance increased as a function of word frequency, i.e. common words were easier to remember. He also found that in high-frequency lists, participants tend to start with the first few presented items and group their output semantically, whereas in low-frequency lists participants initiate their output with the last few items and categorise their output according to the items' phonological similarity. This results in a typical bowed serial position curve for the high frequency lists with both primacy and recency, whereas the low frequency lists yield extended recency and no primacy. These findings have been broadly replicated in several research papers (Raymond, 1969; Tan & Ward, 2000; Ward, Woodward, Stevens, & Stinson, 2003).

(2) Presentation Rate. Overall, a slower presentation rate facilitates recall; this is because the longer the inter-presentation interval, the more time there is for each item to be rehearsed before the next one is presented. Additionally, slower rates also enable more time for more elaborative mnemonic strategies that aid recall. However, slower presentation rates tend to have a favourable effect on the pre-recency portion and thus increase recall for the earlier list items, whereas recency remains unaffected (Glanzer & Cunitz, 1966; Murdock, 1962; Raymond, 1969; Roberts, 1972).

(3) List Length. IFR performance decreases with increasing list length. Murdock (1962) found that varying list length only affected primacy whereas recency remained consistent across list lengths by extending over the last eight presented items. This finding has been replicated by Lewis-Smith (1975) and Roberts (1972). Additionally, Postman and Phillips (1965) categorised the first outputted item as being from either the first or second half of the list. This crude measure of probability of first recall showed that the tendency to start with an item from the second half of the list increased with increasing list length.

Variables affecting Recency

(1) Filled Delay. In delayed free recall (DFR) tasks, participants do not recall immediately after the last list item is presented. Instead, after the last item on the list is presented, they are asked to complete a distractor task, such as mental arithmetic, for a specified amount of time before they are then asked to recall the items in any preferred order. In such experiments, recency is completely eliminated after 30 seconds of distractor activity, whereas the primacy remains unaffected (Glanzer & Cunitz, 1966; Postman & Phillips, 1965).

(2) Final Free Recall. In final free recall, participants are first presented with a number of lists as part of an immediate free recall task. Once the experiment is completed, participants are then given an unexpected test and asked to remember as many items from the entire experiment as they can in any order that they like. Craik (1970) demonstrated that in such tasks, participants tend to recall the first items resulting in a typical primacy effect. However, the end items are the least correctly recalled items and Craik termed this the *negative recency effect*.

CONCLUSIONS FROM CONVERGING EVIDENCE

All of the abovementioned findings resulted in a two-store explanation of memory, such that during the late 1960s, the general consensus in immediate memory research was that the primacy and recency effects in IFR were a result of two separate memory processes (Glanzer & Cunitz, 1966; Postman & Phillips, 1965; Waugh & Norman, 1965). The primacy effect was said to be the result of the output from a long-term store: list items that receive a considerable number of rehearsals are selectively transferred to a more permanent store, which is then accessed during the immediate recall period. By contrast, the recency effect was said to be the result of the output from a more temporary memory storage, whereby presented list items are stored within a limited capacity short–term memory component and have the potential to be displaced by later items or simply forgotten as a function of time.

The recency effect occurs when participants output all contents found in the short-term store (STS) and because earlier items have either been displaced or transferred to long-term memory (LTM), participants are most likely to be left with the last few presented items, and therefore are more likely to be able to recall these. A two-store account also explains the negative recency effect, whereby during the final free recall test, participants can no longer rely on the STS resulting in the elimination of recency and instead the outputted items are from the long-term store (LTS) resulting in primacy effects.

DUAL-STORE MODELS OF IFR

The interest in human memory soared in the 1960s such that Norman (1970) edited a book entitled *Models of Human Memory,* which included 13 different models from different contributors. However, most of these models proposed a dual-store account which was similar to the one proposed by Atkinson and Shiffrin (1968) which has since been termed the 'modal model' (Baddeley, 1986).

MODAL MODEL (ATKINSON & SHIFFRIN, 1968, 1971)

This influential model assumes three separate memory components: the sensory registers, the STS and the LTS. In a free recall task, any input from the environment, first enter the modality-specific sensory registers for a very brief period of time. The information is then rapidly transferred to the limited-capacity STS, where it can be transferred into the more permanent LTS, which has unlimited capacity. The longer the item is maintained in the STS, the higher the probability that the item can be effectively shifted to the LTS. While the information is in the STS, related information from the LTS can also be transferred to STS temporarily to enable faster retrieval. This is because items in the STS are in a more highly accessible state than those in the LTS, although retrieval from the latter is still possible albeit at a slower rate.

According to this model, the STS holds and manipulates information, is under the immediate control of the individual and governs the flow of information in the memory system. This is done through a number of voluntary control processes, such as rehearsal (overt and covert repetition of information), coding (use of context), imaging (use of visual images to remember verbal information), decision rules, organizational schemes, retrieval strategies and problem solving techniques. In this model, primacy can be explained as the output from the LTS, since the first items are maintained for a longer time in the STS via rehearsal and are consequently transferred to LTS. Conversely, recency reflects output from the STS.

THE SAM MODEL (RAAIJMAKERS & SHIFFRIN, 1981)

The search of associative memory (SAM) model is a more updated computational model based on the Atkinson and Shiffrin model. It has a limited-capacity STS or memory buffer and items within it are easily retrieved. When items enter the STS they are stored as they were presented and can be rehearsed. Presented items remain in the STS until the buffer reaches its capacity, after which new items randomly displace the current items. Each item within the STS can be either associated with other items within the list (word-word information), or with the temporal context of the list, (word-context information). Therefore, the probability of an item to be transferred to LTS depends on the time each individual item is stored within the buffer independently **and** the time any combination of items remains in the buffer. Similar to the modal model, recency is a result of immediately outputting from the STS buffer.

The LTS can be conceptualized as a large unlimited capacity matrix containing numerical values that represent the strength of associations formed through the rehearsal processes. Retrieval from the LTS is a two-step cue-dependent process involving sampling and recovery. The chance of an item being sampled is based on the relative strength of association with the item and its context, but decreases with increasing association of other list items and the context. Once an item is successfully sampled, the chance of a word being correctly recalled depends on the absolute association strength of the particular word and does not depend on the association of the word with other list items. Since retrieval is a two-step process, forgetting can occur due to problems with a particular cue, for instance if a particular cue becomes associated with too many items, then it no longer remains effective for sampling purposes. Additionally, any contextual drift may lead to problems with the strength of associations of the items, and this consequently affects recall. As with the modal model, the primacy effect is explained as being retrieval from this LTS.

PROBLEMS FOR DUAL-STORE ACCOUNTS OF MEMORY

(1) Long-term learning as a function of time spent in STS. One of the main assumptions of the Atkinson and Shiffrin model is that the longer an item is stored within the STS, the more likely it is to be associated in the LTS and thus remembered. However, participants perform poorly on tasks that require them to remember details of everyday common objects, such as the US penny in a study conducted in America (Nickerson & Adams, 1979), and the letters located next to numbers on an old-fashioned telephone (Morton, 1967). Additionally, Craik and Watkins (1973) presented participants with 21 word lists and asked participants to recall the last item on the list beginning with a particular letter. The time spent in STS was varied by manipulating the number of interpolated words between the words beginning with the target letter, as well as presentation rate. A final free recall test showed that participants are more likely to recall the words that were reported and recalled more at the slower presentation rates, but there was no relationship between recall and the number of intervening words. In their second experiment, participants were presented with twelve item lists and asked to rehearse the last four items for 20 seconds after the end of the list. A final free recall test showed that despite this, performance for the last few items was worse than for the earlier ones. These studies thus showed that time spent in the STS as well as additional rehearsals of the end items do not enable more effective long-term retrieval.

(2) Long-term recency effects. One of the main findings that supported two-store models was that a filled delay eliminates the recency effect, since such tasks were thought to prohibit participants from using their STS and instead rely on their LTS. However, this explanation was questioned by Tzeng (1973) and Bjork and Whitten (1974) who made use of a continuous distractor free recall (CDFR) task, whereby during list presentation each word was preceded and followed by distractor activity, as well as having a delayed interval after the last item; this was done to prevent rehearsal. These authors found that CDFR tasks result in recency effects, whereas DFR tasks eliminates the recency effect. These long-term recency effects have also been found over longer periods of time, for example, when asking rugby players to name the teams they had played during the season (Baddeley & Hitch, 1977) and when asking people where they had parked their car during a course of twelve working days (Pinto & Baddeley, 1991).

(3) Capacity issues with recency. Watkins and Peynircioğlu (1983) presented participants with lists of 45 words pertaining to three main categories and these were alternated such that every third item came from the same category. They found three simultaneous recency curves, one for each category, rather than an overall recency for the whole of 45 items. This therefore contradicts the idea that recency reflects the capacity of a single STS. Additionally, as previously mentioned, if assuming that recency in IFR and ISR both use a common STS, then doing both tasks simultaneously should result in a performance trade-off. However, performing an IFR task, while concurrently holding a digit load does not seem to severely hinder the performance of either tasks (Baddeley & Hitch, 1974, 1977; Bhatarah *et al.*, 2006).

(4) Temporal contiguity effects. The temporal contiguity effect refers to the grouping of outputs in IFR; typically at long lists participants start their recall with one of the most recent items and consequently recall neighbouring items. According to dual-store models, these effects are due to the neighbouring items being stored together in the STS. However, Howard and Kahana (1999) showed that temporal contiguity effects can be also found in CDFR tasks. To ensure that any two list-items were never stored together within the STS, each item was followed by sixteen seconds of mental arithmetic puzzles. Similar contiguity effects for IFR and CDFR tasks showed that these effects could not be due to a STS.

UNITARY MODELS OF IFR

THE RATIO RULE (BJORK & WHITTEN, 1974)

As discussed in the previous section, the long-term recency effect presented difficulty for dual-store models. Bjork and Whitten (1974) proposed a simple rule that can account for long-term recency effects; this was later called the ratio rule (Glenberg, Bradley, Kraus, & Renzaglia, 1983). The ratio rule states that the size of the recency effect is directly related to the ratio of the total time taken between each list item (inter-stimulus interval: **Δt**) and the total time between the last presented item and recall (retention interval: **T**). Recency is measured by using the slope of the best straight-line fit over the last three serial positions (SPs). This rule implies that the total time that an item needs to be remembered on its own is irrelevant. Instead it predicts that as long as the ratios are similar (e.g. one hour to one hour) then the recency effect should also be similar even for longer time periods such as weeks and years; Baddeley and colleagues have found this in the abovementioned work. Crowder (1976) used an analogy of spatial perspective to explain the ratio rule in more practical terms. He states that when passing a series of telephone poles, the ability to discriminate between each pole depends on the distance between the pole and the observer. If this distant is kept constant, then the discriminability of the series of poles will be a function of the distance between each of them.

CONTEXTUAL ENCODING HYPOTHESIS (GLENBERG *ET AL.*, 1980)

Greene (1992) states that the contextual encoding hypothesis provides an explanation for the ratio rule. Glenberg and colleagues propose that each list has its own psychological context, which is in turn broken down into several fluctuating contextual elements. Although all elements change, they do so at different rates. Effective recall is therefore dependent on how effective the test context is as a retrieval cue; the longer the retention interval, the more time allowed for the test context to change, thus rendering it less effective. The effectiveness of a test context is also dependent on the inter-stimulus interval, since the longer this is, the more likely that different list items are learned against different contexts. The recency effect occurs because the context at test is most likely to closely resemble the context associated with the last item. Given that this last item is learnt against a much more distinct and unchanged test context to the earlier list items, the test context is ineffective for the pre-recency items.

A Recency-Based Account of Primacy (Tan & Ward, 2000)

Both the ratio rule and the contextual encoding hypothesis attempted to explain the recency effects, whereas not fully explaining the primacy effects. Tan and Ward (2000) attempt to account for both primacy and recency effects in IFR by bridging the rehearsal account of primacy with the ratio rule. By utilising an overt rehearsal strategy, they proposed that primacy and recency are the result of a single recency-based mechanism, whereby when an earlier item is rehearsed, it creates a copy of itself that can be used in recall. This means that rehearsal alters a particular item's order within the list to the serial position at which the item was last rehearsed. The probability that a particular item is recalled depends on the number, distribution and recency of rehearsal. Recency occurs due to the last few items being presented very close to the recall period, whereas primacy occurs because there are multiple copies of the rehearsed item, distributed through the list, including some in the recency positions.

The Temporal Context Model (Howard & Kahana, 2002)

The temporal context model (TCM), proposed by Howard and Kahana (2002) is an influential model of IFR that is conceptually similar to the contextual encoding hypothesis and aims to explain recency and the forwards-ordered temporal contiguity effects. Similar to the Glenberg account, the TCM model assumes that items on a list are associated with a context that drifts over time. Therefore, neighbouring items have an identical or a similar context that has the potential to change and update itself through the thoughts and experiences associated with the list items. Furthermore, it is only possible to associate list items with a preceding context during list presentation and this explains the forwards-ordered tendency found in IFR. This asymmetry is caused because item n can affect the context of $n + 1$, but item $n + 1$ cannot contribute to the context of item n.

At recall, the most current context is used as a cue that activates the item representations created by the associations between the present context and items; this explains the recency effects since the end items have the most similar context to the one at test. Once an item is retrieved and recalled, it prompts the recall of other items that share the same or a similar context. One main difference between the TCM and the Glenberg account is that in TCM, the changes in context are not merely random, but a direct result of retrieving earlier contexts that are associated with items that have already been recalled. In TCM-A, an offshoot of TCM, Sederberg, Howard, and Kahana (2008) explain primacy effects as being due to the novelty value that the earlier list items have, and this leads to heightened attention to these items, enabling better recall. Another variant of TCM, the Context Maintenance and Retrieval (CMR) model also accounts for organizational non-temporal clustering in IFR (Polyn, Norman, & Kahana, 2009).

MODERN DUAL-STORE MODELS

COMBINED CONTEXT-ACTIVATION MODEL (DAVELAAR *ET AL*., 2005)

Davelaar *et al.* (2005) propose that the long-term recency effect found in CDFR is different to the recency effect found in IFR, due to several dissociations between the performance in the two tasks, such as output order effects, negative recency effects, task-output effects on lag recency and neuropsychological studies of amnesia. Their neurocomputational context-activation model therefore proposes two separate memory components: an episodic contextual system that can account for long-term recency and an activation-based short-term buffer for short-term recency. The model is made up of a lexical-semantic component, where each item is related to a semantic context and an episodic component, where each item is associated with an episodic context. Each lexical-semantic component has a connection to itself, thus heightening its activation and enables maintenance. It also has the ability to inhibit other items and can form a network with similar semantic items. Additionally, lexical-semantic components benefit from contextual information. Items enter the short-term buffer where they can be subsequently encoded in episodic memory; these items can also be displaced by more highly activated items once the buffer reaches its capacity limit.

At recall, all items within the buffer are outputted first, resulting in recency effects. This is followed by retrieval from the long-term store, a two-step process similar to the one proposed by Raaijmakers and Shiffrin (1981) in the SAM model: sampling and retrieval. The model assumes that since the first few items are within the buffer in sequence for a long time before they start being displaced, they are better recalled, leading to primacy effects. Furthermore, the contextual information for the end and start items is more effective and accessible due to more attention, leading to the recall advantage of these items, hence primacy and recency effects.

INDIVIDUAL DIFFERENCES IN WM CAPACITY (UNSWORTH & ENGLE, 2007)

Unsworth and Engle present a dual-store framework similar to the one by Davelaar *et al.* (2005), by focusing on individual differences in working memory capacity. They compared participants with high and low working memory (WM) capacity as measured by different span tasks. Through confirmatory factor analysis, they also show that IFR is a good measure of working memory capacity. They thus propose that a dissociation between individuals with low and high WM capacity shows that there are two functionally and qualitatively distinct memory components that are similar to the modal model's concepts of STS and LTS respectively: primary memory (PM), a limited-capacity dynamic attention component with an upper limit of four items and secondary memory (SM) which is a permanent store, whereby information is retrieved through the matching of temporal, contextual and categorical cues to those at encoding. The model assumes that recency is a result of an output from PM, whereby all items within it are highly activated and thus outputted first, whereas all pre-recency items are a result of output from SM. The authors do not delineate a mechanism for primacy.

Recency Recall Probability Account (Farrell, 2010)

In his dual-store account, Farrell (2010) introduces conditional recency by analysing those trials in which the last presented item was recalled, regardless of output order. He shows that the probability of recalling the end list item increases with increasing output order in IFR but not in DFR. He states that this dissociation challenges unitary models that do not propose a dichotomy between long- and short-term memory, such as the TCM (Howard & Kahana, 2002) and the scale-independent memory, perception, and learning (SIMPLE; Brown, *et al*., 2007) model (see detailed explanation of SIMPLE on page 53), since this distinction in recency would not be likely if recalling items from a recency-based distribution. Instead, these findings are compatible with the idea that participants recall a sequence of items that terminates with the last item. He therefore suggests that a forward-ordered short-term buffer is required to account for these findings.

The Lehman-Malmberg (2013) Buffer Model of Encoding & Retrieval

Lehman and Malmberg (2013) present a model based on the Atkinson and Shiffrin model, the SAM model and the Retrieving Effectively from Memory (REM) theory originally proposed by Shiffrin and Steyvers (1997). The model assumes that items are stored as episodic images and that their composition depends on a limited-capacity short-term buffer that stores information about each image, as well as the strength of associations of each list item with its context (item-context association) and other list items (item-item associations). The strength of these associations depends on the number of items within the buffer and the contents of the buffer depend on rehearsal and compartmentalization processes. Compartmentalization refers to the intentional eliminated items from the buffer when they are no longer required to perform a particular task (Lehman & Malmberg, 2009, 2011).

Retrieval depends on context cues that initiate sampling. The probability of sampling an item increases if the image trace is very similar to the context cue and this leads to effective recovery. Once an item is successfully recalled, its context cue is updated and this aids the recall of items that were previously held together within the buffer. Primacy is the result of stronger item-context associations at the start of the list since there are less items being rehearsed. In IFR recency occurs because the test context cue is almost identical to the context cues of the items held within the buffer, whereas the recency in CDFR can be explained by the fact that at test, the context cue is very similar to the end-of-list context.

A Review of the Visuo-Spatial IFR Literature

All of the above-discussed models of IFR are concerned with verbal items; this is because there is very little data delineating IFR performance of non-verbal items. To my knowledge there are only two studies examining the free recall on non-verbal stimuli.

Bonanni, Pasqualetti, Caltagirone, and Carlesimo (2007) examined the free recall of spatial locations by presenting participants with a 5 x 5 matrix comprising of 25 squares and during presentation participants saw either six, eight, or ten squares of those 25 changing colour one at a time in a sequence. At test, participants were asked to select the squares that had previously changed colour in any preferred order. Analysis of the serial position curves showed that similar to the IFR of words, there were both primacy and recency effects in the IFR of spatial locations, with extended recency effects at the longest list length. When manipulating presentation rate, Bonanni *et al*. (2007) observed stronger primacy effects when increasing the inter-stimulus time from one second to three seconds.

More recently, Gmeindl, Walsh, and Courtney (2011) compared IFR and ISR performance in a verbal digit span task to a computerized version of the Corsi Blocks Task. Overall performance was much higher for the verbal span task compared to the visuo-spatial one. Additionally, performance in both stimulus domains was better when participants were asked to recall in any order; however, the improvement in performance was much greater for the spatial task than for the verbal one. Critically, in both domains, participants tended to output items in the IFR task in an “ISR-like” manner; however this was twice as common with verbal relative to the spatial stimuli.

In their second experiment, Gmeindl *et al*. (2011) showed that memory for order was superior in verbal stimuli by using a serial recognition task. Participants were presented with two sequences of the same domain and asked to detect any changes to the sequence order. The authors show that participants are better at detecting changes in serial order with verbal stimuli compared to visuo-spatial locations and they conclude that verbal stimuli are more readily bound to serial order than visuo-spatial stimuli.

As can be seen from the current section, there is not much empirical data delineating the IFR performance of non-verbal items. This is because most research about non-verbal memory utilized tasks such as ISR and RoO tasks, resulting in different SPCs. Consequently, this has led theorists to think of verbal and visuo-spatial memory as functionally distinct memory components. The next section will outline models that postulate separate domain-specific stores for verbal and non-verbal items as well as those that propose that memory is a unitary concept.

A REVIEW OF THE VERBAL AND VISUO-SPATIAL ISR LITERATURE

The verbal and visuo-spatial ISR literature will be reviewed together since several models of ISR have focused on the distinction, or lack thereof, between verbal and non-verbal materials. As with IFR, the majority of ISR research is done within the verbal domain and it comes from a long-standing tradition of list learning. In his studies of serial learning using nonsense syllables, Ebbinghaus (1885/1913) found that recall was quicker and better with increasing number of repetitions. However, Jacobs (1887) is usually credited for the earliest experiment involving ISR. When reading out digit sequences to participants between the ages of 11 and 20 years, Jacobs observed that recall increased with age and was better for the higher-achieving children. Additionally, there was an effect of material on recall; Jacobs describes how a group of participants could recall 6.1 nonsense syllables, 7.3 letters and 9.3 digits.

The serial recall span was then utilised by Guildford and Dallenbach (1925) to calculate memory span, which is defined as the length of the list at which all items are perfectly recalled in order for at least 50% of the trials. Crannell and Parrish (1957) found that similar to the work of Jacobs, memory span was dependent on the type of stimuli; it is lowest for words, higher for letters and best for digits.

THE WORKING MEMORY (WM) MODEL (BADDELEY & HITCH, 1974)

The WM model, originally conceived by Baddeley and Hitch (1974) and later updated by Baddeley (1986, 2000, 2007, 2012), is probably the most influential ISR model accounting for ISR findings. It has also been integral in the dissociation of verbal and visuo-spatial immediate memory. Although the term WM is often used interchangeably with the term STS, WM emphasises the active manipulation of information in an otherwise passive limited-capacity store. In their early studies, Baddeley and Hitch (1974, 1977) gave participants a concurrent digit span task, while performing reasoning, comprehension and long-term learning tasks. They found that the cognitive functioning tasks were only mildly affected by the concurrent load and that performance was slower but still at a reasonable level. This trade-off in performance implied that WM has a limited-capacity store, but since both tasks could be done concurrently to a reasonable level, WM was segmented into multiple components.

The original model was made up of three components: the central executive, the articulatory loop, later referred to as the phonological loop and the visuo-spatial sketchpad. The central executive is the principle mechanism and it controls the focus of attention and decision making, while also serving as an interface to long-term memory (LTM). The phonological loop and visuo-spatial sketchpad are limited-capacity slave systems; the former processes phonological and verbal information and the latter processes visual, spatial and kinaesthetic information. In more recent years, Baddeley (2000, 2007) introduced another component to the WM model called the episodic buffer. This limited-capacity buffer is governed by the central executive and links all three of the original components of WM to LTM as well as to perception. This enables the integration and temporary storage of information from different sensory inputs through the use of common multi-dimensional representations, which can then be retrieved through conscious awareness. Since the present work aims to compare verbal and visuo-spatial immediate memory, I will discuss the phonological loop and visuo-spatial sketchpad in greater detail.

THE PHONOLOGICAL LOOP (PL)

The PL is probably the most widely investigated component of the WM model. This is because, as previously mentioned, most memory research before the conception of the WM model was done within the verbal domain. Additionally, the PL rendered itself to be easily testable due to the greater level of detail given in the earlier versions of the WM model. The PL is made up of two components: a passive storage component (phonological store) and an active loop enabling vocal or sub-vocal rehearsal for item maintenance (articulatory process). This has been the result of a number of studies showing that ISR was affected by the phonological similarity of the speech, word length, articulatory suppression and irrelevant speech.

(1) Phonological similarity effect. Baddeley (1966) conducted an experiment asking participants to perform ISR of five-item lists. One group of participants was presented with pure lists of either acoustically similar or dissimilar words, whereas the other group was presented with pure lists of either semantically similar or dissimilar words. He found that in the acoustic group, performance was significantly lower for the similar words than that of the dissimilar words, whereas there was a very small difference between the performance of the similar and dissimilar lists in the semantic group. This effect has been well documented (Baddeley, Lewis, & Vallar, 1984) and was used as evidence for phonological storage, wherein phonologically similar items become less discriminable and thus harder to recall.

(2) Word length effect. Baddeley, Thomson, and Buchanan (1975) compared ISR performance of short country names (e.g. Malta, Cuba) to that of long country names (e.g. Venezuela, Nicaragua) and found that the short country lists were much more likely to be remembered than their longer counterparts. Additionally, the number of words recalled out of five was significantly higher for the short country names. This was also replicated with English words matched on word frequency. Baddeley *et al*. (1975) also compared the ISR performance of words of different spoken duration. They found that the ISR performance of words that take longer to articulate (e.g. tycoon, humane) is worse than that of short words (e.g. bishop, hackle) for the first three of five serial positions. This relationship between speech rate and recall is also supported by a study of Welsh-English bilinguals (Ellis & Hennelly, 1980). Participants typically read English digits faster than Welsh ones and had higher spans in English than Welsh. Additionally, Naveh-Benjamin and Ayres (1986) found that native speakers of languages with multisyllabic digits (e.g. Arabic) had shorter memory spans when compared to those with monosyllabic digits (e.g. English). This converging evidence led to the conclusion that words that take longer to say are not as well recalled as short words because longer words require a longer rehearsal time period, such that by the time the sequence of such words is repeated there has been more trace decay.

(3) Articulatory suppression (AS). Articulatory suppression requires participants to utter a specific word or phrase repeatedly in order to prevent sub-vocal rehearsal. Murray (1967) presented participants with sequences of seven letters and asked them to recall them in serial order. There were four rehearsal conditions; participants where asked to either voice, whisper or mouth the presented letters or to repeatedly say the syllable "the" (AS). He found that recall benefitted the most from voicing the items out loud, whereas AS resulted in the lowest recall performance. Murray (1968) also found that the phonological similarity effect is eliminated by AS for visually presented items but not auditory ones; this was replicated by Baddeley *et al.* (1984). Finally, Baddeley *et al.* (1975) found that AS adversely affects long and short words equally. These findings led to the conclusion that whereas spoken material accesses the phonological store automatically, visually presented materials need to be subvocalized in order to access the phonological store.

(4) Irrelevant sounds/speech effect. When Colle and Welsh (1976) presented participants with visually presented sequences of digits either in silence or concurrently with white noise or an unfamiliar language, they found that only concurrent speech disrupted recall performance. When following up this evidence, Salamé and Baddeley (1986) found that when the irrelevant speech consisted of phonologically similar non-digit words (e.g. “tun”, “woo” to correspond with “one”, “two”) this resulted in an increased disruption relative to when presenting irrelevant digits during stimuli presentation. This led to the incorrect conclusion that this interference was due to phonological similarity; this was subsequently withdrawn, due to evidence that STM was disrupted by a range of sounds, for example, a series of changing tones (Jones & Macken, 1993).

(5) Language Skills and the PL. Since its conception, the PL was thought to be necessary for language acquisition and other core language skills such as reading and comprehension. In a longitudinal study, Gathercole and Baddeley (1989), devised the nonword repetition task (NRT) to examine the role of the PL in language acquisition. The NRT consists of forty spoken nonwords of between two and four syllables, which had to be repeated in the three-second period between each nonword. Gathercole and Baddeley (1989) recruited 104 children at age four and measured nonword repetition, non-verbal intelligence and vocabulary and then retested them a year later. They found that nonword repetition correlated with the vocabulary level at both age four and five, and that the nonword repetition score at age four was a good predictor of vocabulary level at age five.

Additionally, Gathercole and Baddeley (1990) used the NRT task with eight-year old children having Specific Language Impairment (SLI) and compared their performance with that of six-year olds, who had equivalent language development. They found that the SLI group had the equivalent NRT score of four-year olds and that they were sensitive to the phonological similarity and word length effect, except at the longest LL. Gathercole and Baddeley (1990) thus concluded that since perceptual processing and articulation rates of the SLI group were similar to those of the matched controls, the poorer memory performance in SLI is likely to be due a phonological storage deficit.

Studies of second language acquisition have also suggested that acquiring language depends on the PL. Papagno, Valentine, and Baddeley (1991) showed that preventing participants from rehearsal impairs the ability to learn foreign-language vocabulary, but does not interrupt paired-associate learning in their native language. Moreover, phonological similarity and word length effects also affect second language learning, but not the rate of learning of paired words in the native language (Papagno & Vallar, 1992).

THE VISUO-SPATIAL SKETCH PAD (VSSP)

When compared to the PL, the VSSP is much less established. Posner and Konick (1966) conducted one of the first studies in visuo-spatial memory. They showed that a point on a line was correctly recalled for a period of up to 30 seconds following presentation, and that recall decreases with increasing difficulty of interpolated tasks. Phillips and Baddeley (1971) presented participants with a 5 x 5 matrix where up to half of the cells were filled with unnameable stimuli at random. After a retention interval of between 0.3 to 9 seconds, participants were presented with the matrix again and asked to make a same or different judgement. They found that accuracy decreased with increasing retention intervals. However, the most utilised clinical task in visuo-spatial research is the Corsi Blocks Task, which can be seen as the equivalent of digit span in verbal immediate memory. Usually, participants recall about two less items on the Corsi Blocks Task when compared to the digit span (Baddeley, 2012).

Despite the fact that the WM was devised in 1974 and revised in 1986, the architecture of the VSSP was delineated much later. Logie (1995) conceptualises the VSSP as the counterpart to the PL, having two main components: one that stores object identity such as colour and shape (visual cache) and one that is used to rehearse and manipulate spatial information (inner scribe). Similar to the properties affecting verbal ISR, there are a small number of studies showing that there are equivalent variables for the visuo-spatial domain: visual similarity, visual complexity, as well as active and passive interference (Logie, 1995).

(1) Visual similarity effect. The visual similarity effect is the visuo-spatial counterpart of the phonological similarity effect. Recall of visually similar items has been found to be lower than that of dissimilar ones; this has been reported by Hue and Ericsson (1988) and Wolford and Hollingworth (1974) who reported visual similarity effects in the recall of unfamiliar Chinese characters and briefly presented visual verbal stimuli respectively. More recently, Jalbert, Saint-Aubin, and Tremblay (2008) presented participants with a sequence of coloured squares that were presented in different locations and at test asked them to reconstruct the order of the sequence. They found that memory for location and order is equally affected by the stimuli's visual similarity both when the task was done in silence and under AS. Avons and Mason (1999) and Smyth, Hay, Hitch, and Horton (2005) also found this effect for matrix patterns and unfamiliar faces respectively.

(2) Visual complexity effect. The visual complexity effect can be seen as analogous to the word length effect in the verbal domain. In a same/different judgement task, Phillips (1974) presented participants with three types of matrices varying in complexity from 4 x 4 to 8 x 8 containing different unnameable patterns, so that the bigger the matrix, the more complex the presented pattern. He showed that accuracy decreased with increasing number of items presented in the matrix cells, (i.e. pattern complexity); this has been replicated in a similar experiment by Bruyer and Scailquin (1998). Additionally, Parmentier, Elford, and Maybery (2005) found path complexity effects in the Dots task. This converging evidence suggests a limited capacity visuo-spatial component.

(3) Active Interference. Whereas in the verbal domain, AS is used to prevent from rehearsal, spatial tapping (ST) is utilised in the non-verbal domain as means of active interference. Farmer, Berman, and Fletcher (1986) gave participants verbal and spatial reasoning tasks, while concurrently performing AS or ST. They found that AS interfered with verbal reasoning performance but not on the spatial performance; conversely, they showed that ST interfered with spatial but not verbal reasoning. This selective interference has been replicated numerous times (Barton, Matthews, Farmer, & Belyavin, 1995; Smyth & Scholey, 1994) and was taken as evidence for the inner scribe, which has the ability to rehearse visual and spatial information.

(4) Passive Interference. Passive interference can be seen as the counterpart to the irrelevant speech effect in the verbal stimulus domain. This finding has been highly unreliable in that it has not been readily replicated. Logie (1986) showed that presenting irrelevant line drawings of common objects or random matrix patterns disrupts the concurrent visual imagery mnemonic task. In such mnemonic tasks, participants are presented with pairs of unrelated items and encouraged to form an image with the two items interacting, for instance the pair "cow-chair" would conjure an image of a cow sitting on a chair. Quinn and McConnell (1996) devised a passive interference technique called the Dynamic Visual Noise (DVN) whereby participants are presented with, but not required to attend to, black and white squares that change rapidly so as to appear flickering. They found that this interferes with pegword imagery tasks and the level of disruption is related to the number and rate of changes in the DNV. However, a more recent study using DNV has been shown to have no effect on visual memory tasks (ex. matrix pattern tasks, recognition of unnameable characters) other than mnemonic ones (Andrade, Kemps, Werniers, May, & Szmalec, 2002).

Limitations of the WM model

There are three main classes of limitations within the WM model: (1) problems identified by Baddeley (2007) himself, (2) the lack of specification of how serial order is maintained and (3) criticism levelled by other theorists, who prosed alternative models.

Baddeley (2007) reviewed the original WM model and concluded that it was faced with three main problems. First, it could not account for the temporary storage of information that is not attributed to the PL or VSSP. Second, it could not explain how visuo-spatial and phonological information can be integrated. Third, it could not explain the interaction between the temporary WM and LTM. However, he insists that the introduction of the episodic buffer, which is essentially an interface between all of the WM components and LTM, resolved all of these issues.

However, a further shortcoming of the WM was the fact that despite being based on ISR tasks, it neglected to describe the mechanism or process by which serial order is maintained within the WM model (Burgess & Hitch, 1999).

Maintenance of Serial Order

The maintenance of serial order in immediate memory tasks has captured the interest of most modern immediate memory theorists who have developed a number of computational models postulating how serial order is maintained. These models can be categorised into three: those maintaining serial order through chaining, context and activation.

Chaining Models

Early accounts of serial recall (e.g. Ebbinghaus, 1885/1913) postulated that each list item is connected to the next, such that when an item is recalled, it serves as a cue for the neighbouring items, hence the term chaining. Chaining theories had problems explaining how recall commences once an erroneous item is recalled. Modern chaining models overcome this issue by adding multiple weaker associations between an item and other non-adjacent items on the list. Chaining principles have been utilised in the **Theory of Distributed Associative Memory** (Lewandowsky & Murdock, 1989), which proposes a memory vector storing item and order information separately. Whereas item information is merely stored in the vector, order information is combined together to form a new different item. Retrieval probes are used to restore items to their original form and recall is effective if the restored items match the original items more than its various competitors.

POSITION OR CONTEXT MODELS

Position or context models came about as a result of the limitations of chaining models in explaining how recall is affected with item repetition within lists, since repetition leads to a single repeated item being used as a cue for various items (Henson, 1998). Therefore, rather than serial order being solely based on item associations, position or context models require both item association and the temporal context or position of each item. At recall, the context is reset to match that of encoding and as each item is recalled, context is shifted sequentially from one item to the next. Some examples of models that use these principles are the **network model** (Burgess & Hitch, 1992, 1999, 2006), the **start-end model** (Henson, 1998) and the **oscillator-based associative recall model** (Brown, Preece, & Hulme, 2000).

ORDINAL/ACTIVATION MODELS

Ordinal or activation models, assume that serial order does not rely on item-item or position-item associations. Instead, each independent item holds a relative value representing its activation level. At recall, the level of the activation of each item determines the output order, whereby the most active item is recalled first. Once outputted, that particular item is suppressed so that the next most activated item can be successfully recalled. Some examples of models that use this principle is the **primacy model** (Page & Norris, 1998, 2003), which states that each list item is ranked via a primacy gradient, the **serial-order-in-a-box model** and the updated version **context- serial-order-in-a-box model** (Farrell & Lewandowsky, 2002; Lewandowsky & Farrell, 2008), where each item's information is stored as a vector within a weight matrix and the **recurrent neural network model** (Botvinick & Plaut, 2006), which states that serial order is maintained through heightened activity caused by recurrent connectivity in the prefrontal cortex.

SERIAL ORDER OF NON-VERBAL STIMULI

The abovementioned models of serial order have been based in the verbal domain and thus were concerned with explaining the PL. However, since the VSSP was developed as its non-verbal counterpart, it is theoretically possible for context and/or ordinal models to account for visuo-spatial serial order (Vandierendonck & Szmalec, 2011). In a recent article, Hurlstone *et al*. (2014), propose that verbal, visual and spatial information is underpinned by a common competitive queuing (CQ) mechanism whereby for an item to be recalled, it needs to be the most activated item; this item is then suppressed to allow for the subsequent items to be recalled.

Delogu, Nijboer and Postma (2012a, 2012b) have found that memory for serial order is separable to that of item location, such that the latter is an automatic process that requires much less attention than the former. When Delogu *et al*. (2012a) asked participants to remember the location and/or the serial order of familiar visual items and sounds (e.g. picture of a cow and a mooing sound), they found that encoding both features had an adverse effect on serial order but not on item location and that this asymmetry was found in both auditory- and visuo-spatial memory. This asymmetry has been replicated in the auditory-spatial domain by Delogu *et al*. (2012b).

A recent domain-general perspective was also put forward by Abrahamse, Dijck, Majerus, and Fias (2014) who liken memory to a mental whiteboard, where items are spontaneously coded along a spatial continuum. They therefore relate serial order to the spatial attention system, where position markers akin to spatial coordinates mark serial context. Internal spatial attention is required to reconstruct the serial order of a list, by searching through the spatial coordinates and successful retrieval is therefore dependent on the appropriate position markers being selected by spatial attention.

ALTERNATIVES TO THE WM MODEL

The WM model has been as controversial as it has been influential. Variables thought to have an affect on the phonological loop such as the word length effect and the irrelevant speech effect have been researched and questioned in a great number of studies (word length effect: Nairne, Neath, and colleagues; irrelevant speech: Jones and colleagues), leading into alternative propositions of how immediate memory works. In addition, there has been an on-going debate about whether short-term forgetting is due to interference (Nairne, 2002) or trace-decay (Baddeley, 1986). Furthermore, there is debate about the scope of the WM model, in that, it does not explain IFR, recency effects and echoic memory effects amongst others. Finally, and more relevant to the present work, researchers in the field questioned whether immediate memory is indeed fractionated into domain-specific stores, whether there are some common domain-general processes governing memory performance of different modalities and how the WM model accounts for memory performance of domains other than verbal and visuo-spatial, such as olfactory and gustatory memory.

Feature Model (Nairne, 1988, 1990; Neath, 2000; Neath & Nairne, 1995)

The feature model gets its name from its core assumption that list items are made up of a set of features that can take a value of 1, -1, or 0 in the absence of a feature. Therefore, the model assumes only two types of features: modality-independent (MI) and modality-dependent (MD) features. MD features are physical and contextual in nature and consist of both intra-item (e.g. presentation mode and language) and extra-item (e.g. characteristics of experimental room) attributes. MI features represent the item characteristics and these are internally generated through identification and categorization. For instance, reading a word "book" and saying it out loud results in identical MI features but different MD ones. There is a one-to-one relationship in the overwriting of features, such that MD features can overwrite other MD features and MI features can overwrite other MI features. This distinction between the two types of features allows the model to explain modality (i.e. recency advantage for auditory words) and suffix effects (i.e. elimination of modality effect by using an irrelevant auditory extra item at the end of list).

The model distinguishes between a temporary PM and a more permanent SM wherein, memory traces (i.e. a group of features) are encoded to both types of memory simultaneously. Within this framework, forgetting is the result of interference and this is influenced by feature similarity and grouping. A memory trace can be overwritten if any subsequent memory trace is categorised as similar to the one preceding it. At recall, each list item is represented by degraded memory traces in PM and these are matched with the intact representations in SM. The word with the least mismatches is most likely to be recalled, and then suppressed to ensure it is not reselected. Primacy occurs due to the lack of output interference for the first few list items; this output interference increases with increasing list items. Recency occurs because the memory trace of the last few items are not overwritten and has more features enabling discrimination.

Serial order is maintained by accessing traces in the order in which they were encoded in. Trace order is maintained in a vector, similar to the way in which features are preserved. Apart from the modality effect and the suffix effect, the Feature model has proved very effective in explaining several of the effects that the WM model attributed to the phonological loop. The feature model explains the modality effect by stating that auditory presentation provides more useful MD features than visual presentation, hence the larger recency advantage in auditory presentation. The suffix effect is explained by the fact that the MD features of the extra item overwrite those of the end list item. The phonological similarity effect occurs because words with similar sounds also share several MI features leading to poorer matching and more overwriting. Articulatory suppression and irrelevant speech are detrimental to recall since the features of the articulated word or irrelevant speech replace some features of the to-be-remembered list items. Finally, Neath and Nairne (1995) also explain the word length effect by stating that the longer the word, the more segments of features it is comprised of, and at test it is much harder to assemble these segments to enable recall. This was controversial since the model predicts a multi-syllabic word length effect rather than a time-based one as proposed by Baddeley *et al.* (1975). Indeed, the Baddeley *et al*. (1975) time-based word length effects have not been readily replicable when using different word sets (Caplan, Rochon, & Waters, 1992; Lovatt, Avons, & Masterson, 2000).

THE O-OER MODEL (JONES, 1993; JONES, BEAMAN, & MACKEN, 1996)

The object-oriented episodic record (O-OER) model was originally conceived to explain the irrelevant speech effects found in ISR. As previously mentioned, Jones and Macken (1993) found that serial recall of words can be disrupted by irrelevant changing-state sounds (e.g. tones and bangs) as well as speech. Tremblay, Nicholls, Alford, and Jones (2000) found that sine-wave speech disrupted ISR performance regardless of whether it was perceived as speech or not; this was slightly less disruptive than natural speech, thus showing that speech does not have a special status. Additionally, Jones and Macken (1995) found that the phonological similarity of the visually presented words and the irrelevant auditory words does not determine the irrelevant speech effect. Jones *et al*. (1995) presented participants with verbal ISR with a secondary task of either steady-state or changing-state irrelevant speech and compared it to visuo-spatial ISR with a secondary task of either steady-state or changing-state irrelevant tapping. They found that performance on the verbal and visuo-spatial tasks was unaffected by their respective steady-state task and equally affected by their respective changing-state task; consequently Jones *et al*. (1995) argued for functional equivalence between verbal and visuo-spatial memory.

As a result of the above findings, the O-OER model expounds memory as a unitary representational space containing abstract and amodal representations of items and events. Within this framework, memory processes are not functionally distinct from those of attention and perception. Objects are created through processes that detect boundaries, which in turn create objects. The O-OER's mechanisms are based on the changing-state hypothesis (Jones, Macken, & Murray, 1993) that states that change in energy establishes the arrival of a unique object. Serial order is maintained via a chain of associative cues termed links or pointers. When remembering a list of visually presented items, deliberate rehearsal is required for the order to be maintained, since pointers decay over time. Therefore, the ability to recall is inversely proportional to the level of degradation of these pointers. It is important to note however, that the model also allows for access via a non-serial recall procedure.

PERCEPTUAL-GESTURAL ACCOUNT (JONES, HUGHES, & MACKEN, 2006, 2007)

Jones' later work evaluated the need for the phonological store. Within the PL framework, the phonological similarity effect and irrelevant speech effect should only occur if the stimulus has entered the phonological store. Auditory items have automatic access to this store whereas visual items under AS do not (Baddeley, 1986). Jones, Macken, and Nicholls (2004) did not find the predicted interaction between irrelevant speech, AS and modality and an interaction between modality, phonological similarity and AS which could be reduced by adding a suffix. Given that the use of a suffix is an acoustic factor rather than a phonological one, Jones *et al*. (2004) state that properties usually attributed to the phonological store can be better described by a perceptual-gestural account. This view states that the temporal order of a sequence in natural language is itself constrained by syntax, grammar and semantics. In ISR however, these cannot be utilised due to the use of unrelated sets of words. Therefore, ISR performance depends on a more general-purpose perceptual process, as well as motor-planning processes; these processes operate at the sequence level rather than on each individual list item (Hughes, Marsh, & Jones, 2009). During list presentation, items are organized into different auditory streams through pre-attentive and non-volitional perceptual principles. Items within one stream are easier to recall in order than items in various streams and order information is better encoded in sequence boundaries. This evidence comes from the elimination of recency when adding a suffix to the end of the list, since this replaces the last list item at the boundary (Jones *et al*. 2006). Additionally, a time critical motor plan is constructed in order to compensate for the lack of connection between the test sequence and long-term sequence knowledge. Each individual item is loaded onto a generic motor plan, where it is transformed from grapheme and phonological form. This motor plan is required for all types of outputs such as articulatory output (i.e. spoken speech) as well as non-verbal outputs (e.g. pointing movements) and therefore does not require a functional distinction between verbal and non-verbal stimulus domains.

EMBEDDED-PROCESSES MODEL (COWAN, 1988, 1995, 1999, 2005)

Cowan's Embedded-Processes model is a more general and exhaustive model of memory when compared to the WM model. His approach differs from that of Baddeley and colleagues in that, rather than identifying and investigating specific stores and their processes, Cowan's view is concerned more with cognitive processing. Due to its general nature, the Embedded-Processes model can account for memory for all stimulus domains and therefore does not postulate separate domain-specific buffers. Additionally, the model does not propose separate short-term and long-term memory stores. Instead, this model proposes a single memory repository akin to LTM and distinguishes between two subsets of the processing system: (1) a subset of activated elements that is represented in memory and (2) a further subset of elements that are within the focus of attention. The activated subset of elements includes both semantic and sensory information and it replaces the buffers within the WM model. Sensory features can be activated automatically, whereas semantic information requires attention. Therefore, if the activated set contains items with similar features, these interfere with one another. The focus of attention is controlled via automatic responses to the change in the environment as well as through internal and voluntary central executive processes (control of attention). Cowan states that new associations between concurrently presented items can be formed as chunks or events in long-term memory through attention processes.

If similar, stimuli can be grouped into chunks, however if grouping and rehearsal is prevented, an item is represented as a single chunk (Chen & Cowan, 2005, 2009). Adults can hold between three and five chunks in the focus of attention (Cowan, 2001; Cowan *et al*., 2011, but see Mathy & Feldman, 2012). Rather than having a working memory capacity, memory is limited through trace decay and interference. These detrimental factors can be counteracted through sub-vocal rehearsal and attentional refreshing, since these reactivate the items further. Whereas the focus of attention is predominantly represented in the parietal lobes, the control of attention is predominantly represented in the frontal lobes. However, the focus of attention is involved in the retention of items as well as task instruction and processing. Since task processing overlaps with the control of attention, this creates a conflict between the storage and processing of information (Morey & Cowan, 2004). To reach maximum capacity, the scope of attention can be zoomed out to the maximal number of items. It can also be zoomed in if task demands are high due to interference. Individual differences can be somewhat accounted for by the correlation between the ability to control attention and the capacity of the focus of attention (Cowan *et al*., 2005). Although the model is exhaustive and accounts for a lot of data sets, it does not have a detailed account of a mechanism that deals specifically with serial order processing (Acheson & MacDonald, 2009).

VERBAL AND VISUO-SPATIAL DOMAINS: DIFFERENCES AND SIMILARITIES

EVIDENCE FOR MODULARITY

There are three main lines of evidence that are frequently cited as supporting the idea that verbal and visuo-spatial domains are functionally distinct memory subsystems (Hurlstone *et al*., 2014; Parmentier, 2011): dual-task findings, evidence from neuropsychological patients, and neuroimaging studies.

(1) Dual-task findings. In dual-task methods, participants are presented with either a verbal or visuo-spatial task coupled with a concurrent secondary verbal or visuo-spatial task. Such studies have shown that the primary task is adversely affected by the secondary task of the same stimulus domain, such that verbal secondary tasks interfere with verbal primary tasks but not with the visuo-spatial one, and the visuo-spatial secondary task interferes with the visuo-spatial primary task but not the verbal one (Alloway, Kerr, & Langheinrich, 2010; Farmer *et al.*, 1986; Guérard & Tremblay, 2008; Logie, Zucco, & Baddeley, 1990). However, it is important to note that Jones *et al*. (1995) found that verbal and visuo-spatial tasks are unaffected by both steady-state secondary tasks (repeating a single utterance or tapping a single location) but both tasks were impaired when the secondary tasks involved changing-state material (uttering an alphabet sequence or location sequence tapping).

(2) Neuropsychological Patients. A few brain-damaged patients have been reported as having impaired verbal immediate memory, reflected by a poor performance in verbal span tasks, coupled with intact visuo-spatial performance as assessed by spatial span (De Renzi & Nichelli, 1975), whereas another patient had the opposite dissociation (Hanley, Young, & Pearson, 1991). Parmentier (2011) notes that the Hanley *et al*. (1991) paper showing impairment to the VSSP is the only of its kind.

(3) Neuroimaging studies. The use of brain imagery techniques, such as positron emission tomography (PET), and functional magnetic resonance (fMRI) have shown that verbal and visuo-spatial memory tasks recruit different brain regions. Whereas verbal tasks result in heightened activation of the left frontal cortical regions, the retention of visuo-spatial information recruits the right frontal region, right parietal and right occipital areas (Awh *et al*., 1996; Jonides, 1995; Smith & Jonides, 1997; Smith, Jonides, & Koeppe, 1996).

DISSOCIATION BETWEEN VISUAL AND SPATIAL MEMORY

Since Logie's (1995) development of the visuo-spatial sketchpad, there has been an on-going debate as to whether the spatial and visual information is maintained by different cognitive processes. In a recent research paper, Logie (2011) reasserts that the visual cache is used to temporarily maintain a visual array whereas the inner scribe retains any sequential movement within an array. Again, there are three lines of evidence supporting the fractionation of visual and spatial information: neuropsychological evidence, neuroimaging studies and behaviour studies.

Behavioural studies of selective interference have shown that spatial tapping interferes with memory for spatial locations as tested by a Corsi Blocks Task, whereas presenting irrelevant pictures interferes with memory for object identity for example shade recognition of an array of items (Logie & Marchetti, 1991) and reproducing a matrix pattern (Della Sala *et al*., 1999).

Neuropsychological studies have shown a double dissociation with visual and spatial information whereby some brain-damaged patients have deficits when performing spatial tasks, such as the Corsi Blocks Task, but typical performance on a visual task such as the VPT (Della Sala, Gray, Baddeley, & Wilson, 1997); other patients have impaired visual immediate memory performance with intact spatial memory performance (Darling, Della Sala, Logie, & Cantagallo, 2006; Della Sala *et al*., 1999). In a functional imaging study, Xu and Chun (2006) found that memory for object identity heightens activity in the superior intraparietal sulcus and lateral occipital complex, whereas the inferior intraparietal sulcus is involved in spatial processes.

EVIDENCE FOR EQUIVALENCE

Although the fractionation between verbal and visuo-spatial domains is and has been widely accepted within the field of immediate memory, there has been recent heightened interest in evaluating common order processes between the two stimulus domains. In their respective reviews, Parmentier (2011) and Hurlstone *et al*. (2014) list a number of effects that have been found across domains.

(1) Serial position curves (SPCs). The SPC was perhaps the first argument supporting a modular approach to immediate memory. The earliest studies of non-verbal stimuli involved presenting participants with unnameable visual patterns and at test participants were required to make a recognition decision. These two alternative forced choice recognition tests yielded a SPC with no primacy and 1-item recency (Broadbent & Broadbent, 1981; Phillips & Christie, 1977a, 1977b), which contrasted with the bowed curves found in verbal serial recall. Later visuo-spatial studies however, required participants to remember both item and order information. For example, when Smyth and Scholey (1996a) and Jones *et al*. (1995) presented participants with a visuo-spatial sequence and then asked them to recall the sequence in the order it was presented, they found bowed SPCs. These bowed SPCs have been found when using several non-verbal stimuli, such as unfamiliar faces and visuo-spatial matrices, where participants were required to reconstruct the order of the items in which they had been presented (Avons, 1998; Avons & Mason, 1999). Smyth *et al*. (2005) also found bowed SPCs for non-verbal stimuli and additionally showed that recall performance is not impeded by AS. Finally, when serial recall is required to be done in a backward serial order, both verbal and visuo-spatial stimuli yield a similar SPC with enhanced recency and reduced primacy, which is distinct to that of forward-ordered ISR (Farrand & Jones, 1996).

(2) Sequence length effect. Another salient feature of verbal ISR is that, as list length increases, recall accuracy decreases (Crannell & Parrish, 1957; Ward *et al*., 2010). This sequence length effect is not exclusive to the verbal domain since it has been found in visuo-spatial locations (Jones *et al*., 1995; Smyth, Pearson, & Pendleton, 1988), visuo-spatial movements (Agam, Bullock, & Sekuler, 2005), and unfamiliar faces (Smyth *et al*., 2005; Ward *et al*., 2005). Additionally, Avons, Ward, and Melling (2004) have shown that whereas item recall is not very sensitive to sequence length, order recall is highly sensitive to list length.

(3) Error patterns and generalization gradients. Error patterns are also informative with regard to the maintenance of items and their serial order. In serial recall, errors can be either related to the object's identity (item errors) or to the order the item was presented in, that is when a correct item is recalled in the wrong serial order (transposition error). Item errors can be divided into three: intrusions, (i.e. a recalled item which was not in the presented list), omissions and repetitions. Guérard and Tremblay (2008) compared item and transposition errors in verbal and visuo-spatial ISR tasks. They found that in both modalities, item errors are less prevalent than transpositions and that the number of intrusions and omissions increased across serial positions. It is noteworthy that transposition errors, which usually occur in serial positions close to the correct one, create a U-shaped trend in the verbal domain (Henson, Norris, Page, & Baddeley, 1996), this has also been found in RoO tasks of visuo-spatial locations (Guérard & Tremblay, 2008) and visual matrix patterns (Avons & Mason, 1999).

(4) Effects of temporal grouping. When a verbal sequence is subdivided into subgroups by interpolating temporal pauses to create temporal grouping, this improves recall and typically results in primacy and recency effects within each subgroup, creating a scallop-shaped SPC (Frankish, 1985). Additionally, the number of transposition error decreases but gives rise to the number of interpositions, that is, correctly recalling a whole group but in the wrong group order (Ng & Maybery, 2005). These temporal grouping effects have been found for auditory-spatial sequences (Parmentier, Maybery, & Jones, 2004) and visuo-spatial stimuli (Parmentier, Andrés, Elford, & Jones, 2006).

(5) Modality effect. The modality effect in the verbal recall literature refers to the finding that in auditory presentation there is superior recall for the last few presented words when compared to visually presented items (Crowder & Morton, 1969) and this is thought to be the result of a more lasting representation produced by phonological information (Burgess and Hitch, 1999). When comparing verbal and spatial RoO tasks with either visual or auditory presentation for both domains, Tremblay, Parmentier, Guérard, Nicholls, and Jones (2006) found modality effects for both types of stimuli. This effect was also found in the serial recall of musical notes (Greene & Samuel, 1986) and environmental sounds (Rowe & Rowe, 1976).

(6) Suffix Effect. The suffix effect refers to the finding that adding an extra redundant item, such as an auditory word to the end of an auditory-presented list, reduces the modality effect. This is a well-documented finding within the verbal ISR literature, and has been explained to be the result of the suffix gaining automatic access to the phonological store and preventing the last list item from being rehearsed (Baddeley & Hull, 1979). This same-modality suffix effect has been found in the recall of visuo-spatial stimuli, musical notes (Greene & Samuel, 1986), as well as tactile (Mahrer & Miles, 1999) and olfactory (Miles & Jenkins, 2000) stimuli.

(7) Sandwich effect. Baddeley, Papagno, and Andrade (1993) found that when irrelevant words are inserted between the target list items, this impairs ISR performance. Tremblay, Nicholls, Parmentier, and Jones (2005) presented participants with a visuo-spatial RoO task in which they interpolated the target visuo-spatial dots with an irrelevant dot of the same colour presented in the screen centre. They found that this hinders performance on the task, and that this sandwich effect was weakened or eliminated if the irrelevant items and list items were made visually distinct through the use of different colours.

(8) Hebb repetition effect. The Hebb repetition effect took its name after a study conducted by Hebb (1961) where he presented participants with 24 digit sequences for ISR. However, unbeknownst to the participants, one sequence was regularly repeated every three trials. Participants' recall accuracy of the repeated sequence improved gradually, compared to the other filler sequences. This effect has been replicated several times in the verbal domain (Hitch, Flude,

& Burgess, 2009; Page, Cumming, Norris, Hitch, & McNeil, 2006). Recently, this learning effect has been reported for visuo-spatial locations (Couture & Tremblay, 2006) and auditory-spatial locations (Parmentier, Maybery, Huitson, & Jones, 2008). Couture and Tremblay showed that the degree of learning of the repeated sequence is equivalent in the verbal and visuo-spatial domain and that learning does not depend on whether or not participants are aware of the repetition.

COMBINING THE EVIDENCE

When comparing verbal and visuo-spatial recall, Guérard and Tremblay (2008) found both evidence for functional equivalence by finding similar patterns of data in both domains, and evidence for modularity as found by the typical findings of dual-tasks. Parmentier (2011) states that whereas some recall mechanisms are modality specific, others span across modalities. He states that encoding and maintaining perceptual aspects of stimuli necessarily need to be modality specific due to the stimulus' inherent nature. However, 'transitional' information, such as serial order, refers to abstract mathematical concepts that can be generalised across modalities.

This view is somewhat shared by Hurlstone *et al*. (2014) who state that although verbal, visual and spatial domains are functionally distinct, they are underpinned by equivalent mechanisms that drive the similarities across domains. They argue that all short-term memories use a CQ mechanism, where possible items are considered for output in parallel, with the most activated item selected, outputted and subsequently suppressed. They assume that serial order in the verbal short-term memory CQ system is represented by a primacy gradient, position marking, response suppression and cumulative matching, and that item similarity and output interference also affect recall. However, Hurlstone *et al.* argue that it is currently unclear how serial order is represented within the nonverbal CQ systems, primarily because the relevant data sets have not yet been collected.

THE THEORETICAL INTEGRATION OF ISR AND IFR

The earliest comparisons of IFR and ISR were concerned with expounding on the differences in the SPCs and learning curves of IFR and ISR (Deese, 1957; Raffel, 1936; Waugh, 1961). Jahnke (1965) was the first to note that one of the possible reasons for the differences between ISR and IFR is the use of different LLs. All participants were presented with lists of 6, 10 or 15 words for either IFR or ISR. Accuracy was higher for IFR at shorter LLs. The SPCs for ISR showed greater primacy and weaker recency, whereas SPCs for IFR showed stronger recency with increasing LL. Critically, at middle-length lists (6 words) IFR performance showed the highest degree of similarity with ISR.

Rohrman and Jahnke (1965) presented participants with a single list and at test asked them to either recall item or order information only, or both item and order information. They found that accuracy was highest in the IFR condition but there was no significant difference between performance of people who had to either recall order information only, or both order and item information. Therefore, they concluded that the differences between ISR and IFR are due to retrieval. A similar study conducted by Detterman and Brown (1974) compared recall of item and order information for 10 or 15 item lists. Participants were either pre- or post-cued as to which kind of information they had to recall. They found that pre-cueing had no effect on recall and SPCs for both conditions showed recency effects coupled with weak primacy effects. They state that inferior performance in ISR is due to the fact that it requires both item and order information and that the differences in the SPCs of the two tasks was due to encoding strategies.

Beaman and Jones (1998) showed that the magnitude of disruption of irrelevant speech is equivalent in IFR and ISR, when the same materials and list lengths were utilised. More recently, Ward and colleagues have delineated a number of similarities between ISR and IFR by equating methodologies and utilising similar list lengths in both tasks. Bhatarah *et al*. (2008) compared ISR and IFR performance for eight-item lists across three conditions: ISR only, IFR only, and a post-cue group who at test, were told to either recall in any order or in strict forwards order. Bhatarah *et al*. found very similar SPCs for the pre-cued and post-cued conditions of the two tasks, and this implies similarities in the encoding and rehearsal of IFR and ISR tasks. Additionally, ISR and IFR are both equivalently affected by variables such as word length, presentation rate and AS (Bhatarah *et al*., 2009).

Finally, and more relevant to this study, when manipulating LL, Ward *et al*. (2010) showed that at short lists, IFR performance has an "ISR-like" quality, where participants start with the first presented item and continue recalling in forwards order. As LL increases, the tendency to start at the start in IFR decreases and instead participants tend to start with one of the last few list items; this is typical in IFR tasks. Therefore, this finding suggests that IFR and ISR have comparable SPCs when LLs are equated.

The similarities found in ISR and IFR performance suggest the use of a common mechanism. These findings have since propelled the development of unified models of immediate memory that can account for both ISR and IFR performance (Anderson, Bothell, Lebiere, & Matessa, 1998; Brown, Neath, & Chater, 2007; Farrell, 2012; Grossberg & Pearson, 2008).

THE ACT-R MODEL (ANDERSON *ET AL.*, 1998)

The *adoptive character of thought-rational* (ACT-R) model is a cognitive framework that can account for ISR and IFR, recognition memory and implicit memory. The model proposes that memory items are represented by chunks that can be held and accessed via buffers. In ISR, items are hierarchically organised into chunks, where each list item is represented according to its position within each group and in turn, within the list. Recall depends on the activation of chunks; their base-level activation can be increased through rehearsal and decreased with trace decay. At test, retrieval depends on procedural knowledge, which utilises order information to enable recall. This hierarchical structure is not used in IFR; instead items are encoded into a limited-capacity rehearsal buffer in which items are randomly displaced by new items. At recall, the buffer is outputted first, resulting in the typical IFR recency; these are followed by other highly activated items. For an item to be recalled, it requires activation that exceeds a specified threshold. The fact that IFR and ISR are encoded in different ways is problematic, since Bhatarah *et al*. (2008) have shown that these tasks are underpinned by similar encoding strategies.

THE SIMPLE MODEL (BROWN *ET AL.*, 2007)

The *scale-independent memory, perception and learning* (SIMPLE) model is a computational model that explains both IFR and ISR findings without proposing a dichotomy between a short-term and long-term memory. Brown *et al.* (2007) state that there are distinct characteristics of human memory that are prevalent across different timescales, such as the bowed serial position curves found in both immediate memory recall tasks and long-term retrieval memory tasks (Pinto & Baddeley, 1991) and that consequently, recall is time-invariant.

They adapt the telephone pole analogy proposed by Crowder (1976) to explain temporal distinctiveness theory and the four main assumptions of the model. They propose that to-be-remembered events are arranged along a temporal continuum extending from the past to the present, such that each event is equidistant to the next. Due to perspective, the earlier items are logarithmically compressed and at the point of recall, the later items are more discriminable than the earlier ones (first assumption), thus resulting in a recency effect. The inability to discriminate between the list items has an adverse effect on memory retrieval, resulting in forgetting (second assumption). The model assumes that item discriminability depends on the temporal distance from the retrieval time and that the probability of recalling a particular item decreases with increasing confusability with other items (third and fourth assumptions). The model proposes that the primacy effect occurs due to the fact that the first item on the list has only one neighbour and this makes it less confusable than the middle list items.

The SIMPLE model has been subject to controversy due to its proposition of integration of IFR and ISR. Murdock (2008) argues that similarity effects in ISR and IFR are inherently different, whereas item similarity in IFR enhances performance through categorisation, acoustic similarity in ISR has an adverse effect on recall. Similarly, he argues that increasing presentation rate has a facilitative effect in IFR but no effect on probe tasks. In their reply, Brown, Chater, and Neath (2008) state that these differences can be attributed in part to task requirements and in part to the role of rehearsal processes. Finally, they acknowledge that as pointed out by Murdock, the SIMPLE model does not explain inter-response time data and does not account for the output-order effects found in free recall.

THE LIST-PARSE MODEL (GROSSBERG & PEARSON, 2008)

The *laminar integrated storage of temporal patterns for associative retrieval, sequencing and execution* (LIST-PARSE) model is a neuro-anatomical memory model that argues that IFR and ISR share layered circuits in the pre-frontal and motor cortex. Furthermore, it also accounts for the similarities between verbal and non-verbal domains. However, the model assumes different rehearsal and recall processes in ISR and IFR. At encoding, items are activated within a processing hierarchy in which they retain their temporal order through a primacy gradient. The strength of the primacy gradient is dependent on the amount of time spent in WM, since the longer these items are in WM the more highly activated they are. If a list exceeds the memory span a recency gradient occurs, resulting in recency since the last few items are the most highly activated. These gradients enable the grouping of list items within the list chunk network and are also used to activate cells in the motor WM to create a motor plan. Recall is thus dependent on the motor plan transforming into an effective motor action in which items are outputted and subsequently suppressed to enable the recall of other items. The model postulates different selection strategies from WM storage for IFR and ISR, it assumes that these two tasks are underpinned by different rehearsal mechanisms; however, Bhatarah *et al*. (2008) have shown that ISR and IFR utilise similar rehearsal patterns.

THE CLUSTERING ACCOUNT (FARRELL, 2012)

The clustering account is a temporal context computational model that assumes that items occurring close together are grouped into discrete episodic clusters. Indeed, there is an increasing line of evidence that suggests that we may naturally perceive and parse our daily experiences into several events at different temporal contexts. The recall of such events depends heavily on perceptual event boundaries, in that, activities that happen temporally close to the event boundaries are better recalled (Kurby & Zacks, 2008; Swallow, Zacks, & Abrams, 2009).

Similarly, in Farrell’s account list items are parsed into events or episodic clusters that are associated with a unique temporal context, which is made up of a list context, a group context and within-group markers. These are dependent on the position of an item with respect to the start and end of the cluster. Item encoding is based on a primacy gradient, which depends on the particular items’ relative novelty to the other context items. Temporal context changes due to a change in group context, with the addition of a new group, and/or a change in list context with the addition of a new list. For an item within a particular cluster to be recalled, first the temporal context of the particular cluster needs to be accessed, which in turn reinstates the group and list contexts. Item retrieval is achieved using the item's position within a group, and its group position within the list. The cluster at the end of the list remains 'open' due to its resemblance to the test context; therefore items from this cluster are very accurate and this lead to recency effects. The first group within a list context benefits from its temporal distinctiveness, brought about by its novelty, as well as a nominal cue; this leads to primacy effects. Once the group context is retrieved, the forward-ordered nature of recall is achieved through the primacy gradient of the within-group markers. At short lists, such as the ones used in ISR, only one cluster is required, and this remains highly accessible and its forward order is easily maintained and outputted, thus resulting in strong primacy effects. As the lists get increasingly long, multiple clusters are formed; this leads to the last cluster to be highly accessible due to its open state, leading to the typical recency effects found in IFR, whereas the primacy effects are due to the first cluster's temporal distinctiveness. This model can explain the similarities between IFR and ISR data, and due to its modality-independence, it could possibly be generalised across modalities.

SUMMARY AND CONCLUSIONS

Overall, I have summarised and discussed in detail the literature regarding verbal and visuo-spatial IFR and ISR. There are four main points from the present review of the literature. First, I have shown that the visuo-spatial immediate memory recall literature is relatively sparse when compared to the verbal immediate memory one. Second, there is an increasing line of evidence that expounds on a number of similarities between the verbal and visuo-spatial items and these seem to outnumber the number of differences between the two stimulus domains. Third, there are a number of studies that have shown that IFR and ISR are underpinned by common mechanisms. More-specifically, I have shown that in an IFR task using short lists, participants tend to recall in an "ISR-like" manner. Fourth, although there are a number of models that attempt to explain how serial order is maintained within the verbal domain, it is yet unclear whether these models can apply across modalities. Consequently, I will now relate these conclusions to the aims of the present work.

THE PRESENT WORK

The present thesis will first examine whether the forward-ordered tendency in the IFR of verbal stimuli is restricted to a language-based mechanism (e.g. phonological loop) by testing whether this finding can also be found in the visuo-spatial domain. Chapter 2 will first discuss evidence suggesting that this phenomenon may be enhanced by a language mechanism but does not necessitate access to a verbal short-term store or the phonological loop (Grenfell-Essam *et al*., 2013; Spurgeon, Ward, & Matthews, 2014a, 2014b). Consequently, I will first examine whether this phenomenon can be found using a non-verbal visuo-spatial IFR task. Furthermore, I will also directly compare the IFR performance of verbal and visuo-spatial stimuli by equating IFR methodologies for both stimulus domains.

Chapter 3 will investigate whether forward serial order in IFR can be disrupted when test sequences include both verbal and visuo-spatial stimuli that are presented concurrently or in alternation. These dual-modality tasks will help ascertain whether this forward-ordered tendency across stimulus domains is a general property of episodic memory, or whether there are similar yet separate mechanisms operating at each stimulus domain. More specifically, these tasks will help ascertain and compare, capacity, list length and output order effects in single-and dual-modality tasks. Consequently, these will thus aim to answer questions such as, which modality do participants start with when they are presented with concurrent cross-modality stimuli and whether participants recall by modality or in a forward serial order.

In Chapter 4, I will test the effect of list structure on the recall of dual-modality tasks. It is possible that presenting participants with concurrently presented material or stimuli in alternation, results in increased one-to-one associations between modalities that result in alternating outputs by modality (i.e. word-dot-word-dot or vice versa). Therefore, in Chapter 4, the dual-modality tasks will include randomly presented verbal and visuo-spatial stimuli that are unlikely to allow such one-to-one associations, and will further test whether there will be forward-ordered recall in these experimental conditions. Finally, Chapter 4 will also test whether this forward-ordered tendency is dependent on encoding or retrieval. This will be done by presenting participants with both verbal and visuo-spatial stimuli and requiring them to remember both types of stimuli, but post-cueing them at test as to which modality needs to be recalled; this will also further investigate if forward serial order found in the IFR of verbal and non-verbal stimuli is a general property of memory.

Chapter 5 will therefore present the main findings and conclusions form the empirical chapters. I will then present my preferred interpretations of the result by presenting a hybrid model that attempts to explain the capacity, list length and output order effects in single-and dual-modality recall.

Overall, the above mentioned experimental work will contribute to the literature discussing whether serial order is a common process across domains or whether each modality has its own serial order mechanism. Not much research has been done to investigate the IFR of visuo-spatial stimuli; this thesis will also contribute further evidence delineating the similarities between verbal and visuo-spatial IFR. Finally, since recent work has focused on the theoretical integration of IFR and ISR, by showing that there are similar mechanisms for both tasks within the verbal domain; the present work can also have implications for the relationship between visuo-spatial IFR and ISR (see (7) and (8) on Figure 1.1).

CHAPTER 2

CHAPTER 2

The present chapter examines the IFR of non-verbal visuo-spatial material and has two aims – one specific and one general. Specifically, I am interested in the extent to which the novel findings of Ward *et al.* (2010) generalize to experiments where visuo-spatial rectangles and dots are utilized. More generally, I aim to inform the debate concerning the degree to which immediate recall for verbal stimuli is similar or different to that of non-verbal stimuli. I begin by summarizing the Ward *et al*. (2010) findings in further detail.

Ward *et al*. (2010) examined the relationship between IFR and ISR by analyzing output order and list length effects over a series of four experiments where participants were presented with verbal lists of between 1 and 15 words. Participants were then asked to recall as many words as they could remember either in strict forward serial order (ISR) or in any order that they liked (IFR). Despite the fact that research in verbal immediate memory has viewed these two types of immediate memory tasks as separate, thus leading to separate theories and models, Ward *et al.* (2010) showed that the output order and the serial position curves for both tasks are very similar when methods, list lengths and scoring are equated.

More importantly, when participants were presented with a short list of words and were asked to recall it in any order that they wished, they tended to recall the list in an "ISR-like" manner. This tendency to start with the first presented word was greatest for the short list lengths, and decreased with increasing list length. Furthermore, when participants started at the start, they were likely to continue recalling in forward serial order, thus resulting in primacy effects. Conversely, at longer list lengths, participants tended to start with one of the last four presented items in the list, followed by other later items, thus resulting in extended recency effects.

The primacy effects found in the IFR of short lists of words were somewhat surprising, given that one of the most defining characteristics of IFR is the extended recency effects. These extended recency effects have been central to the debate as to whether memory is a unitary concept or made up of a short-term store (STS) and a long-term store (LTS). As outlined in the previous chapter, the earliest dual-store accounts of IFR explained recency as output from the STS (Atkinson & Shiffrin, 1971; Glanzer, 1972; Raaijmakers & Shiffrin, 1981). However, these models were unable to explain recency effects found in the recall of real-world events over longer periods of time (Baddeley & Hitch, 1977; Pinto & Baddeley, 1991; Rubin, 1982) or the recall of items in a CDFR task (Bjork & Whitten, 1974; Glenberg, *et al.*, 1980; Howard & Kahana, 1999).

These recency effects findings across a wide range of time-scales has resulted in unitary accounts of memory that assume common mechanisms for the encoding, storage, and retrieval of all the list items (Brown *et al*., 2007; Howard & Kahana, 2002; Laming, 2006, 2008, 2009; Polyn *et al*., 2009; Sederberg *et al*., 2008; Tan & Ward, 2000). Such models predict that the first item recalled would be one of the last few presented items, rather than the first item, because the recent items are more temporally distinct (Brown *et al*., 2007), or are associated with a temporal context similar to that of during recall (Polyn *et al*., 2009; Sederberg *et al*., 2008), and thus cannot account for the Ward *et al*. (2010) findings.

The majority of current theories of memory concede that some long-term recency mechanism is required, however, there is an on-going debate as to whether recency effects in IFR are a product of both short-term and long-term recency mechanisms (Davelaar *et al*., 2005; Davelaar, Usher, Haarmann, & Goshen-Gottstein, 2008; Farrell, 2010; Lehman & Malmberg, 2013; Raaijmakers, 1993; Thorn & Page, 2008; Unsworth & Engle, 2007; Usher, Davelaar, Haarmann, & Goshen-Gottstein, 2008) whilst others appeal to a unitary view (Howard, Kahana, & Sederberg, 2008; Kahana, Sederberg, & Howard, 2008; Neath & Brown, 2006; Suprenant &

Neath, 2009). Such unitary accounts of memory would predict that the first item recalled in an IFR task would be one of the last few presented items, and therefore the Ward *et al.* (2010) findings of "ISR-like" recall in IFR cannot be satisfactorily explained by these models.

LANGUAGE-SPECIFIC EXPLANATIONS OF THE WARD *ET AL*. FINDINGS

As outlined in the previous Chapter, the primacy effects found in IFR are usually explained to be the result of rehearsal (Tan & Ward, 2000), whereby early list items have more opportunity for rehearsal than later ones. However, Grenfell-Essam *et al*. (2013) have shown that the tendency to output words in an "ISR-like" manner in IFR tasks is unlikely to be mediated by rehearsal. They showed that doubling the rate from one word/second to two words/second, did not affect the probability of first recall data and similar data was also found, albeit reduced, when the IFR tasks were done under articulatory suppression (AS).

More recently, Spurgeon *et al*. (2014b) examined the possibility that the Ward *et al*. (2010) findings could be the result of a verbal STS. Although models of immediate memory assume that the STS is responsible for the heightened accessibility to the later items in IFR tasks, it is possible that when participants are presented with a short list of words that does not exceed the STS capacity, these items remain accessible and are thus outputted in an "ISR-like" manner. For this reason Spurgeon *et al*. (2014b), presented participants with either immediate, delayed or continual distractor free recall tasks including lists of between 1 and 12 words. The tendency to start recall with the first list item was present in all three types of task, albeit at a reduced rate for the delayed and continual distractor task.

Spurgeon *et al*. (2014a) also examined whether the Ward *et al*. (2010) findings were the result of a phonological short-term store, such as the Phonological Loop (PL) proposed by Baddeley in the WM model (1986, 2000, 2007, 2012). Since the PL has been implicated in language learning (Gathercole & Baddeley, 1989), which inherently requires an intrinsic forward-order, it is conceivable that it has the capability of maintaining a list of short words for both IFR and ISR tasks in forward serial order. However, in the IFR of longer lists exceeding its capacity, the earlier items are replaced by the later ones, thus resulting in recency effects. In order to examine this possibility, Spurgeon *et al*. presented participants with IFR and ISR tasks that were done either in silence or under AS. It is assumed that AS prevents both rehearsal and the recoding of written words into the phonological store. Consistent with this, Spurgeon *et al*. found the phonological similarity effect when participants performed the task in silence, but not when they were required to do AS. The tendency to start with the first presented item in IFR was present in both manipulations, albeit at a reduced rate for the AS condition. Therefore, the findings of both the Spurgeon *et al*. (2014a, 2014b) papers show that although the tendency to start with the first list item may be augmented through the use of a verbal STS or phonological recoding, it does not necessitate access to either types of stores.

Overall, the above findings suggest that the tendency to recall IFR items in an "ISR-like manner" does not require a language-specific mechanism. Consequently, it may be possible to find the Ward *et al*. (2010) list length and output order effects in non-verbal IFR since these are, like verbal stimuli under AS, not dependent on phonological coding. Therefore, finding list length and output order effects in non-verbal visuo-spatial stimuli would have two main implications. Generally, it would show that recall of visuo-spatial stimuli is more similar than different to the recall of words and more specifically, it would show that the novel finding by Ward *et al*. (2010) is not a result of a language-specific mechanism confined to a verbal memory store but rather a more general recall tendency found across different modalities.

THE CURRENT EXPERIMENTS

The first and more specific aim of the current experiments is to first test whether the Ward *et al*. (2010) findings are present in the IFR of visuo-spatial materials, both when the tasks are done in silence or under AS. The second aim of these experiments is to further delineate the differences and similarities between verbal and non-verbal immediate memory. As outlined in Chapter 1, when compared to verbal immediate memory, relatively less research has been done on visuo-spatial immediate memory (Farrand, Parmentier & Jones, 2001; Logie, 1995). Early research assessing visuo-spatial stimuli made use of mostly serial recall and reconstruction of order tasks, rather than free recall ones (Farrand *et al*., 2001; Smyth & Scholey, 1996b). The distinctions between recall patterns of verbal and non-verbal stimuli have led to theoretical models postulating two separate memory stores for verbal and visuo-spatial information, the most widely accepted being the Working Memory model by Baddeley and Hitch (1974), where the 'phonological loop' is used for verbal stimuli and the 'visuo-spatial sketchpad' is concerned with visuo-spatial items. In the same way as traditionally ISR was previously said to result in primacy effects and IFR was said to show recency effects (Kahana, 2012), visuo-spatial memory has been said to produce flat serial position curves with one to two-item recency (Broadbent & Broadbent, 1981; Phillips & Christie, 1977a).

However, more recent experimental research has shown that in certain cases where the methodologies of both stimulus domains are made to be as similar as possible, the same recall patterns can be observed. For instance, Farrand *et al*. (2001) have shown that in a dots task, serial position curves can be bowed and state that these curves are dependent on the 'seriation process' rather than stimulus domains. Additionally, they state that the one-item recency in previous visuo-spatial studies are a result of methodology, which was not testing output order but rather visual identity. Ward *et al*. (2005) analysed serial position curves across two type of tasks, serial reconstruction of order, and a two-alternative forced choice test of item recognition to compare recall performance with unfamiliar faces and nonwords. They showed that serial reconstruction of order results in bowed serial position curves, whereas forced choice tasks result in no primacy and very limited recency. They thus conclude that there is functional equivalence across different modalities and that the traditional differences in serial position curves are a consequence of the differences in the experimental methods.

More recently, Guérard and Tremblay (2008) have also shown that when fully equating methods of testing for verbal and spatial information there are similar error patterns. This was done through a comparison of intrusions, transpositions, omissions and fill-in errors of verbal and spatial serial reconstruction of order tasks. Furthermore, in the last decade, staple findings of verbal immediate memory tasks have been also found in the visuo-spatial domain, such as: the modality effect (Tremblay *et al*., 2006), the sandwich effect (Tremblay *et al*., 2005) and Hebb repetition effect (Couture & Tremblay, 2006; Parmentier *et al*., 2008). Overall, this more recent research suggests that similarities between verbal and non-verbal immediate memory can only be observed in empirical data where experimental methods for both modalities are equated.

Although the interest in visuo-spatial immediate memory is on the increase, it is important to reiterate that not much research has been conducted with regard to the FR of visuo-spatial stimuli. However, the study conducted by Bonanni *et al*. (2007) requiring participants to recall visuo-spatial locations from 25 possible grid locations in any order that they preferred, showed both primacy and recency effects in sequences containing six, eight or ten items, with pronounced recency at the longest list. They also show that an increase in the presentation rate results in stronger primacy effects. Additionally, Gmeindl *et al*. (2011) compared performance in a digit span and a computerized Corsi-block task while giving either FR or SR instructions. They showed that participants were more likely to reproduce order in the digit span task relative to the visuo-spatial task. When using a serial recognition task, Gmeindl *et al*. found that participants were more likely to detect a change in serial order in the digit span when compared to the square locations. Whereas participants were slightly better at noticing order mismatch than item mismatch in the verbal task, they were worse at detecting order mismatch when compared to item mismatch in the visuo-spatial task. They thus conclude that serial order is more bound to verbal rather than visuo-spatial stimuli. However, this finding may be due to the fact that firstly, numbers have an inherent order and secondly, that digits are more familiar and visually distinct than visuo-spatial locations.

As aforementioned, the more specific aim of the present chapter is to test whether the Ward *et al*. (2010) novel finding is restricted to verbal stimuli and is possibly due to a mechanism of an immediate memory verbal store. To a certain extent this has been tested by Bonnani *et al*. (2007), however I wished to include a wider range of list lengths as used in Ward *et al*. (2010). Critically, I wanted to test the effects of initiating recall with either the first or last four list items on the subsequent items. Finally, I also wanted to examine at which list length, participants are more likely to start with either the first or last four items on the list. Therefore, I first examined whether these list length and output order effects can be extended to an IFR visuo-spatial task (Experiment 1). Secondly, I wanted to directly compare the recall patterns in verbal and visuo-spatial tasks, by using a similar visuo-spatial task to that used by Gmeindl *et al*. (2011) and comparing it to a traditional verbal IFR task including words rather than digits (Experiment 2). In the third and final experiment of the chapter, I wanted to render the visuo-spatial task more verbal-like, whereby during the response phase of the visuo-spatial task, the screen reset so that participants did not have to select the presented visuo-spatial stimuli from a given set but click on the exact spatial location where the dots where presented; this also reduced the probability of guesses. Lastly, to ensure that language coding did not aid the performance on the visuo-spatial tasks, AS was used in all of the tasks in the present chapter. It was expected that AS would not hinder the performance of visuo-spatial stimuli, and that the list length and output order effects would be found in both silent and AS conditions.

EXPERIMENT 1

This experiment examined the IFR of non-verbal visuo-spatial material. All participants were presented with 88 sequences of visuo-spatial locations, with eight trials of each of eleven different list lengths (lists of 1-8, 10, 12, & 15 spatial locations). This was done in an analogous manner to Grenfell-Essam and Ward (2012) where list lengths 9, 11, 13 and 14 that had been previously used in Ward *et al*. (2010) were excluded, to enable maximization of trials per list length within an experimental session. There were two groups of participants. One group, the Articulatory Suppression (AS) group, was asked to repeat the same word continuously during sequence presentation (Levy, 1971; Peterson & Johnson, 1971). Conversely, the other group, the No AS group, always viewed the stimuli in silence. This manipulation was performed to seek confirmation that performance in the visuo-spatial task was not supported by covert verbal rehearsal.

The main aim of the experiment was to determine whether the list length and output order effects found in Ward *et al*. (2010) could be observed in non-verbal visuo-spatial material. Specifically, I was interested in knowing whether participants will show a tendency to output short visuo-spatial lists with the first item on the list, while initiating the recall of longer visuo-spatial lists with one of the last four items in the sequence. If the results of Ward *et al*.'s (2010) IFR experiment for words are to be generalized to non-verbal stimuli, then the list length effect should be seen in the overall performance of both participant groups. There should be little or no difference in this experiment between the AS and the No AS groups, such that the lack of verbal rehearsal should not change the way in which participants output the spatial locations. It is expected that if the novel finding by Ward *et al*. (2010) is not restricted to the IFR of verbal recall, then participants will show a tendency to start recall with the first presented item in short sequences, while initiating recall with one of the last four visuo-spatial locations in the longer sequences. Experiment 1 will also contribute to the general aim of the present thesis since, if the serial position curves and probability of first recall resemble those from verbal IFR, then this would be further evidence of similarities between verbal and visuo-spatial immediate memory.

METHOD

Participants. A total number of 40 students from the University of Essex were recruited as participants for this experiment in exchange for course credit.

Materials. The stimulus set consisted of 432 rounded rectangles arranged in 18 rows of 24 columns. Each rectangle was white with a black outline and measured 9mm x 8mm and they were distributed over a grey background display measuring 285mm wide by 165mm in height. On each trial, participants saw a different random subset of 30 rectangles. The experiment was presented via the SuperCard application on an Apple Mac Computer, and participants interacted by clicking on selected rectangles using the computer mouse.

Design. The experiment used a mixed factorial design. The between-subjects independent variable was the degree of concurrent articulation with two levels, such that there was a No AS group and an AS group. There were two within-subjects independent variables: list length, with 11 levels (1, 2, 3, 4, 5, 6, 7, 8, 10, 12 and 15 items presented) and serial position with up to 15 levels. The dependent variables were the proportion of rectangles correctly recalled, the proportion of rectangles recalled in the same order as presented, and the probability of initiating recall with the first or with one of the last four presented rectangles.

Procedure. Figure 2.1 shows the procedure for Experiment 1. Participants were randomly allocated into one of the two groups: the No AS and the AS group, such that each group was made up of 20 participants. Participants were tested individually and were given group-specific instructions. They performed four practice trials in the presence of the experimenter, followed by two blocks each of 44 experimental trials. Within each block, there were four trials of each of the eleven different list lengths. The order of these trials within each block was randomised. Participants were encouraged to take a short break between the first and second blocks.

On each trial, participants were presented with a different random subset of 30 rounded rectangles that were distributed across a computer screen. After one second, there was a warning tone, and then a subset of between 1 and 15 of the rectangles darkened one at a time at a rate of one rectangle per second (where each white rectangle turned black for 0.75s with an additional 0.25s inter-stimulus interval where the item returned to its original colour). During the stimulus presentation, the location of the mouse cursor was locked to the location of the "submit" button near the top right-hand corner of the display. Furthermore, participants in the AS group were asked to repeat the word 'the' while the list was being presented, whereas the No AS remained silent throughout the whole experiment.

An auditory cue signalled the start of recall, after which the mouse cursor could be moved, and the participants were free to indicate which rectangles had darkened by clicking on the chosen rectangles in whatever order they liked. The rectangles turned grey upon their selection and could not be selected twice on the same trial. It was also not possible to select more rectangles at test than had been presented. At the same time as the auditory cue to recall was presented, a pair of boxes appeared on the right hand side of the screen indicating the number of rectangles that had darkened on that trial and the number of items that had so far been selected. Participants could only use the "submit" button once they had selected as many rectangles at test as had been darkened. Pressing the "submit" button initiated the next trial.

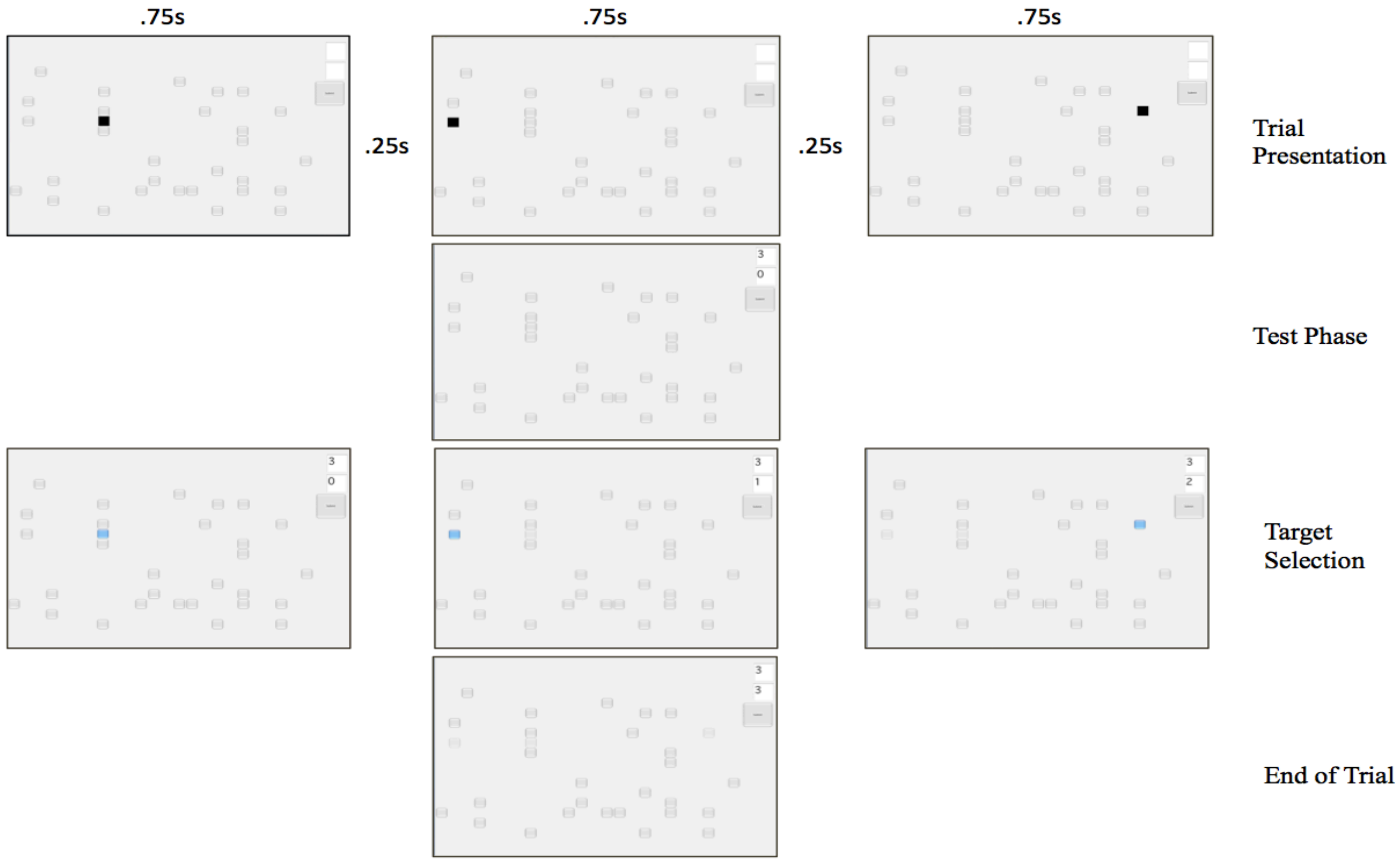

Figure 2.1. Experiment 1: A screenshot of the procedure of Experiment 1.

RESULTS

Overall Accuracy. Figure 2.2 shows the mean proportion of locations correctly selected at each of the 11 list lengths. A 2 (group: AS or No AS) x 11 (list length: 1-8, 10, 12, 15) mixed Analysis of Variance (ANOVA) revealed that there was a non-significant main effect of group, $F(1, 38) = 2.28$, $MSE = .035$, $\eta^2_p = .057$, $p = .139$, a significant main effect of list length, $F(10, 380) = 242.1$, $MSE = .004$, $\eta^2_p = .864$, $p < .001$, and a significant interaction, $F(10, 380)=1.85$, $MSE = .004$, $\eta^2_p = .047$, $p = .050$. Thus, there was little evidence that recall of the visuo-spatial locations was affected by AS.

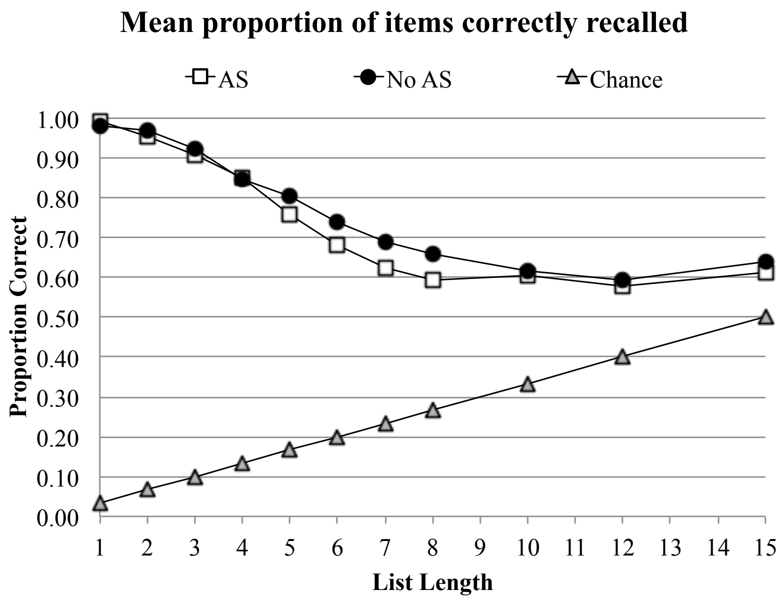

Figure 2.2. Experiment 1: The effect of list length on the mean proportion of correctly recalled items for the AS and No AS groups respectively. Chance was calculated as the list length divided by the number of rectangles present on the screen (30).

Serial position curves (SPCs). Figure 2.3 shows the serial position curves for each of the 11 different list lengths in the No AS (Panel A) and the AS groups (Panel B). As can be seen, recall is close to ceiling levels for list length 1, the curves are relatively flat for list lengths 2-4, and there appear to be more marked effects of serial position at list lengths 5 and greater. In addition, there were very similar serial position curves in both the No AS and AS groups. The serial position curves were analysed at each list length, using a series of 2 (group: AS or No AS) x *n* (serial positions: 1 to *n*) mixed ANOVAs (where *n*, here and henceforth, refers to the list length). The exact statistics for the main effects and interaction for each list length can be found in Appendix 2.1. In summary, AS had a non-significant effect for all but one list length (list length 8, where recall was greater in the No AS group relative to the AS group). The main effect of serial position was significant for list lengths 5-15. Specifically, analyses of the effect of serial position at list length 5 showed primacy, the effects at list lengths 6 to 15 showed both primacy and recency; however list length 15 showed extended recency effects. Finally, all of the interactions between serial position and AS were non-significant, except for list length 15.

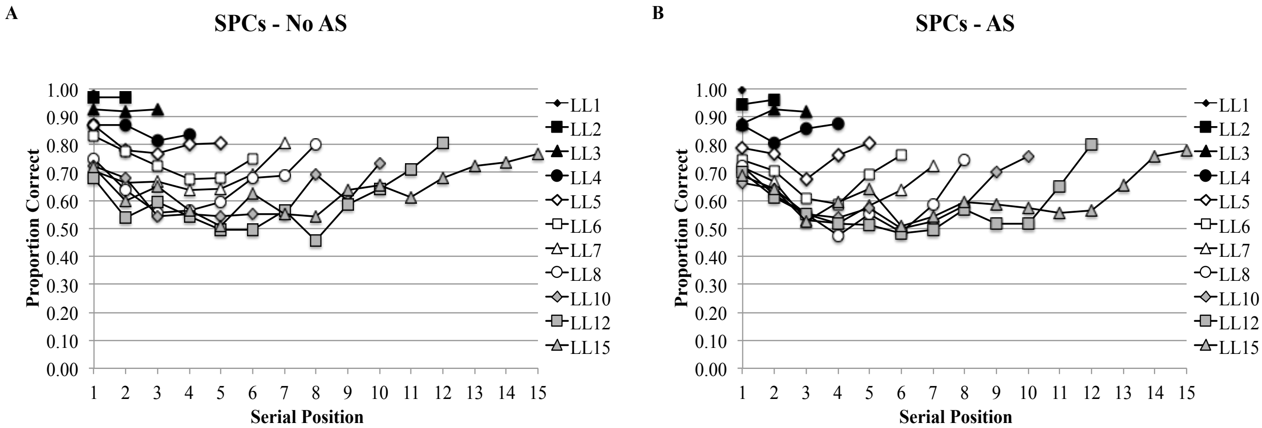

Figure 2.3. Experiment 1: SPCs from lists of 1 to 15 rounded rectangles presented in the No AS (panel A) and AS (panel B) groups respectively.

Probability of first recall (PFR) Data. The probability of first recall (PFR) refers to the number of trials where the first item recalled held a specific serial position within the presented list or sequence (Howard & Kahana, 1999). Table 2.1 shows the PFR proportions for recalled rectangle positions at different serial positions across all lists. It is clear that in the shorter sequences participants tended to start with the first item in the sequence. As the sequences got longer, there was an increased tendency to initiate recall with the last items of the sequence. Figure 2.4 shows data from the No AS (panel A) and AS (panel B) conditions of Experiment 1. Panel A and B both plot the mean probability for each list length that the first rectangle selected was (a) the first rectangle that was presented, and (b) one of the last four rectangles that were presented. Where these two lines intersect, is called the crossover point, that is the list length at which the modal first item recalled changes from being classified as 'SP1' for list lengths shorter than the crossover point, to the Last 4, where the list length is larger than the crossover point.

Table 2.1
Experiment 1: The average proportion of the first rectangle positions recalled in all trials as a function of the list length and the visuo-spatial locations' serial position for the AS and No AS groups respectively

	List Length										
Serial Position	1	2	3	4	5	6	7	8	10	12	15
AS											
1	*0.99*	*0.68*	*0.60*	*0.49*	*0.47*	*0.42*	*0.36*	*0.34*	*0.27*	*0.20*	*0.14*
2		**0.27**	**0.14**	**0.12**	**0.07**	0.10	0.08	0.09	0.05	0.05	0.02
3			**0.20**	**0.17**	**0.10**	**0.05**	0.03	0.04	0.04	0.02	0.03
4				**0.18**	**0.10**	**0.11**	**0.05**	0.04	0.04	0.04	0.04
5					**0.23**	**0.05**	**0.06**	**0.03**	0.02	0.04	0.03
6						**0.20**	**0.10**	**0.02**	0.04	0.01	0.01
7							**0.21**	**0.08**	**0.04**	0.04	0.02
8								**0.29**	**0.07**	0.04	0.02
9									**0.09**	**0.05**	0.02
10									**0.25**	**0.05**	0.02
11										**0.08**	0.03
12										**0.29**	**0.04**
13											**0.09**
14											**0.08**
15											**0.27**
No AS											
1	*0.93*	*0.72*	*0.58*	*0.52*	*0.48*	*0.42*	*0.32*	*0.32*	*0.24*	*0.19*	*0.17*
2		**0.21**	**0.15**	**0.07**	**0.06**	0.07	0.11	0.07	0.03	0.03	0.02
3			**0.17**	**0.08**	**0.08**	**0.05**	0.04	0.01	0.04	0.02	0.01
4				**0.20**	**0.08**	**0.05**	**0.05**	0.02	0.02	0.03	0.02
5					**0.19**	**0.04**	**0.06**	**0.03**	0.04	0.05	0.02
6						**0.23**	**0.10**	**0.07**	0.04	0.01	0.05
7							**0.21**	**0.10**	**0.04**	0.02	0.02
8								**0.26**	**0.09**	0.03	
9									**0.10**	**0.03**	0.04
10									**0.25**	**0.07**	0.04
11										**0.12**	0.07
12										**0.26**	**0.05**
13											**0.05**
14											**0.10**
15											**0.24**

Note: The italicized values represent the proportion of trials in which the first rectangle position recalled was from serial position 1, and the bold values represent the proportion of trials in which the first chosen rectangle was from one of the last four serial positions. The values in regular font represent the proportion of trials in which the first recalled item was from one of the other serial positions.

Both the AS group and the No AS group showed these crossover patterns of data. However, whereas the crossover point for the No AS group is between list length 6 and 7, the crossover point for the AS group is not so well-defined since it seems to extend from lists 5 to 7. For completeness, the Figure also shows the mean probability for each list length that the first rectangle selected was any of the other rectangles that had been presented, or a rectangle that had not been presented.

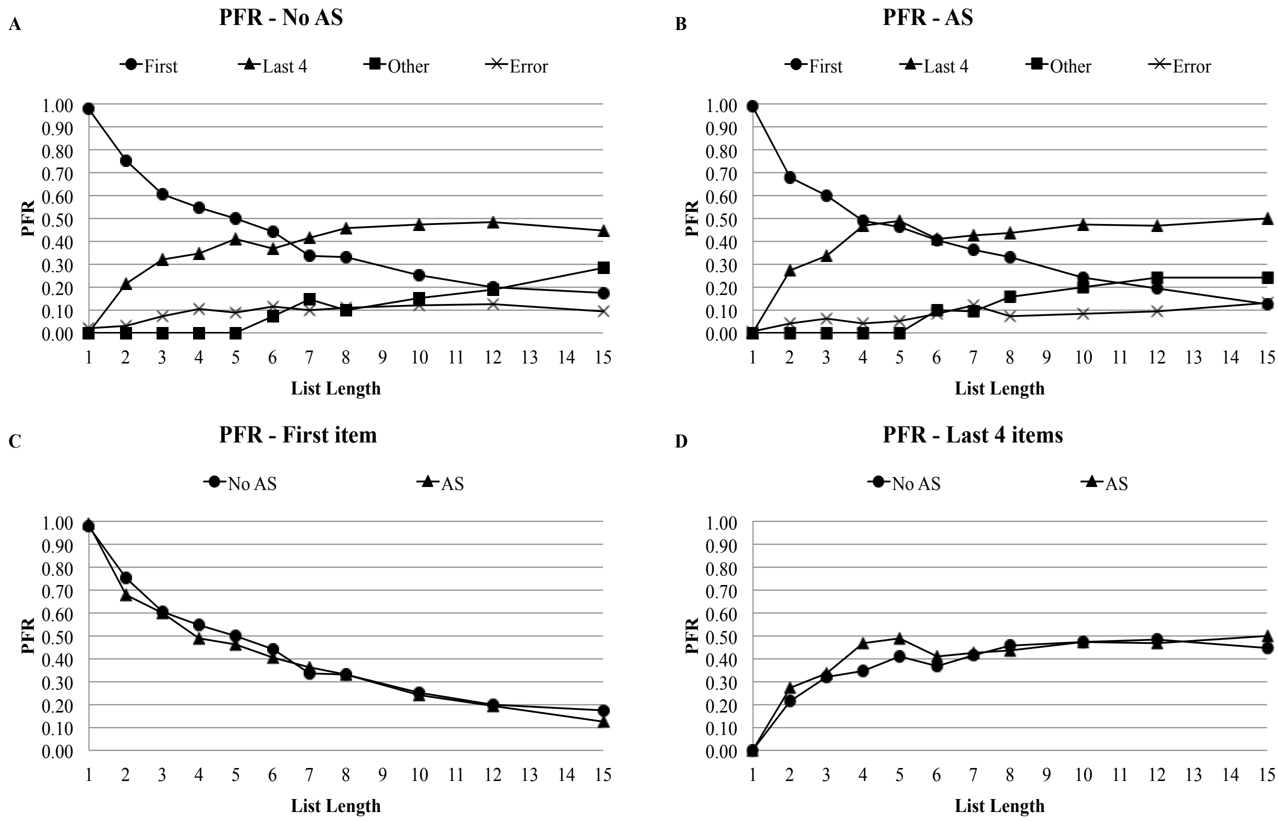

Figure 2.4. Experiment 1: PFR data for the No AS and AS groups. Panels A and B show the proportion of trials in which recall initiated with either the first list item, one of the last 4 items, one of the other items in the list or an error for the No AS and AS groups respectively. Panels C and D show the exact data separated by those trials where participants initiated recall with either the first item or one of the last 4 presented items to enable cross-group comparison.

Figure 2.4 also shows the same data segregated by the proportion of trials where recall was initiated either with the first (panel C) or one of the last four items (panel D) to enable direct cross-group comparisons. I consider first the probability of initiating recall with the first list item. The data for both the No AS and the AS Groups and were analysed by a 2 (group: No AS and AS) x 11 (list length 1-8, 10, 12 and 15) mixed ANOVA. There was a non-significant main effect of group, $F(1, 38)=.150$, $MSE = .365$, $\eta^2_p = .004$, $p = .700$, a significant main effect of list length, $F(10, 380)= 92.4$, $MSE = .026$, $\eta^2_p = .709$, $p < .001$, and a non-significant interaction, $F(10, 380)=.404$, $MSE = .026$, $\eta^2_p = .011$, $p = .945$. Thus, initiating recall with the first list item was affected by the list length, but there was little evidence that it was affected by AS.

A complimentary 2 (group: No AS and AS) x 10 (list length: 2-8, 10, 12 and 15) mixed ANOVA was conducted on the probability of initiating recall with one of the last four list items. There was a non-significant main effect of group, $F(1, 38)=0.046$, $MSE = .464$, $\eta^2_p = .001$, $p = .831$, a significant main effect of list length, $F(9, 342)=8.49$, $MSE = .028$, $\eta^2_p = .183$, $p < .001$, and a non-significant interaction, $F(9, 342)=.834$, $MSE = .028$, $\eta^2_p = .021$, $p =.585$. Again, initiating recall with one of the last four list items was affected by the list length, but there was little evidence that it was affected by AS.

The effect of first item recalled on the serial position curves. Figure 2.5 (panels A and B) shows the serial position curves for the No AS and AS conditions for those trials in which recall was initiated with serial position 1 (that is, when PFR=SP1) using FR scoring. It is clear that there are more extended primacy effects and reduced recency effects in this subset of data. For each list length, these serial position curves were analysed by a 2 (group: AS or No AS) x n - 1 (serial positions: 2 to n) mixed ANOVA using FR scoring. The exact statistics for the main effects and interaction for each list length can be found in Appendix 2.2. In summary, the main effect of serial position was significant for list lengths 6, 8, 10 and 15. At all list lengths, the main effects of AS were non-significant and there were no significant interactions between group and list length.

Figure 2.5 (panels C and D) shows the serial position curves for the No AS and AS groups respectively, for those trials in which recall initiated with serial position 1 using SR scoring. It is clear that participants tended to output the first few rectangles in a forward serial order, despite the fact that this is not required of them. For each list length, these serial position curves were analysed by a 2 (group: AS or No AS) x *n* - 1 (serial positions: 2 to *n*) mixed ANOVA using SR scoring. The exact statistics for the main effects and interaction for each list length can be found in Appendix 2.3. In summary, the main effects of serial positions were significant for all list lengths, with the exception of list length 4. At all list lengths, there were non-significant main effects of AS and non-significant interactions between list length and group.

Figure 2.5 (panels E and F) shows the serial position curves for the No AS and AS conditions for those trials in which recall initiated with one of the last four presented rectangles. These SPCs were analysed by a 2 (group: AS or No AS) x *n* (serial position) mixed ANOVA. The exact statistics for the main effects and interaction for each list length can be found in Appendix 2.4.

In summary, there was a significant main effect of serial position for all sequences with 3 rectangles or more, with the exception of list length 4, reflecting extended recency effects and somewhat reduced primacy effects. There were relatively few significant effects marking AS but there was a significant main effect of AS for list length 8, while all interactions were non-significant.

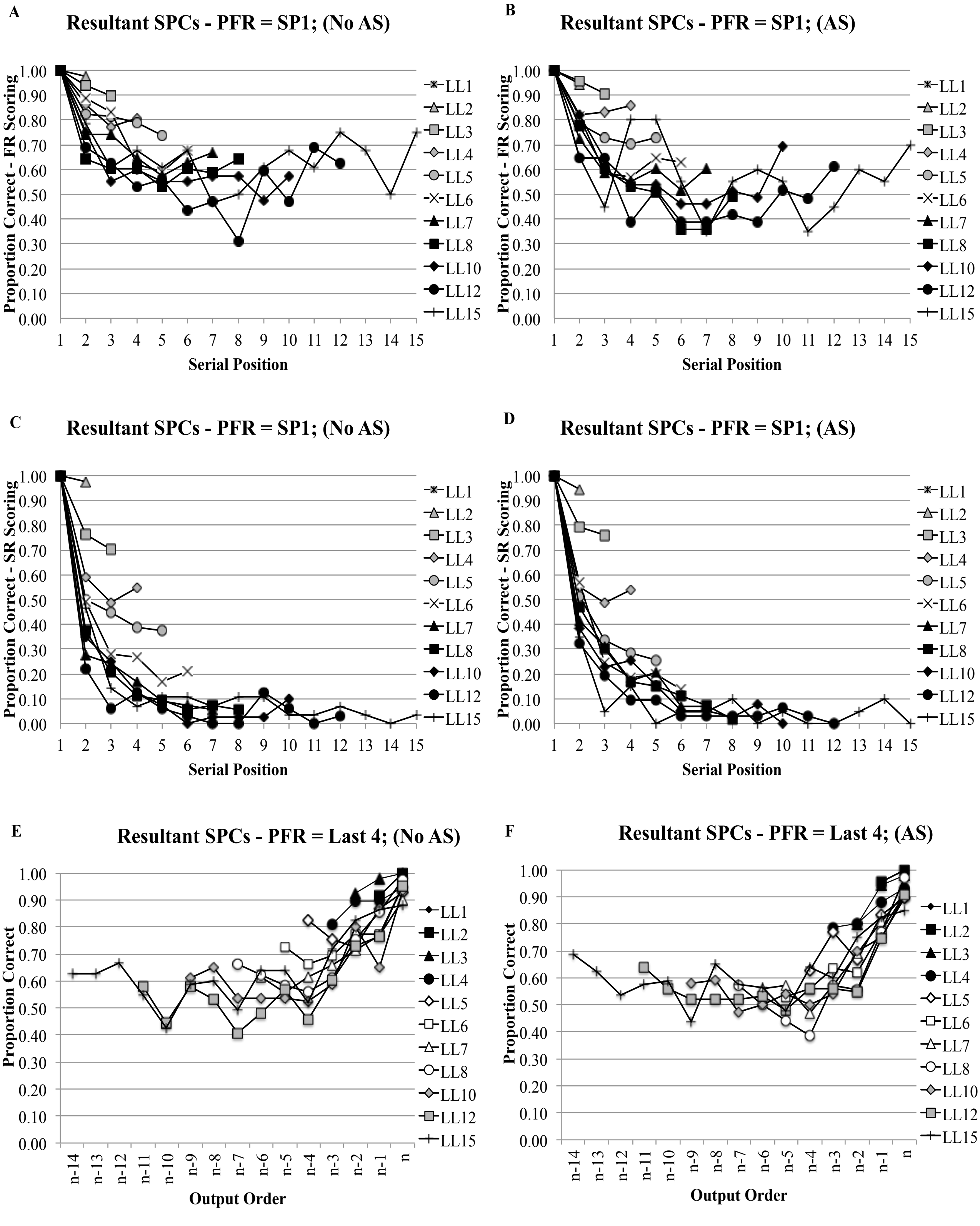

Figure 2.5. Experiment 1: The effect of the first recall on the SPCs for the No AS and AS groups respectively. Panels A and B show the effect of initiating recall with the first stimulus in the list for both groups respectively. Panels C and D show the effect of initiating recall with the first stimulus in the list, for both groups respectively, with the data plotted using serial recall (SR) scoring. Panels E and F show the effect of initiating recall with one of the last four stimuli in the list for the No AS and AS groups respectively.

DISCUSSION

The aim of this experiment was to examine the extent to which language codes might have played a role in the novel findings of Ward *et al*. (2010) and are therefore restricted to verbal IFR. Experiment 1 showed that the patterns of data observed when participants perform IFR with sequences of visuo-spatial locations are qualitatively similar to the patterns of data found in previous studies that have used words as stimuli. Furthermore, the findings were consistent, regardless of whether participants were asked to perform AS or not. Replicating previous findings from verbal IFR (e.g., Jahnke, 1965; Murdock, 1962; Ward, 2002) and visuo-spatial IFR (Bonanni *et al.*, 2007) there are clear list length effects with the visuo-spatial rectangles, regardless of AS. Although the longer the list, the higher the chance of correctly selecting a rectangle location in the sequence, performance was well above chance for all list lengths.

Critically, Experiment 1 showed that in both groups, participants tended to initiate recall with the first item in the list when the list was short, but tended to increasingly initiate recall with one of the last four items in the list when the list length was increased, a finding mirroring that observed with words by Ward *et al.* (2010). In addition, different-shaped serial position curves were observed when the data were conditionalized by the first location recalled. In both the AS and No AS groups, participants showed increased primacy and reduced recency when they started with serial position 1, and there was clear evidence of “ISR-like” recall with short lists when the same data were further examined using SR scoring. In addition, there was increased recency and reduced primacy when recall initiated with one of the last four serial positions.

The demonstration of similar findings under AS further confirms that the findings of Experiment 1 are not due to participants verbally recoding the locations. The data provide convincing evidence that the Ward *et al.* (2010) findings do not necessitate a language-specific mechanism, such as the direct output of an ordered verbal short term memory that was increasingly likely to be overwritten with increasing list items.

Despite the similarities between the data presented here and those of Ward *et al.* (2010), it should be noted that there are some differences in the shapes of the PFR curves. The tendency to initiate recall with the first stimulus item is relatively well maintained with increasing list lengths with words: 1.00, .98, .97, .89 for list lengths 1-4 (Ward *et al.*, 2010, Experiment 3), but for visuo-spatial stimuli, the corresponding values were .93, .72, .58, .52 in the No AS group and .99, .68, .60 and .49 in the AS group. In fact, the data for visuo-spatial stimuli are more similar to those of verbal stimuli under AS (Spurgeon *et al.*, 2014a), and may suggest that IFR of words may additionally be underpinned by a forward-ordered rehearsal mechanism. This direct comparison and possibility was addressed more fully in Experiment 2.

EXPERIMENT 2

The aim of Experiment 2 was to compare more directly the IFR performance on lists of between 1 to 12 words with the IFR performance of equivalent lists of non-verbal stimuli. The findings from Experiment 1 suggested that the tendency to initiate recall with the first list item was stronger with words compared with visuo-spatial stimuli. It may be tempting to ascribe the differences to an additional verbal rehearsal mechanism but this may be premature, as there are a number of remaining differences between the verbal methodology used by Ward *et al*. (2010) and the visuo-spatial one used in Experiment 1. Firstly, verbal free recall tasks usually require the participant to recall as many words as s/he can remember, and they typically output far fewer responses than items in the list. By contrast, in the previous Experiment, participants had to select as many rectangle locations as the number of locations presented. A likely consequence is that some of the responses were forced guesses, particularly at longer list lengths. Secondly, unlike in traditional verbal FR tasks, the possible responses (i.e. rectangles) were still on-screen, making this task somewhat similar to a recognition-based task rather than a genuine FR task.

Moreover, rather than comparing data across experiments, it would be useful to directly compare the findings from verbal and visuo-spatial material within the same experiment. For this reason, this and subsequent experiments engaged in a direct comparison of verbal and visuo-spatial performance in FR tasks.

Experiment 2 repeated elements of Experiment 1 with some changes and additions. There were two groups, one per modality: the verbal stimuli group and the visuo-spatial stimuli group. All participants were presented with 100 lists, containing either words for the verbal stimuli group and rectangle locations for the visuo-spatial stimuli group. There were ten trials each of ten different list lengths (lists of 1-8, 10 and 12). List length 15 was eliminated for practical reasons, to be able to fit in more trials in an experimental session. Half of the trials were performed in silence and the other half was performed under changing-state AS (repeating "1,2,3,4"). Jones, Madden and Miles (1992) showed that repeating a string of consonants ("CHJU") results in more disruption to the serial recall of words than repeating the same syllable ("ah"). Furthermore, Jones *et al.* (1995) also showed the same findings within the spatial domain since there were marked effects of AS in the serial recall of visuo-spatial material when the AS is a changing sequence of verbal material rather than a single repeated utterance. However, these results are not as readily replicable (Meiser & Klauer, 1999) and a non-significant effect of AS on visuo-spatial memory performance has been found regardless of whether the AS is a repeated word or a changing sequence (Smyth *et al.*, 1988). It was therefore expected that the AS would have a marked effect on IFR of verbal but not visuo-spatial stimuli.

The main aim of the experiment was to enable a direct comparison between verbal and visuo-spatial stimuli to determine whether the list length effects found by Ward *et al.* (2010) could be found to a similar extent in both modalities. More specifically, I wished to compare the PFR curves for both verbal and visuo-spatial modalities, since in the previous experiment, the PFR curves looked more similar to that of verbal data under AS (Spurgeon *et al.*, 2014a), rather than those of verbal domain curves without AS found in Ward *et al*. (2010). In order to test whether this difference in results is inherently due to modality differences or whether it can be attributed to the discrepancies in the methods of testing, the visuo-spatial task was adjusted to equate some of the methodological differences.

The first change from the previous experiment was that, in the visuo-spatial condition, participants did not know the length of the presented sequence and were not required to make as many responses as the number of items presented. This was done to make the visuo-spatial task more comparable to traditional verbal IFR tasks. However, these changes were not expected to have an impact on the output order effects since Grenfell-Essam and Ward (2012) have shown that this strategy remains consistent regardless of whether participants know the list length or not. Furthermore, contrary to traditional verbal IFR tasks, the verbal modality stimulus set was restricted, to equate for the fact that the spatial locations available on the screen were also limited to a specified amount. Consequently, some words and spatial locations were repeated within the experiment.

Regardless, of the changes the Ward *et al*. (2010) list length and output order effects were expected in both verbal and the visuo-spatial modality. More specifically, participants were expected to show a tendency to start with the first item on short lists while initiating the recall of longer lists with the last four items presented in both modalities. Furthermore, AS was expected to have a marked negative effect on verbal IFR but not on visuo-spatial IFR. It was of interest to test whether serial position and PFR curves for visuo-spatial material would look similar to that of verbal IFR under AS. More generally, Experiment 2 also sheds light on the similarities between visuo-spatial and verbal immediate memory since it enables a more direct comparison of the two.

METHOD

Participants. A total number of 40 students from the University of Essex were recruited as participants for this experiment in exchange for course credit.

Materials. Stimuli were presented using the 'Supercard' application via an Apple Mac Computer. On each trial, half of the participants saw a list of up to 12 words that were randomly selected for each participant from a subset of 432 words from the Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982). Each word was individually presented in 52-pt Times New Roman font in the centre of the screen. The other half of participants saw a subset of 36 rounded rectangular objects, measuring 9mm x 8mm, selected at random from a 20 x 20 matrix in a 285mm x 165mm frame with a grey background. The objects were white with a black outline. Responses were recorded using the computer mouse of the Apple Mac Computer for the visuo-spatial stimuli and on paper for the verbal stimuli.

Design. The experiment used a mixed factorial design. The between-subjects independent variable was the stimulus domain with two levels: verbal and visuo-spatial stimuli, such that there was a verbal stimuli group and a visuo-spatial stimuli group. There were three within-subjects independent variables: the degree of concurrent articulation with 2 levels (No AS and AS), list length, with 10 levels (1, 2, 3, 4, 5, 6, 7, 8, 10 and 12 items presented), and serial position with up to 12 levels. The dependent variables were the same as those of Experiment 1.

Procedure. Each participant was randomly allocated into one of the two groups: the verbal stimuli group and the visuo-spatial stimuli group, such that each group was made up of 20 participants. Each participant was tested individually and they were informed that they would be shown two practice lists of seven items (one list with and one list without AS), followed by 100 experimental lists of stimuli. The experimental trials were arranged into two blocks, with each block containing 50 trials (five trials of each of the 10 different list lengths). The stimuli appeared on the screen for 0.75s, and the screen was blank during the 0.25 inter-stimulus intervals. The order of the blocks was counterbalanced across participants, and within all blocks, the order of the list lengths was randomized.

Each trial started with a precue instruction either to remain silent (No AS) or to repeat "1,2,3,4" (AS) followed by an auditory tone. Following a computer mouse click, participants saw a sequence of between one and twelve stimuli presented one at a time. The words appeared in the centre of the screen; the visuo-spatial squares darkened one at a time from a randomized sub-set of 36 rectangles. For the No AS condition, participants saw the stimuli in silence as they were presented. For the AS condition, participants saw the stimuli while repeating the sequence "1,2,3,4" during the list presentation. To ensure that AS was done appropriately, the experimental sessions were recorded via Audacity and participants were informed of this. During the presentation of both stimuli types, the location of the curser was locked to a location at the right hand edge of the screen. In both modalities, by contrast to the previous Experiment, participants did not know the list length and the number of responses did not have to match up to the number of presented items.

At the end of the list there was an auditory cue for recall, which was self-paced. The participants in the verbal group wrote down as many words as they could remember, in any order that they wished, in a lined response grid. The participants in the visuo-spatial group clicked on the rectangles on the screen, which they had seen, previously turn black; they were free to respond in any order that they liked. After the participants was satisfied that they had completed their recall, they pressed the "submit" button which started the next trial.

RESULTS

Overall Accuracy. Figure 2.6 shows the overall proportion of words recalled in the verbal group (panel A), as well as the overall proportion of correctly recalled rectangle locations in the visuo-spatial group (panel B). In each panel, overall accuracy is plotted by list length for both the AS and No AS trials. In all conditions, the proportion of correct responses decreased with increasing list length in both verbal and visuo-spatial conditions. Whereas there was a marked difference between the accuracy of the No AS and AS trials in the verbal condition, there was little or no difference between the accuracy of the No AS and AS trials in the visuo-spatial stimuli group, thus confirming that the participants were not verbalizing during this task.

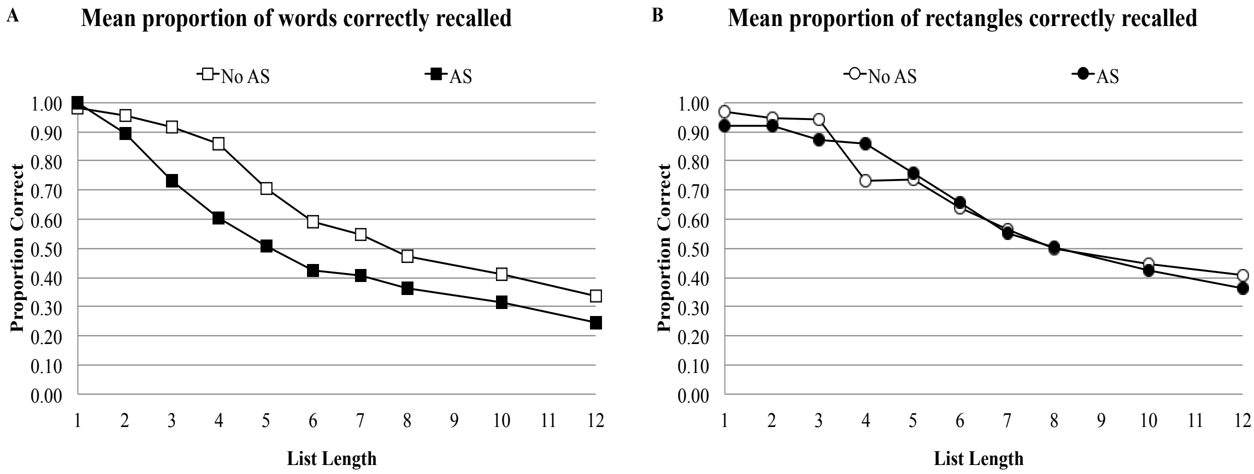

Figure 2.6. Experiment 2: The effect of list length on the mean proportion of correctly recalled words (panel A) and rectangle locations (panel B) for the AS and No AS trials respectively.

Table 2.2 summarizes a 2 (group: Verbal or Visuo-spatial) x 2 (trial type: AS or No AS) x 10 (list length: 1-8, 10, 12) mixed ANOVA that was performed on the proportion of correctly recalled items. Overall, there was a significant main effect of group, AS and list length. There was a significant list length by group interaction, a significant interaction between list length and AS, a significant AS by group interaction as well as a significant three-way interaction between list length suppression and stimuli.

In order to further explore the three-way interaction, a 2 (trial type: AS or silent) x 10 (list length: 1-8, 10, 12) ANOVA was performed on each of the verbal and visuo-spatial stimuli groups (see Table 2.2). In the verbal stimuli group there was a significant list length effect, as well as a significant effect of AS and a list length by suppression interaction. By contrast, in the visuo-spatial stimuli group, there was a significant effect of list length, a non-significant effect of suppression as well as a significant interaction.

Table 2.2
Experiment 2: Summary of the ANOVA analyses conducted upon the overall accuracy data.

	df	*MSE*	*F*	η^2_p	*p*
Overall Accuracy					
LL	9,342	.010	392	.912	< .001
AS	1,38	.013	65.4	.632	< .001
Group (GP)	1,38	.121	8.63	.185	.006
LL x AS	9,342	.007	2.27	.056	.018
LL x GP	9,342	.010	6.10	.138	< .001
AS x GP	1,38	.013	55.5	.593	< .001
LL x AS x GP	9,342	.007	9.98	.208	< .001
Overall Accuracy – Verbal Data					
LL	9,171	.008	302	.941	< .001
AS	1,19	.018	92.8	.830	< .001
LL x AS	9,171	.006	10.7	.360	< .001
Overall Accuracy – Visuo-spatial Data					
LL	9,171	.013	137	.879	< .001
AS	1,19	.009	.291	.015	.596
LL x AS	9,171	.009	3.30	.148	.001

Analyses of the serial position curves (SPCs). Figure 2.7 shows the SPCs for each of the 10 different list lengths for both types of trials (top panels: No AS; bottom panels: AS) for the verbal and visuo-spatial stimuli group respectively. In the No AS verbal condition, recall is close to ceiling levels for list lengths 1-3, the curves are relatively flat at list length 4 and 5 and from list length 6 onwards they are consistently bowed, showing primacy and extended recency effects. In the AS verbal condition, ceiling level performances are only seen for list length 1, and the serial position curves are consistently bowed from list lengths 3 onwards with much more extended recency when compared to the No AS trials, especially in the longer lists. Overall, Figure 2.7 shows that there were marked differences between SPCs in the verbal No AS and AS trials. In the visuo-spatial group, the SPCs are very similar for both silent and AS trials. Additionally, when compared to the verbal group, the visuo-spatial serial position curves are not as bowed. Performance is close to ceiling levels in list lengths 1-3, the curves are relatively flat for list lengths 4 and 5, with marked effects of serial position at list length 6 and greater.

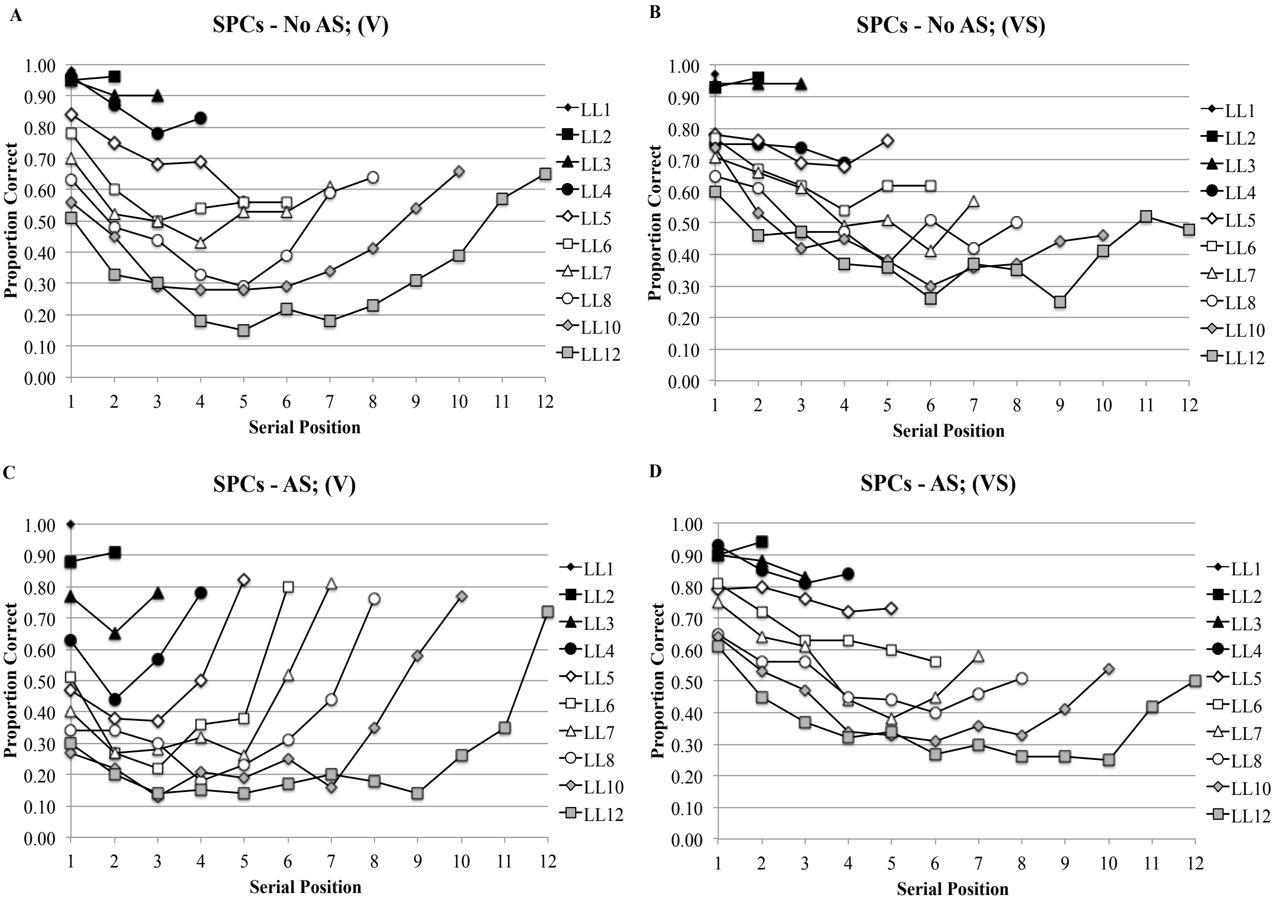

Figure 2.7. Experiment 2: SPCs from lists of 1 to 12 list items for the verbal (left) and visuo-spatial (right) stimuli groups for those the No AS (top) and AS (bottom) trials respectively.

The SPCs for each stimulus type were analysed at each list length, using a series of 2 (trial type: No AS or AS) x *n* (serial positions: 1 to *n*) mixed ANOVAs (where *n* is list length). The exact statistics for the main effects and interaction for each list length can be found in Appendix 2.5. In summary, for the verbal group AS had a significant effect for all list lengths. The main effect of serial position was significant for list lengths 4 and greater. More specifically, list lengths 3-7 showed both primacy and recency, whereas the effects at list lengths 8-12 showed extended recency effects. There was a significant interaction between list length and AS from list lengths 4 and greater.

For the visuo-spatial group, AS had a non-significant effect for all list lengths except 3 and 4. The main effect of serial position was significant for list lengths 6 and greater. More specifically, the curves at list lengths 3 to 5 are linear, there are primacy effects at list length 6 and 7 whereas list lengths 8-12 showed both primacy and recency. Finally, all interactions between AS and serial position were non-significant.

The probability of first recall (PFR) data. Figure 2.8 shows the proportion of trials in which items from different sequence serial positions were recalled first, for each of the 10 different list lengths and for both No AS (top panels) and AS (bottom panels) trials for the verbal and visuo-spatial stimuli groups respectively. Similar to Experiment 1, Panels A - D collapse the raw output into four main categories: 'SP1' – trials in which participant initiated recall with the first presented item, 'Last 4' – trials in which the participant initiated recall with one of the last four items on the list or sequence, 'other' – trials in which the participant initiated recall from anywhere else and 'errors'- trials in which recall was initiated with an error. As previously mentioned in Experiment 1, such plots usually show the list length at which the participants are more likely to shift their recall initiation from the first item on the list to one of the last four items presented – this is termed the cross over point. There was a crossover point for the verbal group: at around list length 7 for the No AS trials and between list lengths 3 and 4 for the AS trials. Conversely, there was no crossover point for the visuo-spatial group. Furthermore, Figure 2.8 also shows the same data segregated by the proportion of trials where recall was initiated either with the first (panel E) or one of the last four items (panel F) to enable direct cross-group comparisons. Table 2.3 shows the results of two 2 (group: verbal or visuo-spatial) x 2 (trial type: AS or No AS) x 10 (list length: 1-8, 10, 12) mixed ANOVAs that were calculated on the proportion of trials where participants initiated their recall with 'Serial Position 1' and on the proportion of trials where recall was initiated with one of the 'Last 4' items respectively. Both ANOVAs showed a significant main effect of list length, a significant main effect of group as well as significant interactions between list length and group, trial type and group and list length and trial type. Finally, the three way interaction between list length, suppression and stimuli group was also significant.

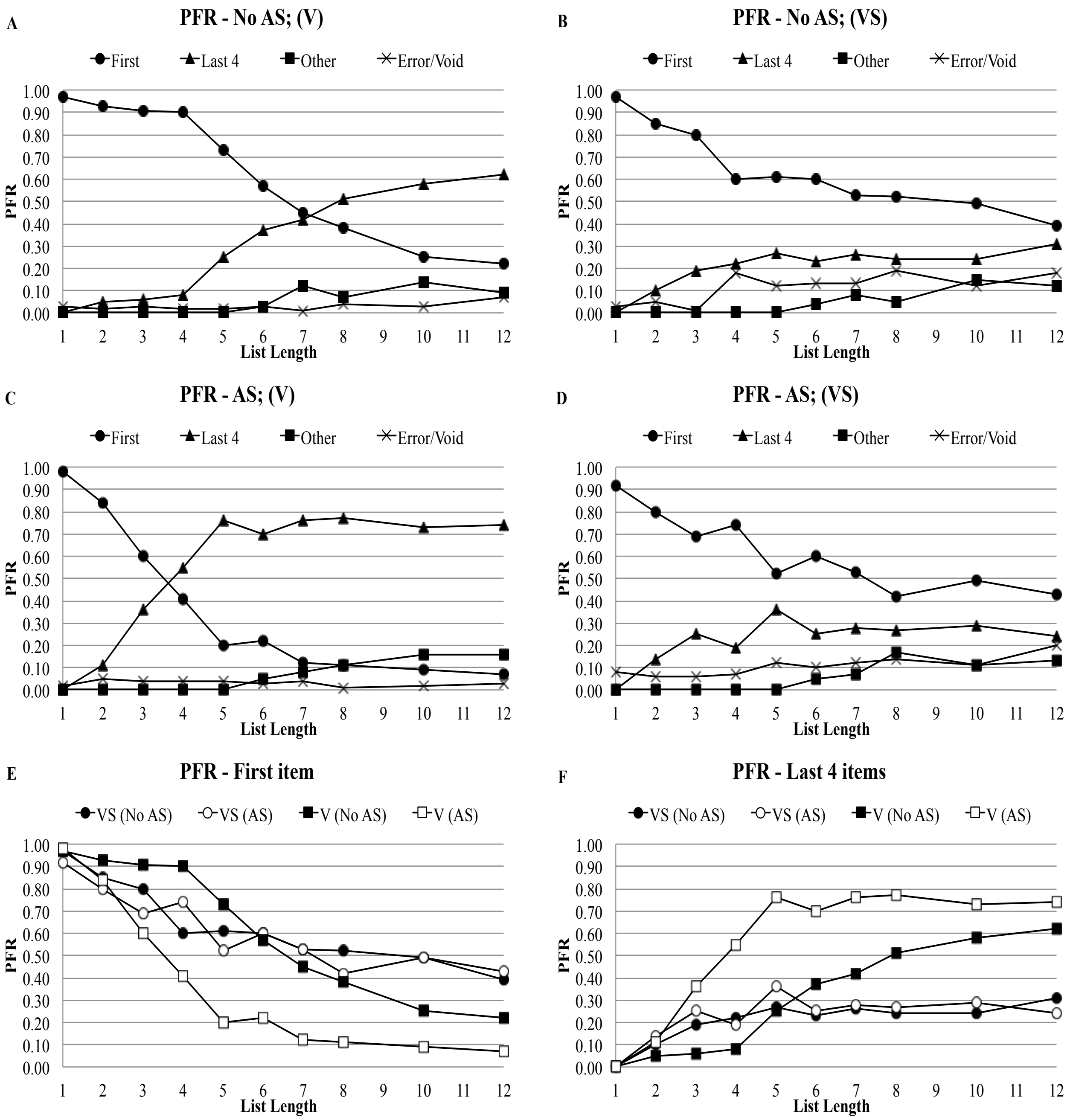

Figure 2.8. Experiment 2: PFR data for the verbal (left) and visuo-spatial (right) stimuli groups for the No AS and AS trials respectively. Panels A to D show the proportion of trials in which recall was initiated with either the first list item, one of the last 4 items, one of the other items in the list or an error for each trial type (No AS and AS) for each stimuli group respectively. Panels E and F show the exact data separated by those trials where participants initiated recall with either the first item or one of the last 4 presented items to enable cross-group comparison.

Figure 2.8 shows that despite the fact that there is no crossover point in the visuo-spatial stimuli group, both modalities showed that as the list length increased, the tendency to initiate recall with the first item decreased, and the tendency to start with the last four items increased. It is clear however, that the tendency to initiate recall with one of the last four presented items is not as strong in the visuo-spatial modality as it is in the verbal domain. Since there was a clear crossover point in the previous experiment, it is still yet unclear whether the present finding is due to visuo-spatial immediate memory mechanisms or whether this can be attributed to the external conditions in which the experiment was conducted.

Table 2.3
Experiment 2: Summary of the ANOVA analyses conducted upon the probability of first recall data.

	df	*MSE*	*F*	η^2_p	*p*
PFR = SP1 (Overall)					
LL	9,342	.044	99.6	.724	< .001
AS	1,38	.067	62.3	.623	< .001
GP	1,38	.579	5.57	.128	.024
LL x AS	9,342	.034	4.50	.106	< .001
LL x GP	9,342	.044	8.88	.189	< .001
AS x GP	1,38	.067	45.1	.543	< .001
LL x AS x GP	9,342	.034	5.85	.133	< .001
PFR = Last 4					
LL	8,304	.044	31.2	.451	< .001
AS	1,38	.083	51.0	.573	< .001
GP	1,38	.664	13.9	.268	.001
LL x AS	8,304	.030	4.83	.113	< .001
LL x GP	8,304	.044	13.5	.262	< .001
AS x GP	1,38	.083	36.7	.491	< .001
LL x AS x GP	8,304	.030	3.73	.089	< .001

The effect of first item recalled on the serial position curves. Figure 2.9 and Figure 2.10 (panels A and B) show the effect of list length and AS on the proportion of items recalled, for trials where recall was initiated with Serial Position 1 for the verbal and visuo-spatial groups respectively. Both figures show the serial position curves with FR scoring for the No AS (panel A) and AS (panel B) trials respectively. For each list length, these serial position curves were analysed by a 2 (trial type: AS or No AS) x *n* -1 (serial positions: 2 to *n*, where *n* is the list length) mixed ANOVA using FR scoring. The exact statistics for the main effects and interactions for each list length can be found in Appendix 2.6. For the verbal stimuli group, the main effect of serial position was significant for list length 8 only, whereas the main effect of AS was significant for list lengths 3 and greater. A serial position by AS interaction was significant only for list lengths 5 and 6. For the visuo-spatial group, the main effect of serial position was significant for list lengths 7 and greater, whereas the main effect of AS was non-significant for all list lengths. There was a significant serial position by AS interaction for list length 7 only.

Figure 2.9 and Figure 2.10 (panels C and D) shows the resultant SPCs for the same data coded using SR scoring for the No AS and AS trials for the verbal and visuo-spatial groups respectively. As seen in Experiment 1, participants have a tendency to recall the first few items presented in forward serial order, despite being instructed that this is not a task requirement. For each list length within each stimuli group, these serial position curves were analysed by a 2 (trial type: AS or No AS) x n -1 (serial positions: 2 to n) mixed ANOVA using SR scoring. The exact statistics for the main effects and interaction for each list length can be found in Appendix 2.7. For the verbal stimuli group, the main effect of serial position was significant for list lengths 3-10. There was a significant main effect of AS on all but list length 12 as well as a significant interaction for list lengths 5, 6 and 10. For the visuo-spatial group, the main effect of serial position was significant for list lengths 5 and greater. There was a non-significant effect of AS for all list lengths except for list lengths 3, 5 and 7 and all interactions were non-significant.

Figure 2.9 and Figure 2.10 (panels E and F) show the effects of AS and list length on the proportion of visuo-spatial locations and words recalled in any order for trials in which recall was initiated with one of the last four presented items. These SPCs were analysed by a 2 (trial type: AS or No AS) x n serial position mixed ANOVAs, one per stimuli group. The exact statistics for the main effects and interactions for each list length can be found in Appendix 2.8. For the verbal stimuli group, there was a significant main effect of serial position and a significant main effect of AS for list lengths 5 and greater. There was also a significant interaction for list lengths 7 and 8. For the visuo-spatial group, there was a significant main effect of serial position for list lengths 3 and 6-12. There was a non-significant main effect of AS for all list lengths as well as a significant interaction between AS and serial position at list length 10.

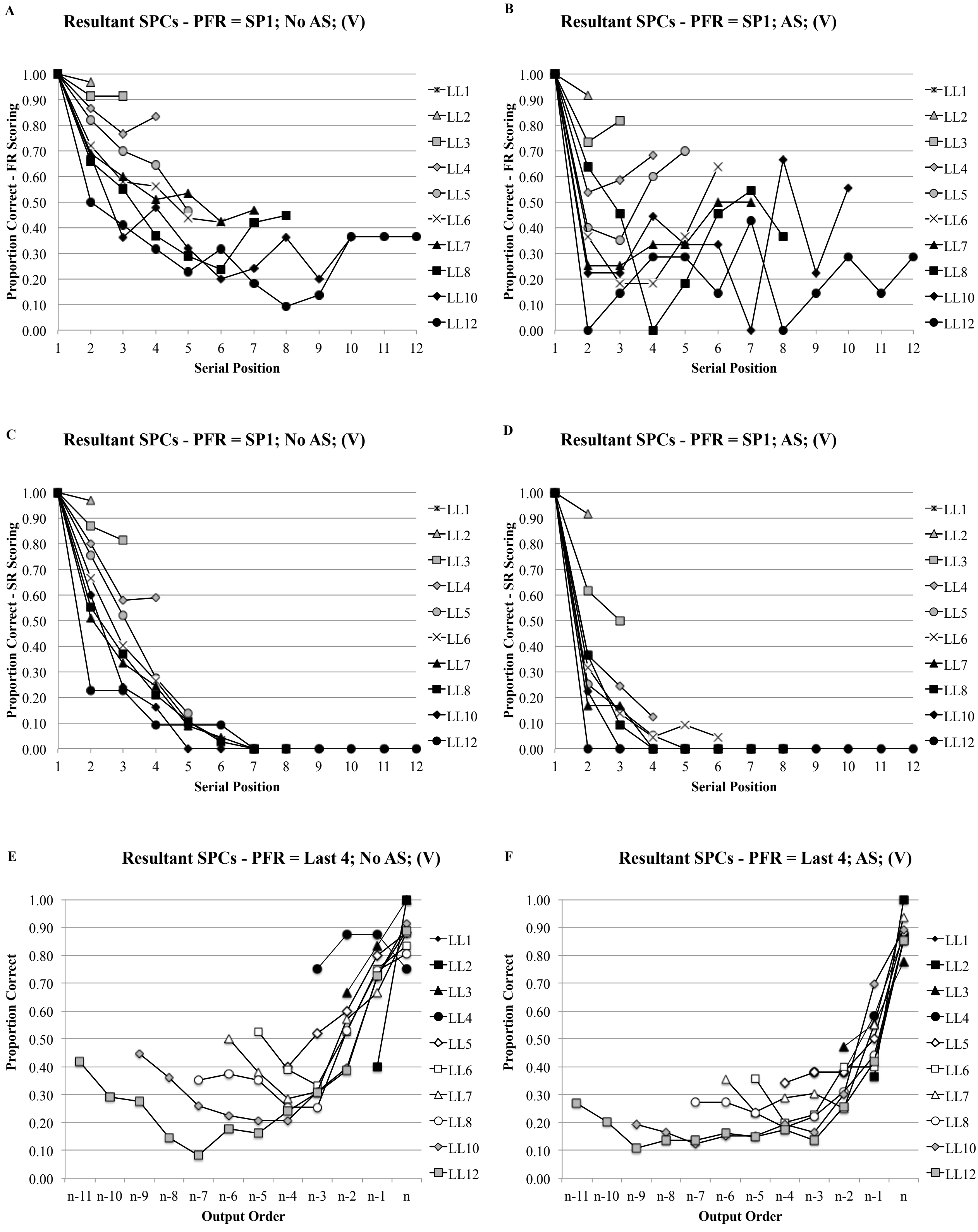

Figure 2.9. Experiment 2: The effect of the first recalled item on the SPCs for the verbal stimuli group for the No AS (left) and AS (right) trials respectively. Panels A and B show the effect of initiating recall with the first presented item in the list using FR scoring. Panels C and D show the effect of initiating recall with the first list item using SR scoring. Panels E and F shows the effect of initiating recall with one of the last four stimuli in the list using FR scoring.

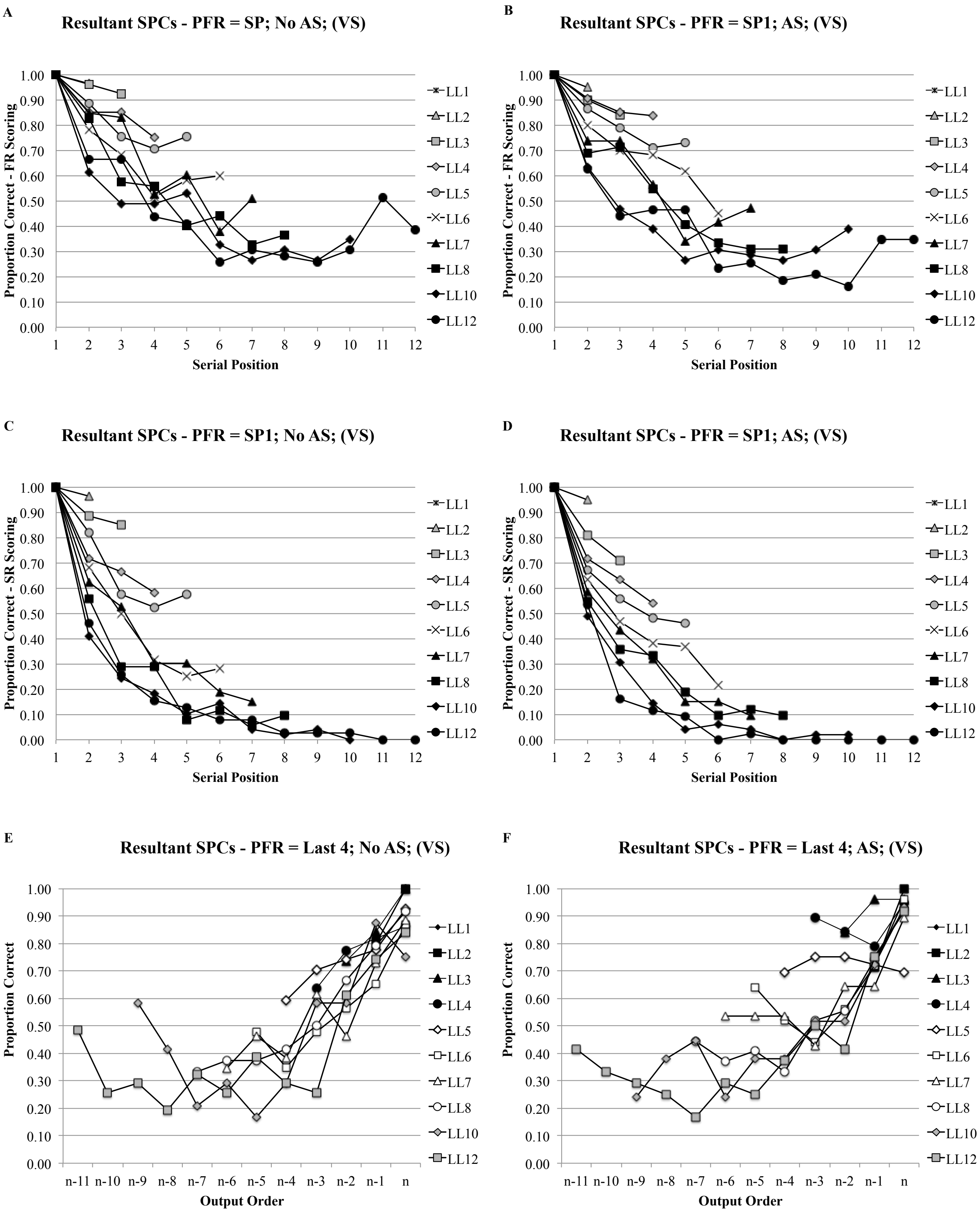

Figure 2.10. Experiment 2: The effect of the first recalled item on the SPCs for the visuo-spatial stimuli group for the No AS (left) and AS (right) trials respectively. Panels A and B show the effect of initiating recall with the first presented item in the list using FR scoring. Panels C and D show the effect of initiating recall with the first list item using SR scoring. Panels E and F shows the effect of initiating recall with one of the last four stimuli in the list using FR scoring.

Discussion

Experiment 2 examined whether performance in free recall tasks in both verbal and visuo-spatial modalities is similar when the methodologies are equated. It is noticeable that overall performance was higher for the visuo-spatial group and that whereas AS had a marked effect in the verbal modality, there was a non-significant main effect of AS in the visuo-spatial modality. This implies that the findings from the visuo-spatial task were not a result of participants using language codes to aid their memory for visuo-spatial locations. Consistent with the findings from the previous experiment, list length effects were present in both stimulus domains since in both groups, performance decreased with increasing list length.

Since visuo-spatial performance does not depend on verbal codes or rehearsal, it would be conceivable for the visuo-spatial performance to be similar to that of verbal material under AS. However, in the current experiment, the SPCs of visuo-spatial material resembled more that of verbal free recall when conducted in silence, since there was no heightened one item-recency found in the AS trials of the verbal group. As regards the PFR data, the curves for the different modalities are quite distinct from one modality to the other. Whereas in the verbal group there was a typical crossover point for the No AS trials and an earlier crossover for the AS trials, there were no crossover points for the visuo-spatial modality. In fact, the PFR curves for the visuo-spatial modality resembled more of those for serial recall than those of free recall, since PFR curves for serial recall do not always crossover (see Grenfell-Essam & Ward, 2012). However, it is noticeable that the PFR curve for the verbal stimuli under AS resembles the visuo-spatial findings from Experiment 1. Recall that the proportions of starting with SP1 in the first four list lengths (list lengths 1-4) in the visuo-spatial stimuli in Experiment 1 were of .93, .72, .58, and .52 in the No AS group and .99, .68, .60 and .49 in the AS group. In the present experiment the corresponding values in the AS trials of the verbal group were .98, .84, .60 and .41, resulting in a steeper PFR curve.

Although there are several similarities to the findings by Ward *et al*. (2010), in that the serial position curves show both primacy and recency, and that these varied according to the list length, it is clear that in the present experiment, the tendency to start with SP1 is stronger than the tendency to start with one of the last four presented items, especially in the visuo-spatial domain. Additionally, whereas in the verbal stimuli, the tendency to start with the first item on the list is extremely reduced at the longest list lengths (at around .20 at LL12), in the visuo-spatial domain, participants maintain the tendency to start with SP1 to a higher level in the longer lists (at around .40 at LL12). Therefore, from the present experiment it is clear that firstly, when recalling visuo-spatial stimuli, the tendency to start with the first presented item is strong, but decreases steadily over the first five list lengths, especially when compared to the strongly maintained tendency of the verbal stimuli. Secondly, although this tendency continues to decrease as the list length increases in both modalities, it is clear that the tendency to initiate recall with SP1 is stronger at the longer list lengths (LL8 and greater) in the visuo-spatial domain when compared to the verbal one. On the other hand, although the tendency to initiate recall with one of the last four presented items in the visuo-spatial task increases with increasing list length, this does not increase to the same degree as that of verbal stimuli. These differences might be therefore conducive to the fact that there is no crossover point in the PFR curves for visuo-spatial stimuli.

The tendency to recall items in forwards order is present in both modalities, and this was shown in the resultant SPCs using SR scoring; this was stronger for the verbal stimuli group. However, there could be other potential limitations that might have resulted in the following patterns. The fact that the possible responses remained on screen during the response phase, rendered the visuo-spatial task to resemble a recognition task, and this arguably hinders the possibility of a direct comparison of two modalities.

Overall, the above discussed data shows a number of similarities between the free recall of verbal and visuo-spatial material. However, there are some differences especially with regard to the PFR curves, whereby the tendency to initiate recall from the first item on the list is more maintained at the later list lengths in the visuo-spatial group, whereas the tendency to start recall with one of the last few items on the list is not as strong as in the verbal domain. Nevertheless, the list length and output order effects found by Ward *et al*. (2010) were present in both modalities, to different extents. Due to the limitations of the present experiment, it was decided that an empirical design properly equating verbal and visuo-spatial tasks was necessary.

EXPERIMENT 3

Experiment 3 is very similar to Experiment 2 in that it has two groups, one per modality (verbal stimuli group and visuo-spatial stimuli group). For both modalities, list length 15 was reintroduced and the experiment was made up of ten trials for each of the eleven list lengths (lists of 1-8, 10,12 and 15), having a total of a 110 trials, half of which were done with concurrent AS while the other half were done in silence. As in the previous experiment, changing state AS was used.

The aim of Experiment 3 was to enable a fairer comparison of the IFR of verbal and visuo-spatial material by further equating the methodologies. The main difference between the verbal and visuo-spatial task in Experiment 2 was that whereas the IFR of the lists of words occurred in the absence of external cues, the IFR of the visuo-spatial stimuli occurred in the presence of a set of 36 visuo-spatial rectangles that remained on screen at test as well. Therefore, the differences observed between the IFR of the verbal and visuo-spatial material in Experiment 2 may reflect either differences in the stimulus domain or differences between the degree of environmental support that was available at test: the test of verbal stimuli was pure recall, whereas the test of non-verbal stimuli was recognition-based.

Consequently, the rectangle locations task utilized in Experiment 1 and 2 was replaced with a dots task, where participants were presented with up to 15 visuo-spatial circles, presented one at a time in different locations on the screen, and at test, participants saw a blank screen and were required to click at the locations of the circles in whatever order they liked. They were encouraged not to guess and they were allowed to make as many or as few responses as they wished (but no more responses than there had been stimuli). Since this visuo-spatial FR task is more matched to a typical verbal FR task, the extent of the "ISR-like" tendencies in IFR of short lists of verbal and non-verbal stimuli could be more closely compared.

METHOD

Participants. A total number of 40 students from the University of Essex participated in exchange for course credit in this experiment.

Materials. Stimuli were presented using the 'Supercard' application via an Apple Mac Computer. On each trial, half of the participants saw a list of up to 15 words that were randomly selected for each participant from a subset of 412 words from the Toronto Word Pool (Friendly, *et al.*, 1982). Each word was individually presented in 52-pt Times New Roman font in the centre of the screen. The other half of the participants saw a sequence of dots, where each dot had a diameter of 35mm and its spatial location was selected at random from 412 different spatial locations on the screen, in a 285mm x 165mm frame with a grey background. The objects were black with a black outline. Responses were recorded using the computer mouse of the Apple Mac Computer for the visuo-spatial stimuli and on lined paper for the verbal stimuli.

Design. The design of the experiment was equivalent to that of Experiment 2, with the exception of changes to two within-subjects independent variables: list length had 11 levels instead of 10 and serial position had up to 15 levels.

Procedure. The procedure was similar to that of Experiment 2, with the exception that the visuo-spatial stimuli were circular instead of rounded rectangles, and were presented on a blank screen rather than from a selection of previously presented items (see Figure 2.11). Furthermore, there was an additional list (list length 15), meaning that the experiment was made up of two blocks each containing 55 experimental trials, where each block consisted of 5 trials of each of the 11 different list lengths. Participants were given as much time as they required to make their responses and were asked to try and recall as many items as they could in any order that they liked. During the sequence presentation in both modalities, the mouse cursor became inactive to prevent the subjects from using mouse movements as a memory aid in the visuo-spatial group; this was also done for the verbal group to maintain consistency. Once the sequence of stimuli ended, the cursor became active once again. After the participants was satisfied that they had completed their recall, they pressed the "submit" button which started the next trial.

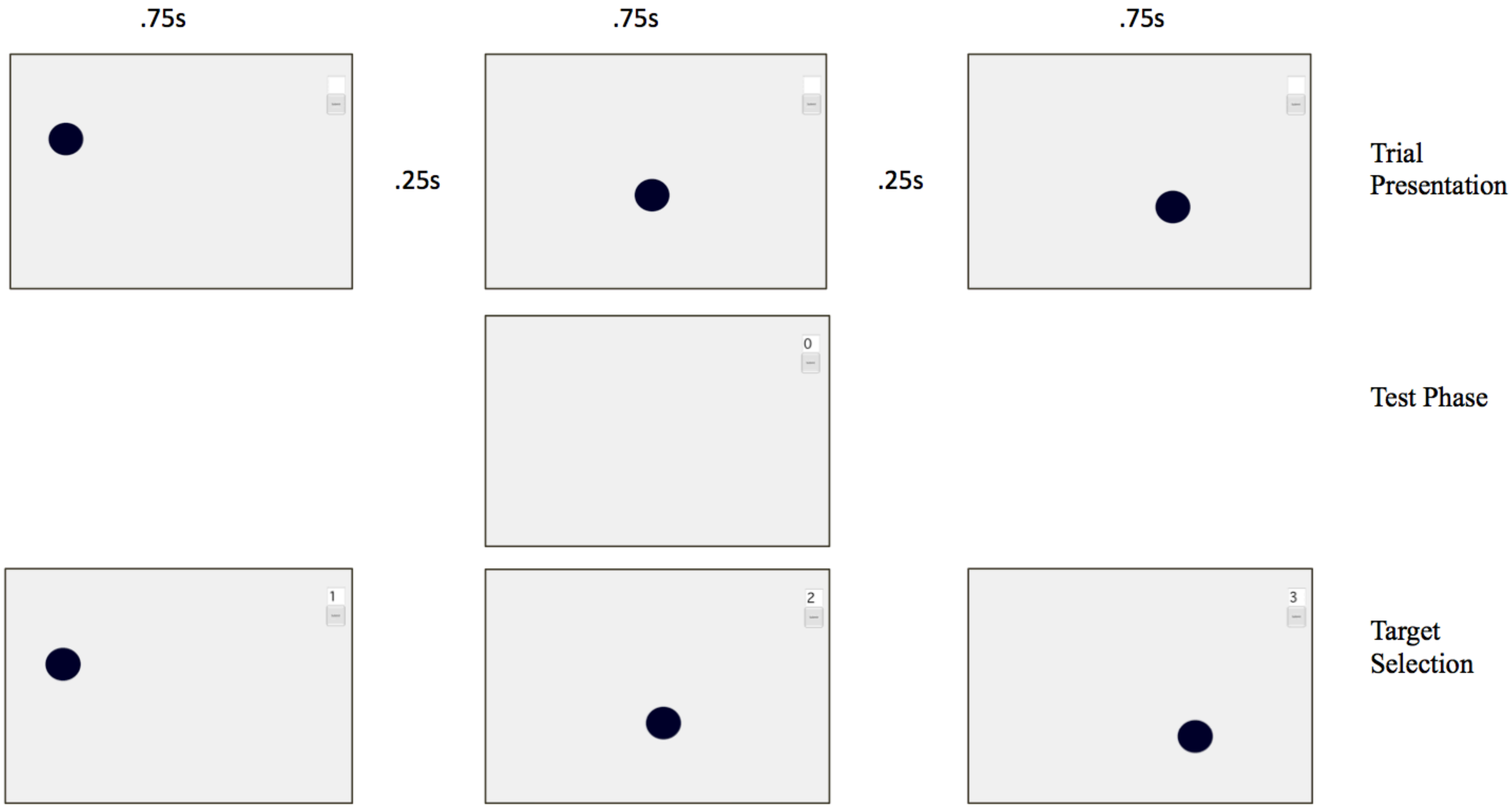

Figure 2.11. Experiment 3: A screenshot of the procedure of Experiment 3.

<u>RESULTS</u>

Overall Accuracy. For a visuo-spatial response to be considered correct, participants had to click within the circumference of the presented visuo-spatial dot, and therefore clicks just outside this circumference were considered incorrect. Figure 2.12 shows the proportion of correctly recalled words in the verbal group as well as the proportion of correct visuo-spatial responses that corresponded to the positions of presented dots. In each panel, overall accuracy is plotted by list length for both the No AS and AS trials. In all conditions, the proportion of correct responses decreased with increasing list length. It is clear that the accuracy in recalling the locations of the circles (panel B) was considerably lower than the accuracy in recalling the words (panel A). In addition, whilst there was a marked difference between the accuracy of the No AS and AS trials in the verbal condition (panel A) there was little or no difference between the accuracy of the No AS and AS trials in the visuo-spatial stimuli group (panel B).

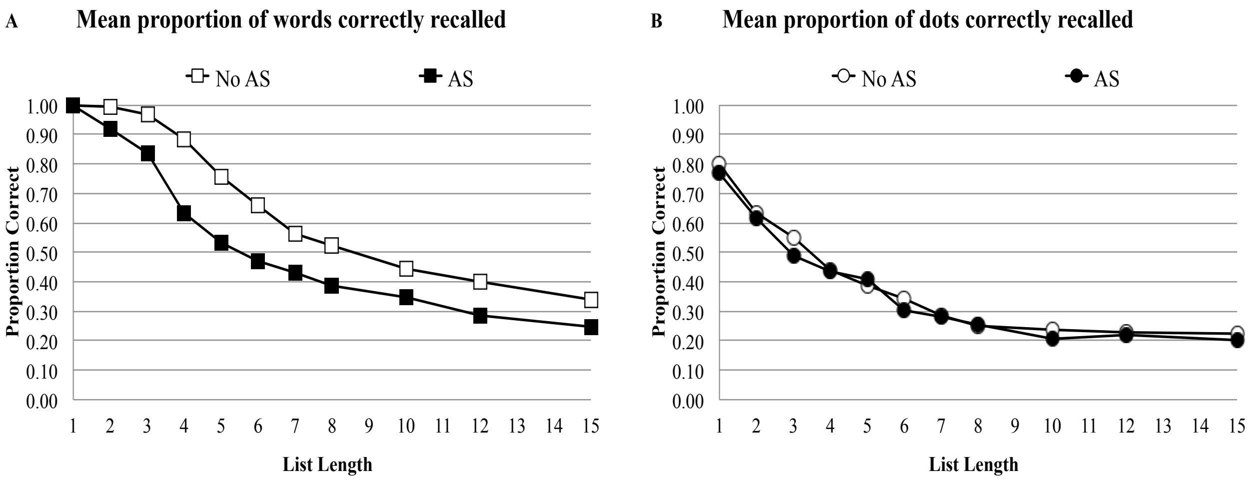

Figure 2.12. Experiment 3: The effect of list length on the mean proportion of correctly recalled words (panel A) and circle locations (panel B) for the AS and No AS trials respectively.

Table 2.4 summarizes a 2 (group: Verbal or Visuo-spatial) x 2 (trial type: AS or No AS) x 11 (list length: 1-8, 10, 12, 15) mixed Analysis of Variance (ANOVA) that was performed on the proportion of correctly recalled items. Overall, there was a significant main effect of list length, AS and stimulus group. There was also a significant interaction between list length and stimuli group and between AS and stimuli group, a significant interaction between list length and AS, as well as a significant three-way interaction between list length, AS, and stimulus group.

In order to further explore the three-way interaction, a 2 (trial type: AS or No AS) x 11 (list length: 1-8, 10, 12, 15) ANOVA was performed on each of the verbal and visuo-spatial stimulus groups' data (see Table 2.4). In the verbal stimuli group there was a significant list length effect, as well as a significant effect of AS and a list length by AS interaction. By contrast, in the visuo-spatial group, there was a significant main effect of list length, but a non-significant effect of AS and a non-significant interaction.

Table 2.4
Experiment 3: Summary of the ANOVA analyses conducted upon the overall accuracy data.

	df	*MSE*	*F*	η^2_p	*p*
Overall Accuracy					
LL	10,380	.012	319	.893	< .001
AS	1,38	.009	136	.782	< .001
GP	1,38	.095	123	.764	< .001
LL x AS	10,380	.007	2.83	.069	.002
LL x GP	10,380	.012	13.5	.262	< .001
AS x GP	1,38	.009	80.4	.679	< .001
LL x AS x GP	10,380	.007	4.56	.107	< .001
Overall Accuracy – Verbal Data					
LL	10,190	.007	370	.951	< .001
AS	1,19	.010	196	.912	< .001
LL x AS	10,190	.005	10.6	.357	< .001
Overall Accuracy – Visuo-spatial Data					
LL	10,190	.170	83.3	.814	< .001
AS	1,19	.008	4.01	.174	.060
LL x AS	10,190	.010	.501	.026	.888

Serial position curves (SPCs). Figure 2.13 shows the SPCs for each of the 11 different list lengths in both the No AS and AS conditions for the verbal and visuo-spatial stimuli groups respectively. The SPCs for each stimulus type were analysed at each list length, using a series of 2 (trial type: AS or No AS) x *n* (serial positions: 1 to *n*) mixed ANOVAs. The exact statistics for the main effects and interaction for each list length can be found in Appendix 2.9.

In summary, for the visuo-spatial group, AS had a non-significant effect for all but one list length (LL 10). The main effect of serial position was significant for list lengths 6-15. More specifically, the curves at list lengths 2 and 3 were linear; list lengths 4-8 showed both primacy and recency, while list lengths 10 and greater had extended recency effects. Finally, all of the interactions between AS and serial position were non-significant.

For the verbal group, the main effect of serial position was significant for list lengths 3-15. More specifically, list lengths 3-5 showed primacy, list lengths 6-8 showed both primacy and recency, whereas the effects at list lengths 10-15 showed extended recency effects. There was a significant reduction due to AS at all list lengths, and also a significant interaction between list length and AS for list lengths 3-15. AS greatly affected earlier serial positions, but led to a 1-item recency advantage.

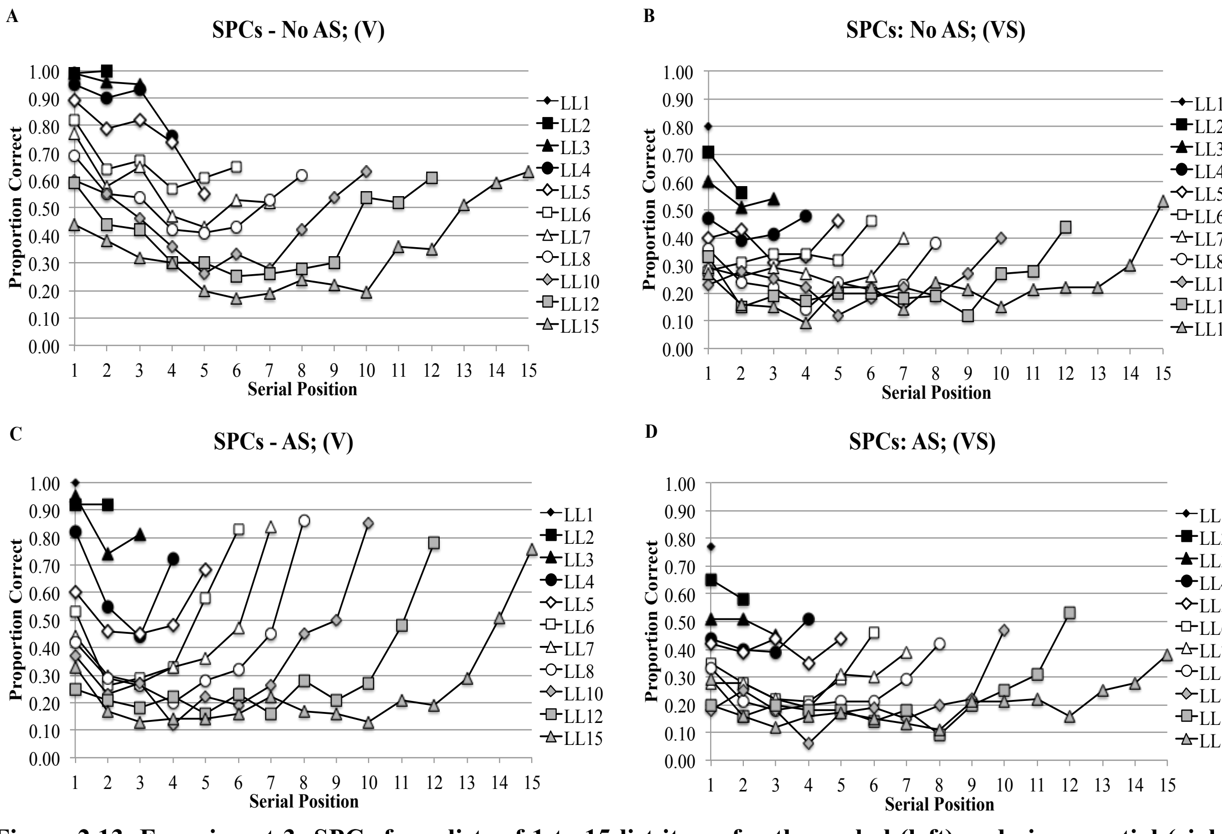

Figure 2.13. Experiment 3: SPCs from lists of 1 to 15 list items for the verbal (left) and visuo-spatial (right) stimuli groups for those the No AS (top) and AS (bottom) trials respectively.

The probability of first recall (PFR) data. Figure 2.14 shows the proportion of trials in which items from different serial positions were recalled first, for each of the 11 different list lengths and for both No AS and AS trials for the verbal and visuo-spatial stimuli groups respectively. Figures 2.14 (panels A and B) refer to the IFR data from the lists of words, with and without AS whereas Figure 2.14 (panels C and D) refer to the IFR data from the visuo-spatial circles task, with and without AS, respectively. Furthermore, Figure 2.14 (panels E and F) also shows the same data segregated by the proportion of trials where recall was initiated either with the first (panel E) or one of the last four items (panel F) to enable direct cross-group comparisons.

For the lists of words, participants tended to initiate recall with the first word on short lists but initiated recall with one of the last four words with longer lists. There were very few initial errors, but there was a large effect of AS on where recall started: the tendency to initiate recall with the first word was reduced (but not eliminated) when lists of words were recalled under AS. For the lists of visuo-spatial stimuli, participants tended to initiate recall with the first dot on short lists but initiated recall with one of the last four dots with longer lists. There was a high degree of error in accuracy, especially when compared to the verbal stimuli, but little effect of AS on where recall started.

Table 2.5 shows the results of two 2 (group: Verbal or Visuo-spatial) x 2 (trial type: AS or No AS) x 11 (list length: 1-8, 10, 12, 15) mixed ANOVAs that were calculated on the proportion of trials where participants initiated their recall with 'Serial Position 1' and the 'Last 4' items respectively. Both ANOVAs showed significant main effects of list length, AS and stimuli group as well as significant interactions between list length and stimuli group and between AS and list length. Furthermore, there was a significant interaction between AS and stimuli group, as well as a significant three-way interaction between AS, list length and stimuli group.

Figure 2.14 shows that despite the differences in accuracy levels in the verbal and visuo-spatial tasks, all panels show that as the list length increased, the tendency to initiate recall with the first item decreased, and the tendency to start with the last four items increased. Finally, it is also noteworthy that AS in the visuo-spatial group, unlike in the verbal group, did not have an adverse effect on the tendency to initiate IFR with the first list item, implying that recall in visuo-spatial tasks was not aided through language recoding. Overall, the PFR data for both domains show that these list length and output order effects are present for both verbal and visuo-spatial stimuli, implying similar mechanisms of recall in both modalities.

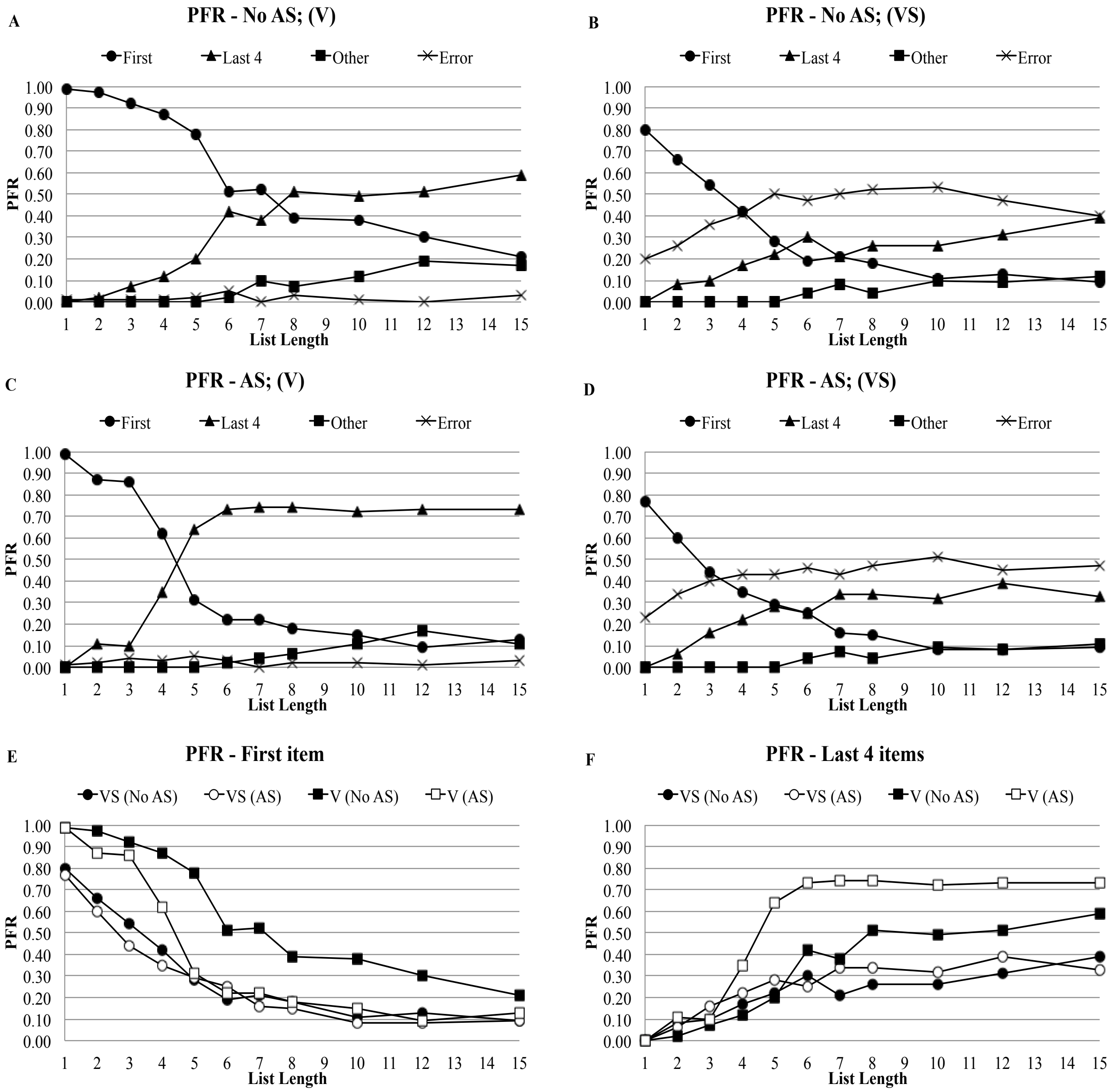

Figure 2.14. Experiment 3: PFR data for the verbal (left) and visuo-spatial (right) stimuli groups for the No AS and AS trials respectively. Panels A to D show the proportion of trials in which recall initiated with either the first list item, one of the last 4 items, one of the other items in the list or an error for each trial type (No

AS and AS) for each stimuli group respectively. Panels E and F show the exact data separated by those trials where participants initiated recall with either the first item or one of the last 4 presented items to enable cross-group comparison.

Table 2.5
Experiment 3: Summary of the ANOVA analyses conducted upon the probability of first recall data.

	df	*MSE*	*F*	η^2_p	*p*
PFR = SP1 (Overall)					
LL	10,380	.049	119	.758	< .001
AS	1,38	.095	31.0	.449	< .001
GP	1,38	.334	28.9	.432	< .001
LL x AS	10,380	.030	2.51	.062	.006
LL x GP	10,380	.049	4.64	.109	< .001
AS x GP	1,38	.095	16.3	.300	< .001
LL x AS x GP	10,380	.030	4.12	.098	< .001
PFR = Last 4					
LL	9,342	.051	40.8	.518	< .001
AS	1,38	.096	37.2	.495	< .001
GP	1,38	.578	13.1	.256	.001
LL x AS	9,342	.033	3.67	.088	< .001
LL x GP	9,342	.051	8.30	.179	< .001
AS x GP	1,38	.096	18.6	.329	< .001
LL x AS x GP	9,342	.033	2.13	.053	.027

The effect of the first recall on the serial position curves. Figures 2.15 (panels A and B) show the effect of list length and AS on the proportion of items recalled, for trials where recall was initiated with Serial Position 1 for the verbal stimuli group. For each list length, these serial position curves were analysed by a 2 (trial type: AS or No AS) x *n* -1 (serial positions: 2 to *n*) mixed ANOVA using FR scoring. The exact statistics for the main effects and interactions for each list length can also be found in Appendix 2.10. For the verbal stimuli group, the main effect of AS was significant for list lengths 3-8, which showed that AS reduced recall of lists of words relative to the No AS conditions. The interaction between AS and serial position reached significance for list lengths 4, 8 and 15, showing that AS tended to reduce early and middle serial positions but enhance a single-item recency. Finally, there was a significant main effect of serial position for list lengths 5, 10, and 15, showing significant primacy effects and (at longer list lengths) significant recency effects.

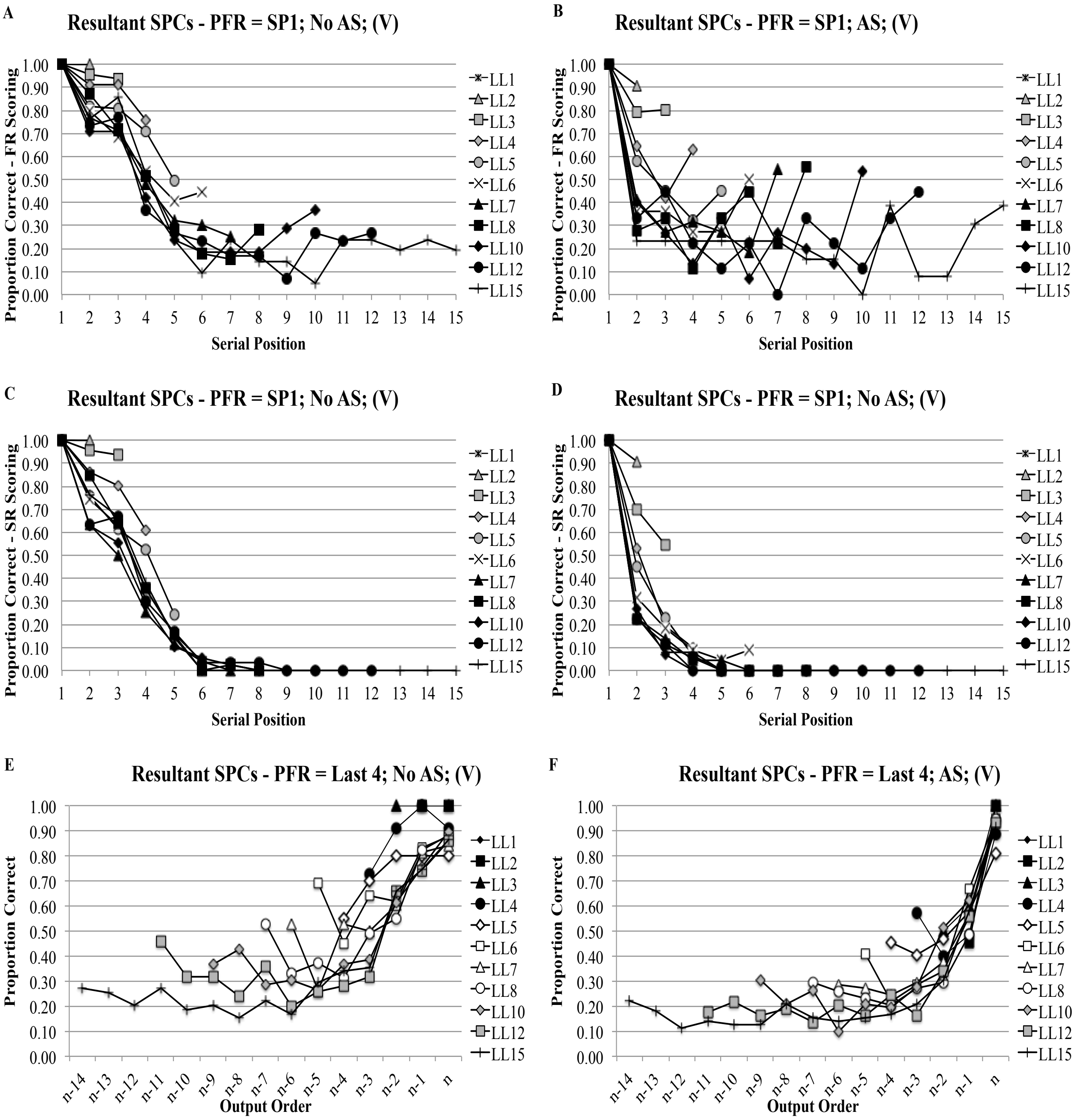

Figure 2.15. Experiment 3: The effect of the first recalled item on the SPCs for the verbal stimuli group for the No AS (left) and AS (right) trials respectively. Panels A and B show the effect of initiating recall with the first presented item in the list using FR scoring. Panels C and D show the effect of initiating recall with the first list item using SR scoring. Panels E and F shows the effect of initiating recall with one of the last four stimuli in the list using FR scoring.

Figures 2.16 (panels A and B) shows the effect of list length and AS on the proportion of items recalled, for trials where recall was initiated with Serial Position 1 for the corresponding visuo-spatial group. The exact statistics for the main effects and interactions for each list length can be found in Appendix 2.10. For the visuo-spatial group, the main effect of serial position was significant for list lengths 5 and 7. There were no significant main effects of AS, and all interactions between list length and AS were non-significant except for list length 3.

Figures 2.15 and 2.16 (panels C and D) show the SPCs for the same data coded using SR scoring for the No AS and AS list length trials for both the verbal and visuo-spatial group respectively. For each list length within each stimuli group, these serial position curves were analysed by a 2 (trial type: AS or No AS) x n -1 (serial positions: 2 to n) mixed ANOVA using SR scoring. The exact statistics for the main effects and interaction for each list length can be found in Appendix 2.11.

For the verbal stimuli group, the main effect of serial position was significant for all list lengths, indicating strong serial ordered recall. There was a significant main effect of AS for all list lengths except list length 7, as well as a significant interaction for all but list lengths 5 and 7. These data show that the IFR of the lists of words was performed in an “ISR-like” manner and that it was more affected by AS.

By contrast, for the visuo-spatial group, the main effect of serial position was significant for list length 5, indicating some evidence of forward ordered recall. There was only limited effects of AS. More specifically, there was a non-significant effect of AS for all list lengths, and there was only one significant interaction between AS and serial position at list length 3. Figures 2.15 and 2.16 (panels E and F) show the effects of AS and list length on the proportion of words (Figures 2.15E and 2.15F), and dot locations (Figures 2.16E and 2.16F, recalled in any order, for trials in which recall was initiated with one of the last four presented items. These SPCs were analysed by a 2 (trial type: AS or No AS) x n (serial position) mixed ANOVAs, one per each stimuli group. The exact statistics for the main effects and interactions for each list length can be found in Appendix 2.12.

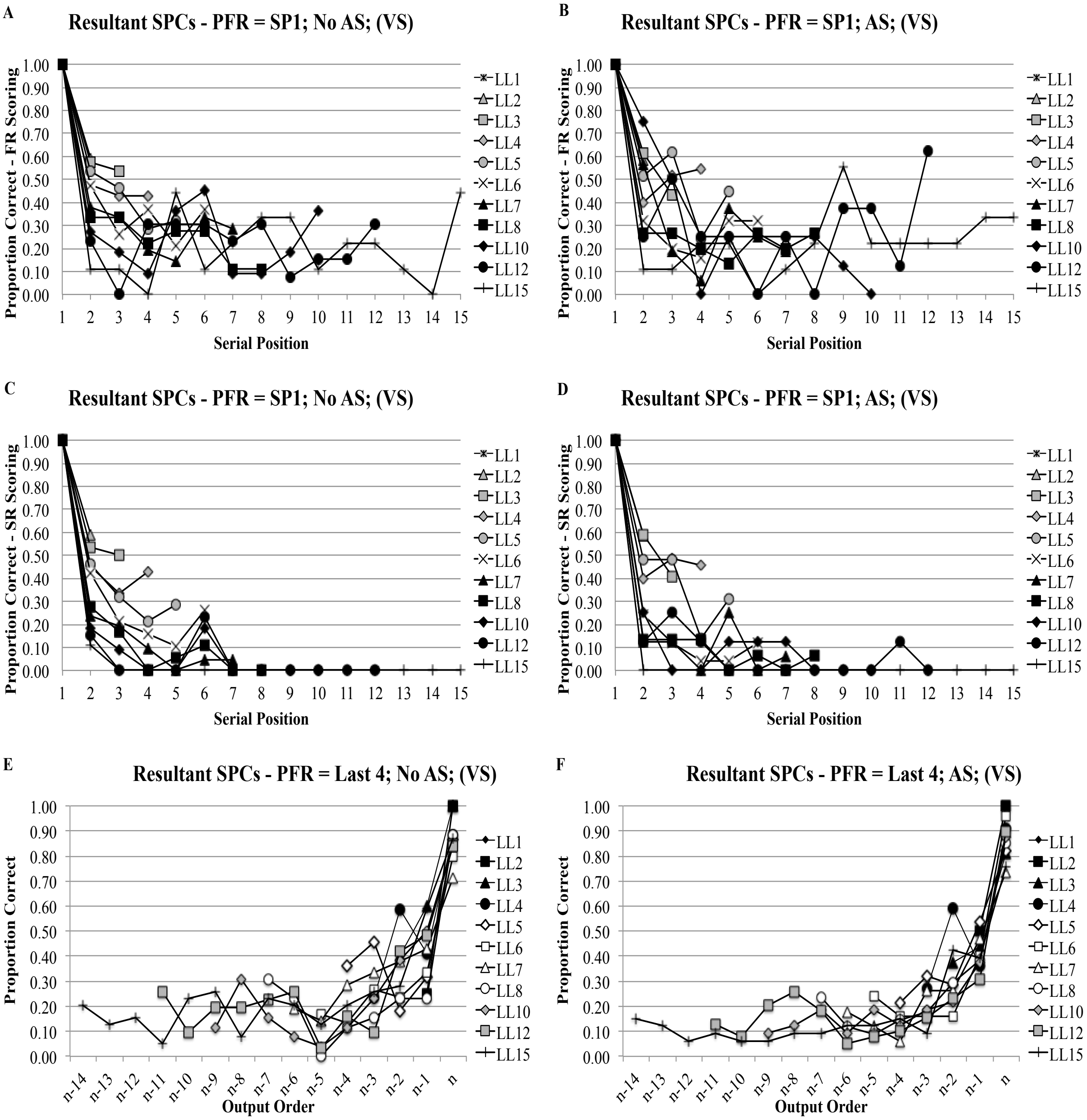

Figure 2.16. Experiment 3: The effect of the first recalled item on the SPCs for the visuo-spatial stimuli group for the No AS (left) and AS (right) trials respectively. Panels A and B show the effect of initiating recall with the first presented item in the list using FR scoring. Panels C and D show the effect of initiating recall with the first list item using SR scoring. Panels E and F shows the effect of initiating recall with one of the last four stimuli in the list using FR scoring.

For the verbal stimuli group, there was a significant main effect of serial position for all list lengths of 5 words or more, reflecting extended recency effects. Additionally, there was a significant main effect of AS for list lengths 5 and greater; and significant interactions between

AS and serial position at list lengths 4-7, 12, and 15. AS reduced verbal recall, particularly at early serial positions. For the visuo-spatial group, there was a significant main effect of serial position for all list lengths, reflecting extended recency effects. There were significant main effect of AS only for list lengths 4, 7 and 15 reflecting reductions in recall under AS at these three list lengths, but all the interactions between AS and serial position were non-significant.

DISCUSSION

The aim of Experiment 3 was to equate the methodologies of verbal and visuo-spatial IFR tasks, to enable further comparison between the two modalities. Although as modalities, verbal and visuo-spatial stimuli are inherently very distinct, effort was put into this experiment to ensure that both tasks in both modalities were as similar as possible.

There are six general findings from Experiment 3. Firstly, it was noticeable that overall performance in the visuo-spatial task of the present experiment was much lower than in the previous experiments, as well as lower than performance in the verbal task. This is likely to be because participants had to click on the exact spatial locations of a sequence of visuo-spatial stimuli in Experiment 3, in the absence of any environmental support for those locations. Furthermore, it is also possible that visuo-spatial recall in Experiments 1 and 2 benefitted from additional guesses. Undeniably, guesses could still occur in the present experiment; however these were not supported by the presentation of possible items, since participants saw a blank screen at test.

Secondly, and consistent with the previous experiments, AS did not have a marked effect on the performance of the visuo-spatial task, implying that the results obtained in the visuo-spatial task were on the whole unaided by the participants' use of verbalization (and verbal rehearsal). In contrast, although verbal memory performance was greatly reduced by AS, the task remained possible, a result suggesting that verbal rehearsal augmented (but was not strictly necessary) for IFR (a result similar to Grenfell-Essam *et al.*, 2013; and Spurgeon *et al.*, 2014).

Thirdly, the shapes of the serial position curves in the visuo-spatial task look similar to those of the verbal task performed in silence. When performed under AS, verbal SPCs have increased recency effects especially in the longer list lengths. This shows that despite the different levels of performance in both tasks, primacy and recency effects can be seen in non-verbal stimuli, resulting in bowed curves.

Additionally, PFR data shows that despite the different performance levels between the verbal and visuo-spatial IFR, the same strategy to recall stimuli in both modalities was similar. In the verbal task, the crossover point was between list length 7 and 8 in the No AS trials, and between list length 4 and 5 under AS. In the visuo-spatial group, the crossover point for the No as trials was between list length 5 and 6, while in the AS trials there was an extended crossover point from list length 5 to 6. This reinforces the idea that regardless of the stimulus type, participants tend to start with SP1 in short lists, while initiating recall with one of the last four presented items in longer lists.

However, the tendency to initiate recall with the first item remained high over list lengths 1-4 with verbal stimuli (.99, .97, .92, .87) but decreased more sharply with visuo-spatial circles (.80, .66, .54, .42). There are three possible explanations for this finding. One possibility is that these differences reflect the difference in overall accuracy between the two types of stimuli: verbal stimuli might vary in more dimensions (orthographic, phonological, semantic, temporal) than visuo-spatial (spatial, temporal) and that to initiate recall of the first item necessarily requires that that first item is accessible. A second possibility is that the effect of temporal order on the IFR of visuo-spatial stimuli is diluted by the effects of the spatial proximity of the items and the position of the items relative to the cursor at the start of test. A third possibility is that a general forward-ordered tendency could be augmented for verbal stimuli by co-articulating and /

or rehearsing short sequences of 3-4 items which are later retrieved in forwards order. In line with this third possibility, the tendency to initiate recall with the first item declined markedly over list lengths 1-4 with verbal stimuli when presented under AS.

Finally, a comparison of the SPCs scored with FR and SR scoring reveals that two of the largest factors contributing to the shapes of the curves are list length, as well as the type of scoring used. The resultant SPCs showed that the first item recalled determines the shape of the SPC. When recall was initiated with the first presented item, there was increased primacy and reduced recency effects, but when recall was initiated with one of the last four items, there was decreased primacy and extended recency effects. Resultant SPCs in SR scoring revealed a tendency to recall items in forwards order in both modalities, albeit stronger in the performance of the verbal group in the No AS trials. It is possible that this might support Gmeindl *et al.*'s (2011) finding that serial order is more spontaneously bound to verbal stimuli relative to visuo-spatial stimuli.

In summary, the list length and output order effects previously found by Ward *et al.* (2010) can also be found in non-verbal visuo-spatial stimuli, since the results from the dots task showed that participants had a tendency to start at the start in short lists, whereas when asked to recall longer lists they had the tendency to start with one of the last four presented items. This finding thus supports the idea that the novel finding by Ward *et al.* (2010) is not confined to verbal material, but can be extended to other modalities. Therefore it can be concluded that these list length and output order effects are not exclusively underpinned by a language-specific mechanism, since it is also present in the absence of verbalisation. This finding, in turn contributes to the more broad aim of the present thesis that is, to expose similarities between the verbal and visuo-spatial stimulus domains. The experiment shows that when the methodology of tasks is properly equated, the FR pattern of visuo-spatial material is similar to that of verbal stimuli.

General Discussion

The three experiments in this chapter had two aims. The first aim was to examine whether the tendency to recall a short list of words in IFR with the first presented item and subsequently in a forward-ordered manner (Ward *et al*., 2010), is reliant on a language-specific mechanism. To this end, I examined whether I would find similar list length and output order effects with non-verbal, visuo-spatial stimuli. The second aim of this set of experiments was to examine the functional similarities and differences between the IFR of verbal and visuo-spatial stimuli. Accordingly, I systematically examined and compared serial position curves and probability of first recall curves across a wide range of list lengths in the verbal and visuo-spatial domain.

List Length and Output Order Effects Across Domains

By manipulating list length, Ward *et al*. (2010) showed that when participants are required to recall a short list of words in any order that they liked, their preferred output strategy is to recall the items in an "ISR-like" manner, whereby they start with the first item and continue recalling in forwards order. These list length and output order effects have been replicated in the verbal domain (Experiments 2 and 3) as well as extended to the visuo-spatial domain across all three experiments. More specifically, it is clear that regardless of whether participants were presented with verbal or visuo-spatial material, they tended to initiate recall with the first list item in shorter lists, while initiating recall of longer lists with one of the last four presented items. Furthermore, the first item recalled was predictive of successive recalls, and this can be seen in the shape of the serial position curves when these were conditionalised by whether participants started at the start or with one of the last few items. In such serial position curves, there was a recall advantage for early list items when recall was initiated with the first item, and there was reduced primacy and extended recency when recall started with one of the last four presented items.

Additionally, whereas AS had a negative effect on recall performance of verbal stimuli; the visuo-spatial performance remained constant across experiment regardless of whether participants viewed the stimuli in silence or under AS. Spurgeon *et al*. (2014a, 2014b) showed that these output order and list length effects in verbal IFR, can also be observed in the absence of phonological coding and in continual distracter free recall conditions. Consequently, these findings coupled with the present findings from Experiments 1 to 3 support the idea that the list length and output order effects found in Ward *et al*. (2010) do not necessitate a language-based mechanism such as a verbal STS or the Phonological Loop (Baddeley, 1986, 2007, 2012) and could therefore reflect a more general property of memory that holds across a range of materials and timescales.

SIMILARITIES BETWEEN VERBAL AND VISUO-SPATIAL MEMORY

As previously discussed in Chapter 1, there are very few investigations of visuo-spatial IFR (Bonanni *et al*., 2007; Gmeindl *et al*., 2011), and therefore, Experiments 1 to 3 provide a rich data set that enables the comparison of verbal and visuo-spatial IFR . There were a number of gross similarities between both types of IFR tasks. First, in both domains, overall accuracy decreased with increasing list length. Second, there were very similar serial position curves across both domains. More specifically, at short lists, the curves were relatively flat due to primacy. However, the serial position curves were increasingly bowed with increasing list length, such that there were both primacy and recency effects at the longer list lengths. Third, there were also similarities in the probability of first recall data. In both the verbal and visuo-spatial domain, participants tended to start with the first list item at the shorter list lengths, but as the lists got longer, participants shifted their first recall to one of the last four items. Finally, the resultant serial position curves that were conditioned by the first recalled item (SP1 or Last 4) also show similarities across both stimulus domains. When participants' first response is the first list item, they are more likely to continue recalling the subsequent items in a forward ordered manner, leading to extended primacy effects and reduced recency effects. Conversely, when participants start their recall with one of the last few list items, they are more likely to continue their recall with the later list items, resulting in extended recency effects and reduced primacy.

DIFFERENCES BETWEEN VERBAL AND VISUO-SPATIAL MEMORY

Despite the gross similarities discussed in the preceding section, there are also some differences between the verbal and visuo-spatial data. Firstly, when the tasks were properly equated in Experiment 3, there was a marked difference between the overall performance of the verbal and visuo-spatial tasks. Whereas the shorter verbal lists yielded ceiling levels performance, recall accuracy for the shorter visuo-spatial lists was below ceiling levels. Furthermore, the primacy and recency effects in the visuo-spatial domain were somewhat weaker relative to those in the verbal modality.

There are four possible lines of arguments that could explain these differences. A possible explanation for these findings could be that perhaps visuo-spatial items are less well bound to their temporal context than verbal stimuli (Gmeindl, *et al.*, 2011). Alternatively, the output order of visuo-spatial items is additionally affected by the spatial proximity of responses, such that physically close stimuli are outputted successively regardless of their presented serial order. Therefore, it is possible that the spatial proximity of stimuli supersedes their serial order (Gmeindl, *et al.*, 2011). Abrahamse *et al.* (2014) attempt to explain the Gmeindl *et al.* findings, through their theory that posits that serial order is closely related to spatial attention. In this framework, serial order is coded with position markers that act as spatial coordinates within the spatial attention system and thus correct recall depends on the spatial attention system's ability to select the accurate the specific position markers. Abrahamse *et al*. (2014) argue that visuo-spatial material is less bound to serial order because the maintenance of the external visuo-spatial sequence interferes with the internal spatial system that is required to maintain serial order. A final argument that could explain these differences, is that the individual representations of verbal stimuli very along more stimulus dimensions (e.g. orthographic, semantic, phonological) than the visuo-spatial stimuli and therefore verbal stimuli may benefit from phonological recoding and rehearsal, which may enhance serial position effects.

Another difference between the IFR of verbal and the visuo-spatial material is that whereas the former stimulus domain is adversely affected by AS, the latter is not affected. In the verbal IFR, AS reduced overall accuracy, as well as reducing the tendency to start a short list of words with the first list item. This difference in the results, therefore suggests that whereas verbal material benefits from phonological recoding that can occur in the absence of AS, visuo-spatial IFR is not mediated by verbal recoding. Initially these findings could be interpreted as evidence for the Phonological Loop (Baddeley, 2000, 2007, 2012) that contributes to the forward-order tendency in IFR. However, because the tendency to recall lists of items in IFR in an "ISR-like" manner is also found in situations where the Phonological loop is not used, that is, in the IFR of visually presented words under AS (e.g. Experiment 2 and 3; Spurgeon *et al*., 2014a), and in visuo-spatial IFR, then it is possible to conclude that the forward ordered tendency in IFR may be augmented by the Phonological loop but does not necessitate it.

Overall, although there are a number of differences between the verbal and visuo-spatial domain, there are also gross similarities between the two. These similarities observed between verbal and visuo-spatial in IFR are comparable to those observed in ISR-related tasks as reported by Guérard and Tremblay (2008), who propose three possible explanations for these findings. First, it is possible that there are separate verbal and visuo-spatial memory stores that each maintain the serial order of items in equivalent ways, such that for example, the phonological loop operates in a similar way to the visuo-spatial sketch pad (Logie, 1995).

Second, it is possible that there is a non-modular memory that retains the serial order of all stimulus domains, but the patterns of selective interference arise when the primary and secondary tasks rely on more or less similar perceptual organization of the stimuli and more or less similar gestural execution of the responses (Jones *et al*., 2006, 2004). A third and final possibility, is that there is a non-modular memory that retains the serial order of all stimulus domains, but the patterns of selective interference arise due to the degrees of similarity between the features of the primary and secondary tasks (e.g. Cowan, 1995, 2005; Nairne, 1990; Neath, 1999; Oberauer & Kliegl, 2006).

It would appear that all of these three possibilities are equally able to account for the present findings in IFR. For this reason, the subsequent chapters will attempt to help distinguish between these domain-specific and domain-general approaches through the analysis of list length, capacity and output order effects in dual-modality tasks.

SUMMARY AND CONCLUSIONS

Chapter 2 presents three experiments that have examined and equated the methodologies for and compared visuo-spatial and verbal IFR. It is clear that the list length and output order effects found by Ward *et al*. (2010) may be enhanced by a verbal mechanism but do not necessitate it. This is because regardless of stimulus domain, in IFR, participants tend to start at the start in shorter lists, and with one of the last four items in longer lists. The data also suggest that there are a number of gross similarities between the verbal and visuo-spatial stimulus domains, and that these can only be properly delineated by equating the methods of testing.

CHAPTER 3

CHAPTER 3

The present Chapter sought to examine whether the similarities in list length and output order effects delineated in Chapter 2 are a result of two separate mechanisms, one for the verbal and one for the visuo-spatial modality that operate independently but in quasi-similar ways as proposed by dual-store models, such as the highly influential model Working Memory Model (Baddeley, 1986, 2000, 2007, 2012; Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Logie, 1995). This states that the phonological loop and visuo-spatial sketchpad are used for the verbal and visuo-spatial modalities respectively, and that these component mechanisms have independent capacities and output orders. An alternative possibility is that, the findings from Chapter 2 can be interpreted within an amodal general episodic memory that operates on all stimulus domains at all timescales, as proposed, for example by the Object-Oriented Episodic Record model (O-OER; Jones, *et al.*, 1996), the perceptual-gestural model (Jones *et al.*, 2006, 2007) and the embedded–processes model (Cowan, 1988, 1995, 1999, 2005). Such models propose that memory is a unitary abstract space containing representations of items from different modalities and that the recall of items is done through a domain-general retrieval mechanism that depends on the use of pointers (O-OER), motor processes (perceptual-gestural account) or item activation levels (embedded-processes model).

As outlined in Chapter 1, this research question of modularity versus equivalence between the verbal and visuo-spatial domains has been investigated a number of times, and there seems to be evidence in favour of both modularity and equivalence of different modalities. The overwhelming amount of evidence for equivalence comes from comparing verbal and visuo-spatial serial recall tasks to test whether highly replicable verbal phenomena can also be found in the non-verbal domain. Such research has shown similar SPCs (e.g. Avons, 1998; Smyth *et al.*, 2005), similar error patterns and generalization gradients (Guérard & Tremblay, 2008), similar temporal grouping effects (Parmentier *et al*., 2004; 2006) as well as the modality effect (Tremblay *et al*., 2006), suffix effect (e.g. Greene & Samuel, 1986), sandwich effect (Tremblay *et al*., 2005) and Hebb repetition effect (Couture & Tremblay, 2006; Parmentier *et al*., 2008) in the non-verbal domain. The evidence for modularity comes from neuropsychological patients (De Renzi & Nichelli, 1997; Hanley *et al*., 1991), neuroimaging studies (e.g. Awh *et al*., 1996; Smith *et al*., 1996) and dual-task findings (e.g. Alloway *et al*., 2010; Farmer *et al*., 1986; Guérard & Tremblay, 2008). Dual-tasks findings are particularly relevant to the experiments in the present Chapter since it involves the free recall of both verbal and visuo-spatial stimuli, presented either concurrently (Experiment 4), or in alternation (Experiment 5).

THE IMPLICATIONS OF DUAL-TASK FINDINGS

In Baddeley's (1986, 2007) model, the domain-specific stores are able to store and rehearse information within them independently of each other and therefore, it is possible for this to be done concurrently and in similar ways. This assumption comes from the finding that different tasks requiring different mental processes (e.g., maintaining a small verbal memory load while performing a verbal reasoning task) could be performed simultaneously without too much cost to the performance of either task (Baddeley & Hitch, 1974). Consequently, the WM model proposes that preventing rehearsal (e.g., articulatory suppression or spatial tapping) of a particular domain should only affect the memory for that specific domain; this is referred to as selective interference.

However, Jones *et al*. (1995) found strong domain-general interference by preventing item rehearsal; both spatial tapping and articulatory suppression resulted in equal disruption of spatial and verbal serial order memory. Furthermore, Meiser and Klauer (1999) found different patterns of interference depending on whether the rehearsal suppression was done at encoding or during the retention interval. When spatial tapping and articulatory suppression was done during stimulus presentation, this resulted in domain-specific selective interference, whereby articulatory suppression interfered solely with verbal recall and spatial tapping interfered only with visuo-spatial recall. This selective interference was found in the verbal domain even when the rehearsal suppression was done during retention. However, both types of rehearsal suppression interfered with visuo-spatial performance when these were done during retention. Although Meiser and Klauer interpret the results as evidence for a domain-specific system, Morey and Mall (2012) note that this pattern of results shows that memory for non-verbal sequences, unlike that for verbal sequences, is more susceptible to domain-general interference. The findings of the previous Chapter are somewhat consistent with selective interference, since articulatory suppression had an adverse effect on verbal memory but not on visuo-spatial memory. In conclusion, it is clear that preventing participants from rehearsing list items during encoding has an adverse domain-specific effect. However, what happens when the cross-modality secondary task also requires retention to enable recall? Recent studies by Cowan, Morey and colleagues have combined verbal and visuo-spatial tasks, whereby both stimulus domains are presented concurrently.

THE FINDINGS FROM CROSS-DOMAIN CONCURRENT TASKS

In a series of experiments attempting to establish WM capacity, Saults and Cowan (2007) presented participants with same-different judgement tasks involving either a visual array of coloured shapes and/or an auditory array of simultaneous spoken digits from different voices. There were two types of trials: unimodal, where participants were presented with and required to remember items in only one modality, and bimodal, where participants were presented with and asked to remember all items from both modalities. When comparing the WM capacity for unimodal and bimodal trials, Saults and Cowan found that the capacity measured in the bimodal tasks equalled the sum of the capacity of the unimodal verbal and visuo-spatial trials. This was also found in cases where sensory masks were utilised to ensure that modality-specific features could not be used as a memory aid during the task judgement. This led to the conclusion that there is a central capacity limit that is at least shared between visuo-spatial and auditory-verbal memory.

More evidence of a single WM capacity was found by Cowan and Morey (2007), who asked participants to perform articulatory suppression while being presented with either one or two sets of stimuli. The latter could be made up of either two verbal lists (one consonants, one digits), or two visuo-spatial arrays (different sets of coloured objects presented on the right or left hand side of the screen, or one visuo-spatial and one verbal display. To ensure that task difficulty at encoding and retention was consistent in both within- and cross-modality trials, participants were promptly cued following stimulus presentation as to which set would be tested after a period of retention, thus allowing for selective rehearsal in cases where one set was tested. This was then compared to those trials were participant were required to retain both sets. At test, participants were required to indicate whether a particular probe had been previously been seen during the presentation phase. Cowan and Morey found that although the costs of retaining two sets of stimuli (as opposed to one) were very similar regardless of whether the items where similar or different, there was also evidence that within-modality interference was larger than cross-modality interference and that this was mainly due to encoding. This can be seen from the marked difference between single-task trials and the post-cued trials indicating the to-be-retained set, which disappeared when comparing those trials where both needed to be encoded and retained versus those with a post-cue. Cowan and Morey conclude that domain-specific representations need to be quickly consolidated into a more domain-general store.

Although the evidence from the above discussed research is invaluable in answering the question of whether there are domain-general or domain-specific sources, it is of more relevance to the present work to discuss the effects of cross-modality lists in instances where serial and output order can be analysed. For example, Depoorter and Vandierendonck (2009) used same-different judgement tasks with a dual component to test whether serial order is coded in a domain-general or domain-specific way. They presented participants with a primary task, followed by a maintenance period that was filled with a secondary task. Participants had to immediately recall items from the second task and then recall items from the primary task. They then manipulated the modality of the primary and secondary task (verbal or visuo-spatial) and whether the to-be-remembered information was item identity or serial order. They found that irrespective of the modality of the tasks, there was marked interference when serial order was the task requirement, whereas there was little evidence of interference if only item identities of both tasks were required. Consistent with the Meiser and Klauer (1999) findings, their results showed that auditory-verbal tasks interfere more with visuo-spatial tasks than vice versa, since when the verbal order memory task was embedded within the spatial task, performance was considerably lower than in those cases where the visuo-spatial order memory task was embedded within the verbal order memory one. They therefore concluded that that serial order can be coded in a modality-independent manner. These finding has been recently replicated by Vandierendonck (2015) using auditory-verbal and visuo-spatial serial recall tasks to avoid overlaps between the presentation and recall of the two modalities. Additionally, Morey, Cowan, Morey, and Rouder (2011) also found this dissociation when comparing temporally overlapping auditory and visual arrays.

Morey and Mall (2012) compared recall performance in verbal and visuo-spatial reconstruction of order tasks using both single- and dual-task methodologies. Participants were presented with either lists of verbal or visuo-spatial material in the single-modality condition, or with both modalities interleaved in the dual-task condition. They also manipulated whether participants knew which modality was going to be tested before stimulus presentation (cued) or not (uncued). Firstly, Morey and Mall observed similar bowed serial position curves for both modalities and secondly and consistent with previous research, they found an asymmetry in dual-task interference, whereby visuo-spatial material is more adversely affected by concurrent verbal material than verbal material is affected by concurrent visuo-spatial material.

They therefore conclude that these findings support the various commonalities found between the verbal and visuo-spatial domain. However, the asymmetry in the interference was reflected only in the last few verbal items on the list and Morey and Mall state that this could reflect additional separate domain-specific store for the verbal domain. However, there was no evidence of a counterpart to this in the visuo-spatial domain. Alternatively, it is possible that the degree of reliance on domain-general processes varies across modalities. Perhaps, visuo-spatial memory requires more such processes and is perhaps more closely related to attention more than verbal memory (Gmeindl *et al*., 2011) or there are fewer rehearsal resources available to visuo-spatial memory when compared to the verbal domain (Camos, Lagner, & Barrouillet, 2009). It is noteworthy that Morey, Morey, van der Reijden and Holweg (2013) also found this asymmetry between verbal and visuo-spatial memory performance when using the above described retro-cue designs (Cowan & Morey, 2007) which has the advantage of isolating interference caused by maintaining two stimulus domains from interference from concurrent encoding.

Overall, it seems that whereas interference from the prevention of rehearsal through articulatory suppression or spatial tapping has resulted in varying conclusions leading to disparate views of immediate memory, a more parsimonious domain-general view of memory has emerged from methodologies using a primary and a secondary task or two concurrent tasks. There is limited experimental work requiring participants to perform the FR of concurrently presented auditory-words and visuo-spatial dots. The use of FR as opposed to SR of mixed-modality lists is advantageous, in that it shows the spontaneous and preferred output order in outputting two stimulus types. This will answer questions such as which modality do participants start with, whether they output by modality/channel-by-channel and whether they spontaneously output in a forward-ordered "ISR-like" manner.

THE CURRENT EXPERIMENTS

There are three main aims of the experiments in the present chapter. The first aim of Experiments 4 and 5 was to firstly replicate the list length and output order effects found in Chapter 2, that is, the tendency to start at the start in short lists and with one of the last four presented items in longer lists.

The second aim was to determine the immediate memory capacities for both the verbal and visuo-spatial domain, when participants are presented with and asked to recall a single modality. These single-task capacities enabled comparison to the respective recall performance for both modalities in the dual-task condition, and tested whether recall is adversely affected when participants are presented with (and are required to recall) both auditory-words and visuo-spatial dots. Whereas dual-store domain-specific models would predict no interference between the two modalities and therefore similar immediate memory capacities for each modality regardless of whether participants were presented with one or two modalities, amodal abstract models would predict a capacity limitation since they would be able to hold a specified number of stimuli at one time, for example four chunks (e.g. Cowan's focus of attention, 2005).

The third aim of these two experiments was to examine the analysis of the output orders of the two modalities when both stimulus domains are recalled. Early studies of dichotic presentation such as the ones by Broadbent (1954, 1956, 1957a), showed that if participants were presented with two sequences of digits simultaneously, they tended to output the digits channel-by-channel, that is the digits inputted in one ear first, followed by those inputted to the second ear. Consequently, Broadbent (1957b) put forward a filter theory to account for these split span findings, whereby there are two separate systems: the S system and the P system. The S system is concerned with storage and is able to hold simultaneously presented stimuli, while the P system, which stands for perceptual system, is concerned with the processing of information; this is similar to attention. He likens the model to a Y-shaped tube, whereby items are dropped into each of the two stems through to the filter. The way in which items are output thus depends on the mechanism chosen by the filter. The findings of the split span task are a result of the filter outputting one stem first followed by the other; the errors made during the recall of the second ear is due to temporal decay. Additionally, the reason why pair-by-pair recall is not preferable to channel-by-channel outputting is because the former requires the filter to constantly switch from one stem to the other, whereas the latter requires only one switch.

These split span findings have also been found in bi-sensory presentation, whereby visual and auditory-verbal stimuli were presented simultaneously (Dornbush, 1968). In both manipulations, channel-by-channel report was preferable with the second reported channel being less accurate than the one preceding it. These findings are affected by presentation rate, rather than whether there is dichotomous or bi-sensory presentation, whereby a faster presentation rate of two items per second accentuates the results more than slower presentation of one item per second (Murdock, 1974). These findings also extend to situations when the channels are not separated by modality or input location but by other factors such as voice characteristics. Wingfield and Byrnes (1972) separated items by channel by having male and female voices and dictated output strategy. Consistent with the aforementioned findings, they found that participants perform better when they output by channel. They state that pair-by-pair recall may be less accurate due to temporal decay, since reaction time data showed that participants take longer to output items pair-by-pair when compared to channel-by-channel output. When taking this output order research into consideration, it is reasonable to expect participants to output by modality, whereby they output as many items as they can remember from one modality before proceeding to the other modality, as this may be a preferred or natural way of streaming two stimulus types.

Recall orders also have important implications to test whether the output order effects found in both verbal and non-verbal material are a result of one general retrieval mechanism or two separate, yet similar retrieval mechanisms. If there are two separate mechanisms, then it is possible for participants to retrieve from the start of the list from one modality and the last few items from another modality, since stores can be accessed independently from one another. Alternatively, if these output order effects are a result of a general episodic memory which replays events sequentially in forwards order, regardless of their modality, then it is possible to find constrained orders between modalities, whereby the serial position of one item in any modality matches that of the other modality when these are recalled in a yoked order.

To further understand how capacities and output orders can help ascertain whether there is a domain-general retrieval mechanism or two domain-specific ones, I will use an analogy of different recording devices. A domain-specific store can be compared to two separate recording mechanisms, such as a recording tape for auditory material and a silent camera for visual stimuli. These separate recording devices, therefore have independent capacities and because they are separate and thus able to "rewind" to different points separately, they have potential for unconstrained orders. Hypothetically, one device can start recall from the start of the list while the other starts at the end of the list. Since recall requires the output from one domain-specific mechanism, in this framework, it is conceivable that it is more efficient for one modality store to be output first, followed by the outputting of the other, rather than consistently switching between stores.

If one were to liken a single domain-general retrieval mechanism to a multimedia modern video recorder that captures both sight and sound, then it is expected that such a mechanism would show a central limited capacity that holds all types of stimulus domains. At retrieval, the device "rewinds" back to the to-be-recalled events in order to effectively recall them; this results in constrained output orders, such that neighbouring items are recalled closely together leading to temporal contiguity effects.

EXPERIMENT 4

Experiment 4 compared the IFR of verbal and visuo-spatial material when these were presented individually, to the IFR of concurrently presented verbal and visuo-spatial stimuli. All participants were presented with 50 lists, either of auditory-words, visuo-spatial dot sequences, or simultaneously presented auditory-words and visuo-spatial locations. There were three participant groups: the auditory-verbal group, the visuo-spatial group and the parallel presentation group. In all groups there were ten trials of each of the five different list lengths: 1, 2, 4, 8, 16, where in the parallel presentation group there was one word and one visuo-spatial dot for list length 1 and so on.

The specific aims of Experiment 4 were three-fold. First, I wanted to confirm the findings from Chapter 2, where list length and output order effects typically affecting verbal material are also shown to affect visuo-spatial material in similar ways. More specifically, that participants tend to start at the start with short lists and this tendency decreases with increasing list length. The increase in list length leads to participants changing their recall strategy by starting with one of the last four presented items at the longer list lengths.

The second aim of the present experiment was to compare the capacity of verbal and visuo-spatial performance in tasks where participants were presented with and had to recall either auditory-words or visuo-spatial locations to the verbal and visuo-spatial performance of participants who were presented with both modalities simultaneously. Specifically, it is of interest to test whether maintaining concurrent stimuli reduces recall accuracy for either modality.

The third and final aim of Experiment 4 was to examine the recall pattern for dual-modality tasks comprising of auditory-words and visuo-spatial locations. Previous research on recalling from multiple channels encourages two main possibilities that could be found in participants' output orders. The first possibility is that since these two modalities are inherently distinct, participants may recall the items using a channel-by-channel strategy, outputting one modality first followed by a second modality as found by Broadbent (1958) and Dornbush (1968). The second possibility is that participants output in an alternating manner, whereby they consistently switch between modalities. If this is the case, then it would be of interest to test whether consequently recalled different modality items are temporally contiguous, that is, whether or not they have proximate serial positions, and whether lag transitions have an effect on inter-response time. Regardless of which possibility is true, it was of interest to identify which modality was output first, whether there was forward-ordered output, and whether there were list length and output order effects overall.

METHOD

Participants. A total number of 60 students from the University of Essex participated in exchange for either course credit or a small payment.

Materials. Stimuli were presented using the 'Supercard' application via an Apple Mac Computer. On each trial, one third of the participants heard a spoken list of up to 16 words that were randomly selected for each participant from the the Auditory Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982). These .voc formatted files were downloaded from Michael J. Kahana's Computational Memory Lab website (http://memory.psych.upenn.edu/Word_Pools) and converted to .wav files. The words were spoken in a female voice in a US accent, and the files were of the same temporal duration. There were a total of 484 different files, of which a different random 414 were presented to each participant. The second third of the participants saw a sequence of black dots, where each circle had a diameter of 35mm and its spatial location was selected at random from 414 different spatial locations on the screen, in a 375mm x 280mm frame with a grey background. The final third of participants saw a sequence of black circles while simultaneously hearing spoken words. Responses were recorded using the computer mouse of the Apple Mac Computer for the visuo-spatial stimuli, while responses were recorded with ‘Audacity’ for the auditory-verbal stimuli, so as to enable offline scoring.

Design. The experiment used a mixed factorial design. The between-subjects independent variable was the performance of free recall when using either verbal, visuo-spatial, or both stimuli respectively, such that there was an auditory-verbal stimuli group, a visuo-spatial stimuli group and the parallel presentation group. There were two within-subjects independent variables: list length, with 5 levels (1, 2, 4, 8, and 16 items presented for the auditory-verbal and visuo-spatial groups and 2, 4, 8, 16, 32 items for the parallel presentation group) and serial position with up to 16 levels for the auditory-verbal and visuo-spatial group and 32 levels in the parallel presentation group. The dependent variables were the proportion of items correctly recalled, the proportion of items recalled in the same order as presented, the probability of initiating recall with the first or with one of the last four stimuli, as well as the time taken between responses. For the parallel presentation group there were additional dependent variables: the number of visuo-spatial outputs, the number of items correct as a proportion of actual outputs, the proportion of trials where recall was initiated with a word, the number of times a specific string of three outputs were made, as well as the number of times a specific lag transition was made.

Procedure. Each participant was randomly allocated into one of the three groups: the auditory-verbal stimuli group, the visuo-spatial stimuli group and the parallel presentation group such that each group was made up of 20 participants. Each participant was tested individually and was given group-specific instructions. All participants were informed that they would be shown two practice lists of eight stimuli (eight words and eight dots in the parallel presentation group), followed by 50 experimental lists of stimuli. The experimental trials were arranged into two blocks; each block contained 25 trials (five trials of each of the five different list lengths). All stimuli were presented for 0.75s, with 0.25s inter-stimulus interval. The order of the list lengths was randomized and each trial started with a pre-cue instruction thus allowing participants to initiate the stimuli presentation whenever they were ready to do so.

Following a computer mouse click, participants were presented with between 1 and 16 stimuli presented one at a time in the single modality groups, or 32 stimuli for the parallel presentation group, where a dot and a word were presented in parallel. The words were spoken through a headset, whereas the visuo-spatial circles appeared at different screen locations. During the presentation of both types of stimuli, the location of the curser was locked to a location at the right hand edge of the screen. At the end of the list there was an auditory cue for recall. The participants in the auditory-verbal group said out loud as many words as they could remember, in any order that they wished; responses were recorded via a microphone for offline scoring. The participants in the visuo-spatial group clicked on the locations of the screen where they had previously seen the circles, and they were also free to respond in any order that they liked. The participants in the parallel presentation group had to recall words and visuo-spatial locations in the same way as the other participants, and they were instructed to recall as many items from both modalities as possible, in any preferred order. After the participants were satisfied that they had completed their recall, they pressed the “submit” button which initiated the next trial.

RESULTS

Capacity and Replication

Overall Accuracy. Verbal and visuo-spatial performance in the parallel presentation condition was separated by modality and compared to the performance of the auditory-verbal and visuo-spatial group respectively as shown in Figure 3.1. Table 3.1 shows two separate 2 (group: single- vs dual-modality task) x 5 (list lengths) ANOVAs, one for the verbal and visuo-spatial modalities respectively. There was a significant main effect of list length, a non-significant main effect of group and a non-significant interaction when comparing the verbal performance of the auditory-verbal group to that of the parallel presentation group. Similarly, there was a significant main effect of list length, a non-significant main effect of group and a non-significant interaction when comparing the non-verbal performance of the visuo-spatial group to that of the parallel presentation group. Overall, there was a slight but non-significant difference in recall accuracy when participants were presented with, and had to recall, either one or two different modalities; this small decrease in accuracy is bigger for the visuo-spatial than the verbal domain.

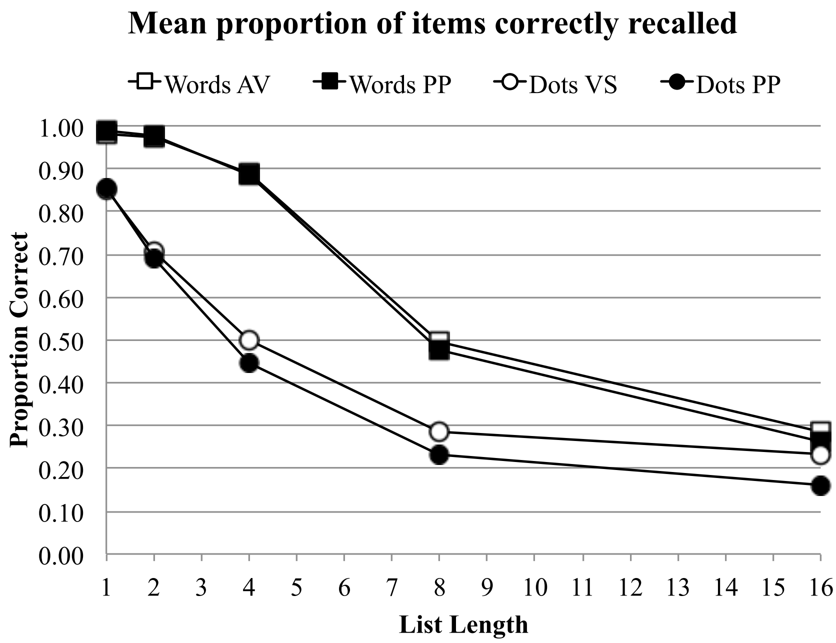

Figure 3.1. Experiment 4: The mean proportion of correctly recalled words in the auditory-verbal (AV) and parallel presentation (PP) groups and the mean proportion of correctly recalled dot locations in the visuo-spatial (VS) and parallel presentation (PP) groups respectively.

Table 3.1
Experiment 4: Summary of the ANOVA analyses conducted upon the overall accuracy data.

	df	*MSE*	*F*	η^2_p	*p*
Overall Accuracy – Verbal Data					
LL	4,152	.003	1548	.976	< .001

GP	1,38	.009	.243	.006	.625
LL x GP	4,152	.003	.889	.023	.472
Overall Accuracy – Visuo-spatial Data					
LL	4,152	.010	329.1	.896	< .001
GP	1,38	.031	2.31	.057	.137
LL x GP	4,152	.010	1.00	.026	.408

The number of output dot locations across groups. Figure 3.2 shows the number of visuo-spatial outputs made by participants as a proportion of total possible outputs (6200 outputs) as well as the correct number of outputs as a proportion of actual output visuo-spatial items. Participants in the visuo-spatial single-modality group output more visuo-spatial responses than those participants in the parallel presentation group (5093 vs 3800 outputs). An independent samples *t*-test showed that this difference in the number of outputs across groups was significant, $t(38) = 4.61$, $p < .001$, $d = 1.45$. As regards the number of correct outputs as a proportion of actual output items, participants in the parallel presentation group made a higher proportion of accurate responses out of the dot locations clicked. However, this difference between groups was non-significant, $t(38) = 1.53$, $p = .134$, $d = .470$.

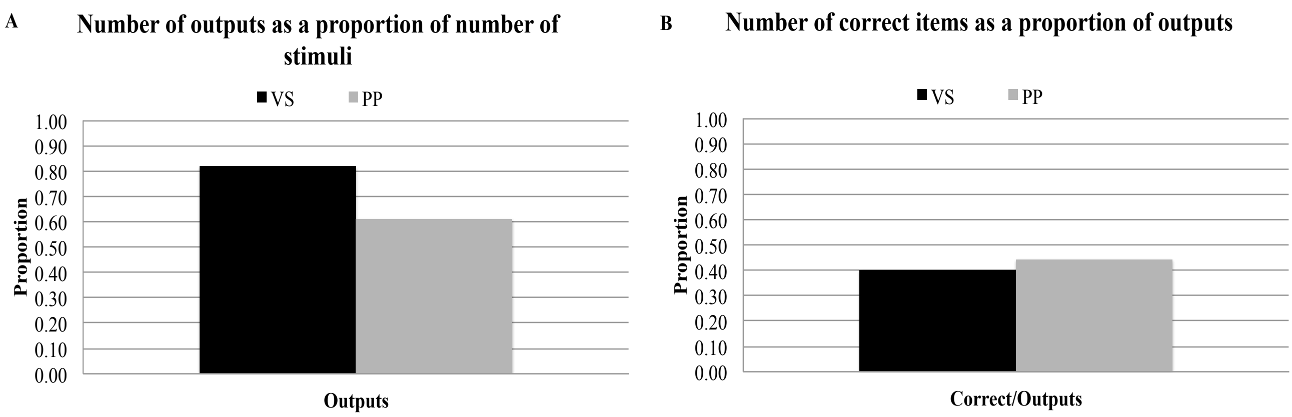

Figure 3.2. Experiment 4: The total number of output dots as a proportion of all possible outputs (panel A) and the total number of correct responses as a proportion of actual outputs (panel B) for the visuo-spatial (VS) and parallel presentation (PP) groups.

Serial Position Curves (SPCs). Figure 3.3 shows the SPCs of the groups separated by modality. It is clear that performance for each modality is very similar regardless of whether participants had to remember one or two modality types, and that the verbal performance is slightly more consistent across groups than visuo-spatial performance. The serial position curves for each stimulus type were analysed at each list length, using a series of 2 (group: single- vs dual-modality tasks) x *n* (serial positions: 1 to *n*) mixed ANOVAs (where *n* is list length). The exact statistics for the main effects and interaction for each list length can be found in Appendix 3.1.

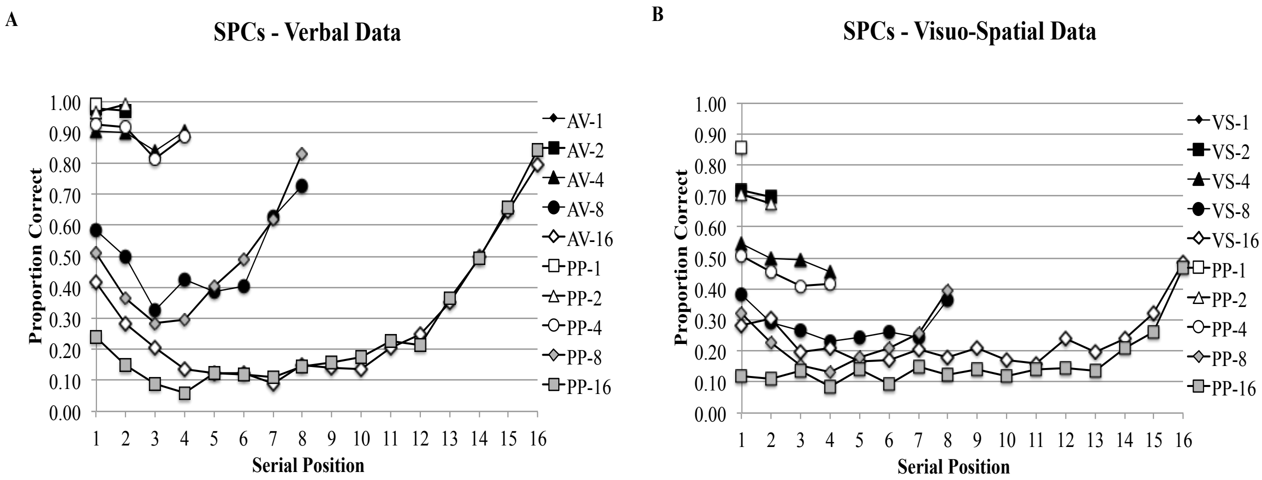

Figure 3.3. Experiment 4: SPCs for the verbal data, taken from the auditory-verbal (AV) and parallel presentation (PP) groups (panel A) and for visuo-spatial data from the visuo-spatial (VS) and parallel presentation (PP) groups (panel B).

In summary, the main effect of group on verbal performance was non-significant at all list lengths. There was a significant main effect of serial position at list lengths 4, 8 and 16. More specifically, list length 4 yielded a linear curve showing primacy, list length 8 showed both primacy and recency and list length 16 showed extended recency. Furthermore, interactions were only significant for list length 8 and 16. For the visuo-spatial performance, there was a non-significant main effect of group for all but list length 16. There was a significant main effect of serial position for list lengths 8 and 16. More specifically, the serial position curve for list length 4 was linear, list length 8 showed equal amounts of primacy and recency, while at the longest list length there was extended recency. Across both domains, it is clear that being presented with concurrent cross-modality stimuli did not affect the recency portion of the curve; the advantage for the earlier items however was somewhat reduced.

The probability of first recall (PFR) data. Figure 3.4 (Panels A – B) shows the PFR curves for the verbal and visuo-spatial data respectively, when the first recalled item was either the first list item, one of the last four items or an error. For the parallel presentation group, performance was segmented by modality to enable comparison with the respective single-modality tasks. Panels A and B also show the crossover point, which is the list length at which the modal first item recalled changes from being classified as 'Serial Position 1' for list lengths shorter than the crossover point to 'Last 4', where the list lengths is larger than the crossover point. For the auditory-verbal group, the crossover point was at list length 8, while that of the visuo-spatial group was between list lengths 8 and 16. In the parallel presentation group the crossover for the visuo-spatial and verbal performance separately was between list lengths 4 and 8 in both modalities, implying that the shift between initiating recall with 'SP1' to 'Last 4' items occurs earlier when the participants are presented with cross-domain stimuli concurrently.

Furthermore, Figure 3.4 (Panel C) shows the mean probability for each of the five list lengths that the first item recalled was the first item presented for each group, where the parallel presentation group was separated by modality. Figure 3.4 (Panel D) shows the same data but with the mean probability that the first item recalled is one of the last four items presented. Overall, participants tended to start at the start at the shorter list lengths and start with one of the last four presented items at the longer list lengths.

Table 3.2 shows the exact statistics for two 2 (group: single- vs dual-modality) x 5 (list lengths) ANOVAs conducted for the verbal and visuo-spatial domains to test whether there was an effect of list length and group on starting with the first or last four presented list items respectively. The PFR data was therefore segregated by modality, whereby the visuo-spatial and verbal performance on the parallel presentation group was separated and compared to performance of the visuo-spatial and auditory-verbal groups respectively. For the visuo-spatial modality, the probability of initiating recall with the first presented items decreased significantly with list length, while the probability of initiating recall with one of the last four presented items significantly increased with list length; in both cases there was a non-significant main effect of group and a non-significant interaction. Similarly, for the verbal modality, the probability of starting recall with the first item decreased with increasing list length and there was a non-significant main effect of group and a non-significant interaction. The probability of starting with one of the last four items significantly increased with list length; there was also a significant main effect of group and a significant interaction.

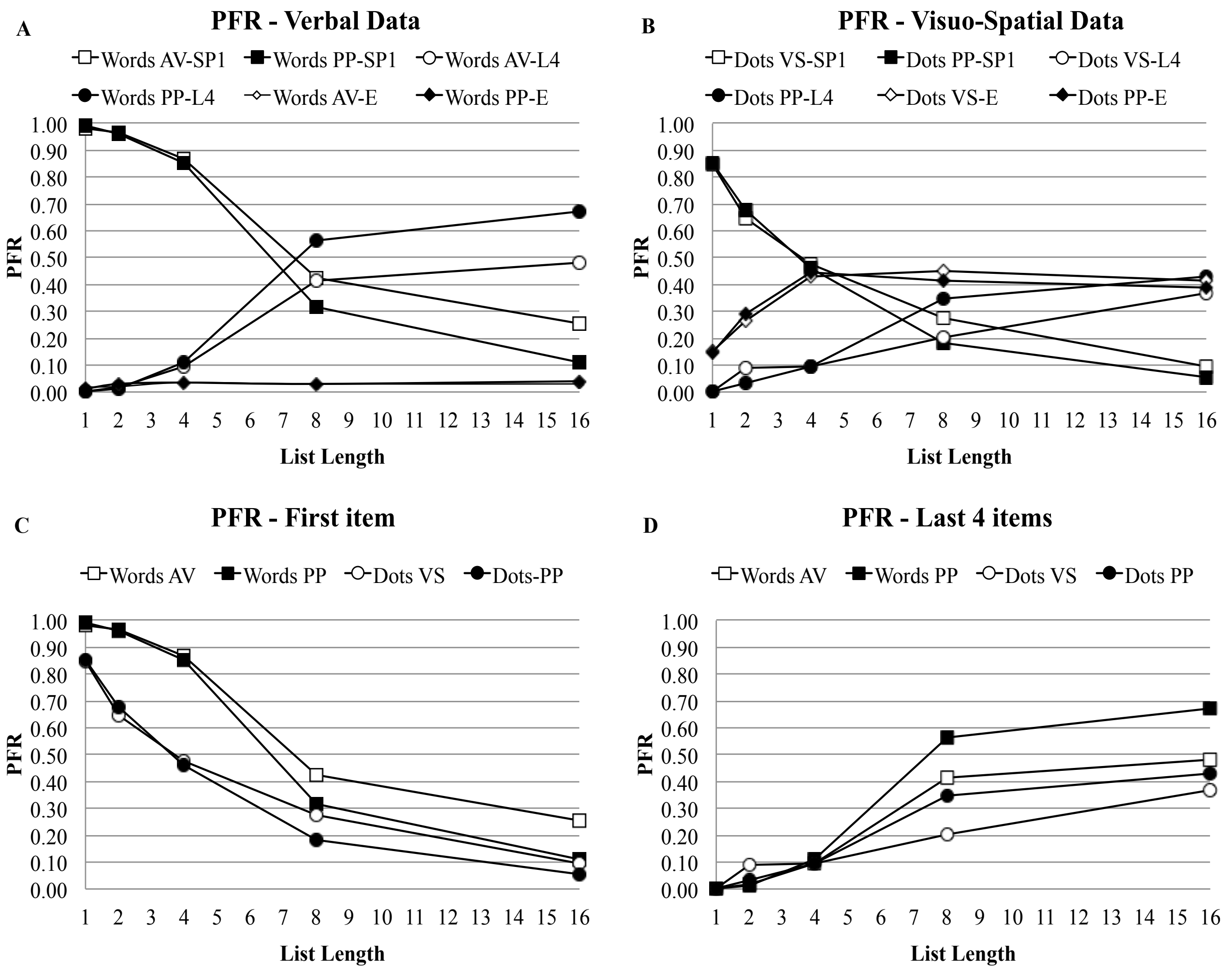

Figure 3.4. Experiment 4: PFR data for the verbal (panel A) domain taken from the auditory-verbal (AV) and parallel presentation (PP) groups and visuo-spatial (panel B) domain, taken from the visuo-spatial (VS)

and parallel presentation (PP) groups respectively. These show the proportion of trials in which recall was initiated with either the first presented item, one of the last four items or an error. Panels C and D separate the same data according to those trials where recall was initiated with either the first item on the list or one of the last four list items respectively.

Table 3.2
Experiment 4: Summary of the ANOVA analyses conducted upon the Probability of First Recall (PFR) data

	df	*MSE*	*F*	η^2_p	*p*
PFR = SP1 (Verbal Data)					
LL	4,152	.026	214	.849	< .001
GP	1,38	.071	1.98	.049	.168
LL x GP	4,152	.026	1.89	.047	.115
PFR = SP1 (Visuo-spatial Data)					
LL	4,152	.025	158	.806	< .001
GP	1,38	.047	.513	.013	.478
LL x GP	4,152	.025	.843	.022	.500
PFR = Last 4 (Verbal Data)					
LL	3,111	.034	94.6	.719	< .001
GP	1,37	.092	4.71	.113	.036
LL x GP	3,111	.034	3.73	.092	.013
PFR = Last 4 (Visuo-spatial Data)					
LL	3,105	.026	30.4	.465	< .001
GP	1,35	.071	.419	.012	.129
LL x GP	3,105	.026	1.93	.052	.522

The effect of first item recalled on the serial position curves. Figure 3.5 (Panels A-B) shows the SPCs for those trials in which recall was initiated with serial position 1 using FR scoring, separated by modality for the parallel presentation group and compared to the corresponding single-modality group's performance. Overall, there are extended primacy effects and reduced recency effects in this subset of data. For each modality, these SPCs were analysed at each list length by a 2 (group: single-vs dual-modality) x n - 1 (serial positions: 2 to n, where n is the list length) mixed ANOVA (see Appendix 3.2). In the verbal domain, there was a significant main effect of serial position and a non-significant main effect of group at all list lengths; all interactions were non-significant. For the visuo-spatial data, there was a significant main effect of serial position and a main effect of group only at list length 8; all interactions were non-significant.

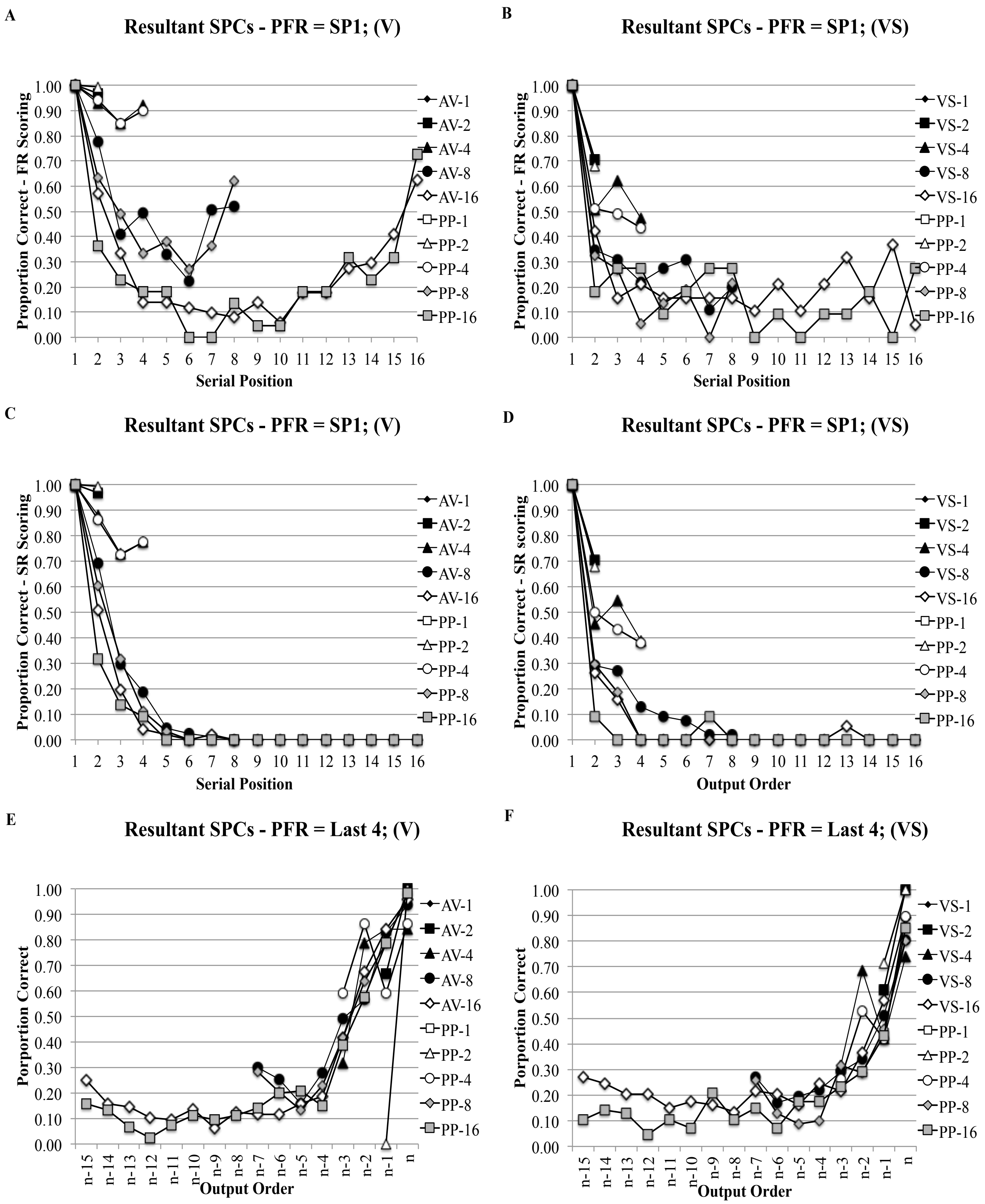

Figure 3.5. Experiment 4: The effect of the first recalled item on the SPCs, separated by modality (left panels: verbal; right panels: visuo-spatial). Panels A and B show the effect of initiating recall with the first presented item in the list using FR scoring. Panels C and D show the effect of initiating recall with the first list item using SR scoring. Panels E and F shows the effect of initiating recall with one of the last four stimuli in the list using FR scoring.

Figure 3.5 (Panels C-D) shows the effects of group and serial position for the subset of data where participants initiated recall with the first presented item, using SR scoring. For each modality, these SPCs were analysed at each list length by a 2 (group: single- vs dual-modality) x *n* - 1 (serial positions: 2 to *n*, where *n* is the list length) mixed ANOVA (see Appendix 3.3). For both modalities, there was a significant main effect of serial position, and a non-significant main effect of group for list lengths 4, 8, and 16; all interactions were non-significant.

Figure 3.5 (Panels E-F) also shows the effect of group and serial position on the proportion of items recalled in any order, where recall was initiated with one of the last four presented items. For each modality, these SPCs were analysed at each list length by a 2 (group: single- vs dual-modality) x *n* (serial positions, where *n* is the list length) mixed ANOVA. The exact statistics for the main effects and interactions for each list length can also be found in Appendix 3.4. For both the verbal and visuo-spatial modality there was a significant main effect of serial position and a non-significant main effect of group at list length 4 and greater; all interactions were non-significant.

Detailed Analysis of Output Order in the dual-modality task

First item output by the parallel presentation group. Using participants' response times, it was possible to ascertain the modality with which participants start their recall, when they are presented with concurrent stimuli of different modalities, that is, whether the first output item was a word or a visuo-spatial dot. Figure 3.6 shows the proportion of trials initiated with a word or a dot respectively at each list length. It is clear that on the majority of trials participants initiated recall with a word. A within-subjects ANOVA showed that there was a main effect of list length on the proportion of trials started with a word, $F(4,76) = 2.62$, $MSE = .019$, $\eta^2_p = .121$, $p = .042$. Furthermore, at each list length, the proportion of trials initiated with a word was compared to a test value of 0.5 (probability of starting with either a word or a dot) using independent samples t-tests. These showed that the number of trials initiated with a word are significantly higher than expected by chance (all *p*s < .001).

First three outputs made by the parallel presentation group. From the previous chapter, it has been made clear that the first output item predicts what participants output next. In order to discern whether participants were outputting using a channel-by-channel strategy, the first three output items were analysed. When participants are presented with items from both modalities, there are eight possible ways of outputting the first three items: DDD, DDW, DWD, DWW , WDD, WDW, WWD and WWW (where D stands for dot and W stands for word). Table

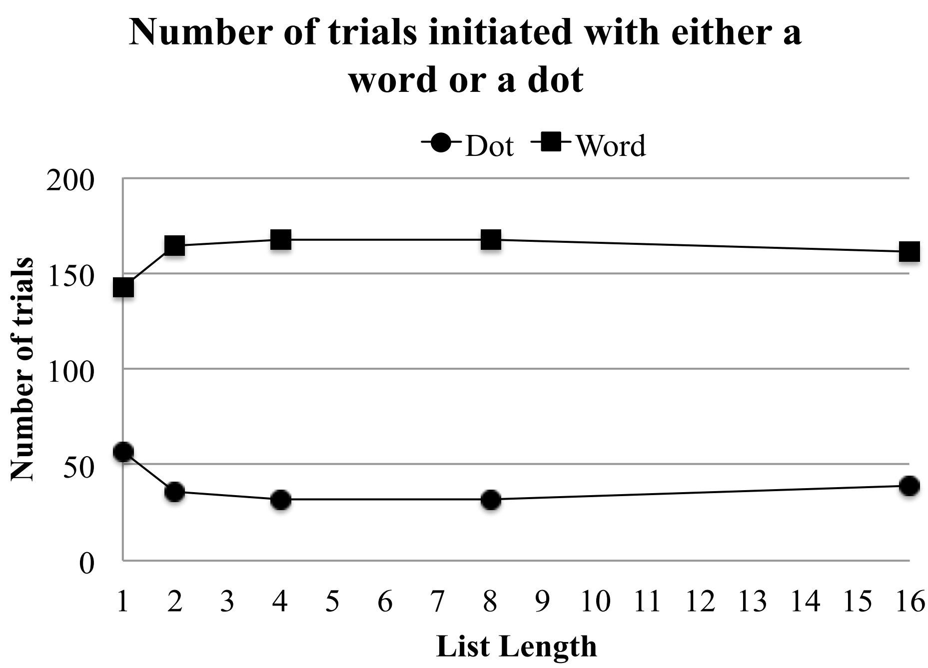

Figure 3.6. Experiment 4: The total number of trials where the first output item was either a visuo-spatial dot or a word at each list length.

3.3A shows the number of times a particular string of first three outputs was output; List Length 2 contained 1 word and 1 dot and was therefore excluded, since an output of a word was necessarily followed by a dot and vice versa.

Table 3.3A shows that the preferred output strategy for the first three output is by far WDW, meaning that participants were more likely to alternate across modalities rather than output channel-by-channel. Table 3.3B shows the number of correctly recalled list items when participants started their output with one of the eight possible output strategies. Although outputting three consecutive dots has the highest number of accurate items, it is noteworthy that this strategy was only used 7 times across all trials. When taking into consideration the most popular strategies for output it is clear that alternating the first three outputs (WDW or DWD) yielded higher number of correctly recalled items. Appendix 3.5 showed that when segregating the number of items recalled by modality, then outputting three items of the same modality consecutively will result in a heightened recall accuracy for that particular modality. However, alternating between modalities still results in a reasonable number of correctly recalled items.

Table 3.3A
Experiment 4: The number of occurrences of each of the eight possible output strategies for the first three outputs of the parallel presentation group for list lengths 4 and greater.

	First three outputs								
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW	Total
List Length									
4		1	18	17	24	**137**	3		200
8	2		15	15	7	**147**	1	13	200
16	2	1	11	18	11	**135**	1	21	200
32	3	1	15	20	11	**115**	1	34	200
Total	7	3	59	70	53	**534**	6	68	800

Table 3.3B
Experiment 4: The average number of list items recalled for each of the eight possible output strategies for the first three outputs of the parallel presentation group for list lengths 4 and greater.

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
List Length								
4		4.00	3.28	3.59	3.21	**3.34**	3.00	
8	5.00		5.00	5.20	4.14	**5.44**	5.00	5.31
16	8.00	4.00	6.64	5.39	4.91	**5.76**	5.00	5.14
32	8.00	6.00	7.40	6.30	7.82	**6.90**	5.00	5.91
Average	7.14	4.67	5.39	5.17	4.64	**5.29**	4.00	5.56

Note: W stands for word; D stands for dot. List length 2 was eliminated because there were only two options of outputs: DW or WD. Outputs refer to the modalities of the first three responses, irrespective of whether the response is correct or not

The effect of PFR = SP1 in the verbal domain on the visuo-spatial domain. Given the strong tendency to start with the first or one of the last four presented items (i.e. PFR = SP1 or PFR = Last 4), it is possible to test for constrained outputs by analysing whether the tendency to start with a particular item in one modality mirrors that of the other. Out of the total 1000 trials within Experiment 4, 729 trials were started with either a word-dot or dot-word transition. Data from the shortest list length (i.e. 1 word and 1 dot) was eliminated, since outputs from such a list were necessarily word-dot or dot-word transitions. Table 3.4 shows the number of trials where the first word and visuo-spatial dot output, were (1) output consecutively and (2) had identical within-modality serial positions. Overall, it is clear that when participants started with the first item or one of the last four items in one modality, the consecutive cross-modality output often had a matching serial position.

Table 3.4
Experiment 4: The number of trials where the first word and first visuo-spatial dot output consecutively had matching within-modality serial position. These were classified into three categories: the probability of starting with the first item, one of the last four items or an error.

		Visuo-Spatial Data			
		PFR = SP1	PFR = Last 4	PFR = Error	**Total**
Verbal Data	PFR = SP1	**243**	12	164	419
	PFR = Last 4	7	**185**	82	274
	PFR = Error	13	8	15	36
	Total	263	205	261	**729**

The number of observed chunks. In order to examine whether participants are outputting in a channel-by-channel manner, the number of observed chunks were analysed. In this context, a chunk is defined as a number of same-modality items output in succession. For example an output of WWDDDWW (where D stands for Dot and W stands for Word) is made up of three chunks. If participants were outputting by modality, then it would be expected to find a total of two output chunks (where one chunk reflects all verbal output and the other reflects all visuo-spatial outputs). Table 3.5 shows the average number of chunks output for each list length. The shortest list length, (i.e. one word and one visuo-spatial dot) was also not included here, given that to output both list items, participants would necessarily have to chunk outputs into two. Overall, it is clear that across all list lengths participants are not outputting by modality since the average chunk size is consistently greater than two.

Table 3.5
Experiment 4: The average number of chunks output by participants at each list length.

List Length	Average number of chunks
2	3.760
4	6.810
8	7.400
16	7.660

Lag transitions. Appendix 3.6 shows the total number of transitions from each of the possible serial positions (*n*) to the next output item (*n* + 1). This data was then used to calculate lags of between + and -15, which are shown in Appendix 3.7 and graphically presented in Figure 3.7. Positive lags denote consecutively recalling two items in forwards order, that is transitions to later list items, whereas negative lags denote transitions to earlier list items (Kahana, 2012). To calculate lag transitions, the serial position of output *n* + 1 is deducted from the serial position of output *n*. For example, if a participant recalls the item in SP1, followed by the item in SP3, this would result in a lag of +2. Alternatively, if participant recalls the item in SP3 followed by the first item on the list, this would result in a -2 lag transition. Due to the parallel presentation of two stimulus domains in the current experiment, a lag of zero was possible and it denoted the consecutive output of a concurrently presented word and dot.

Kahana (2012) states that lags have two main characteristics: first, shorter lags are more frequent than moderate and longer lags and second, that positive lags are more frequent than negative ones. Together, these findings are termed the contiguity effect, whereby consecutively output items are far more likely to come from close serial positions than from distant ones, and that recall transitions are more likely to go forward than backward (Kahana, Howard, & Polyn, 2008; Kahana & Miller, 2013).

Figure 3.7 shows three main salient points. First, the number of 0 lags outnumber both the positive and negative lags and that the majority of these transitions are word-dot (WD) outputs. Second, +1 lag transitions were predominantly dot-word (DW) transitions. Third, there is the typical asymmetry between positive and negative lags that is mostly pronounced at the -1 and +1 lags. This asymmetry is more pronounced for DW and word-word (WW) transitions. Overall, it is clear that when participants are asked to recall concurrently presented words and dot in any preferred order, they are most likely to recall a word followed by the dot of the same serial position. Once this is executed, participants are then likely to move on to the word from the consequent serial position and so on.

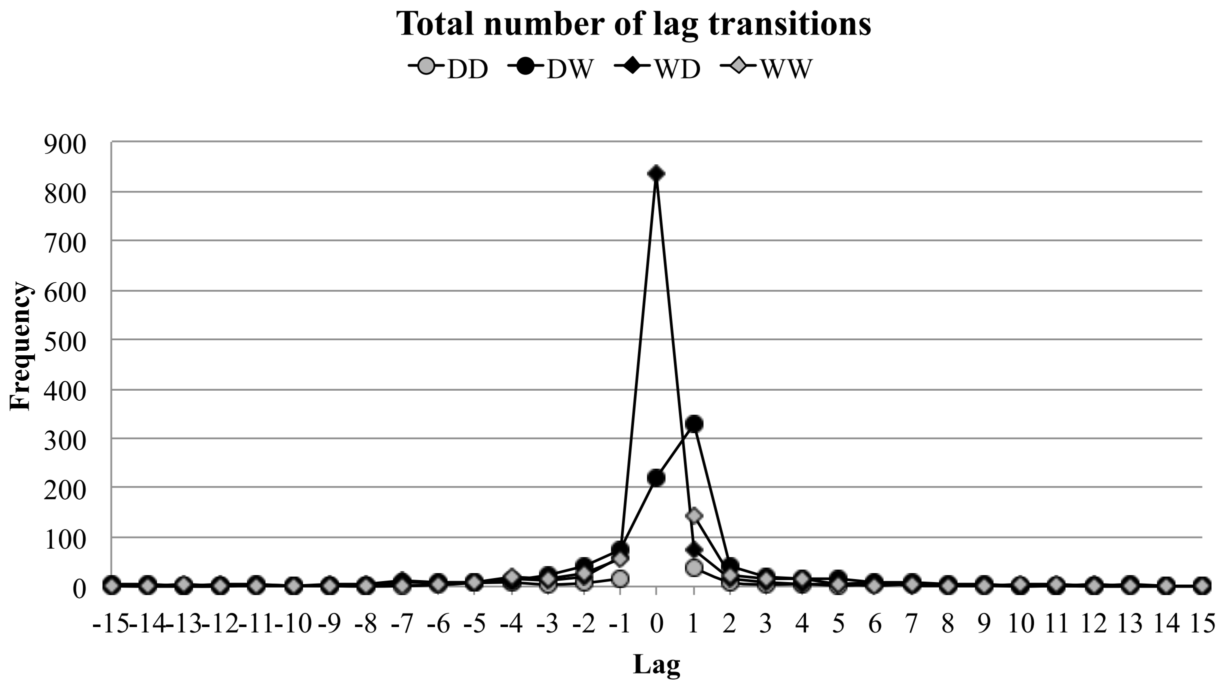

Figure 3.7. Experiment 4: The frequency by which a particular lag transition was made. Smaller lags denote transitions between items of close SPs, whereas larger lags denote transitions between items that are further apart in the list.

Inter-response times (IRTs). For the purpose of the thesis, inter-response time refers to the time taken between the end of a response and the onset of a subsequent item.

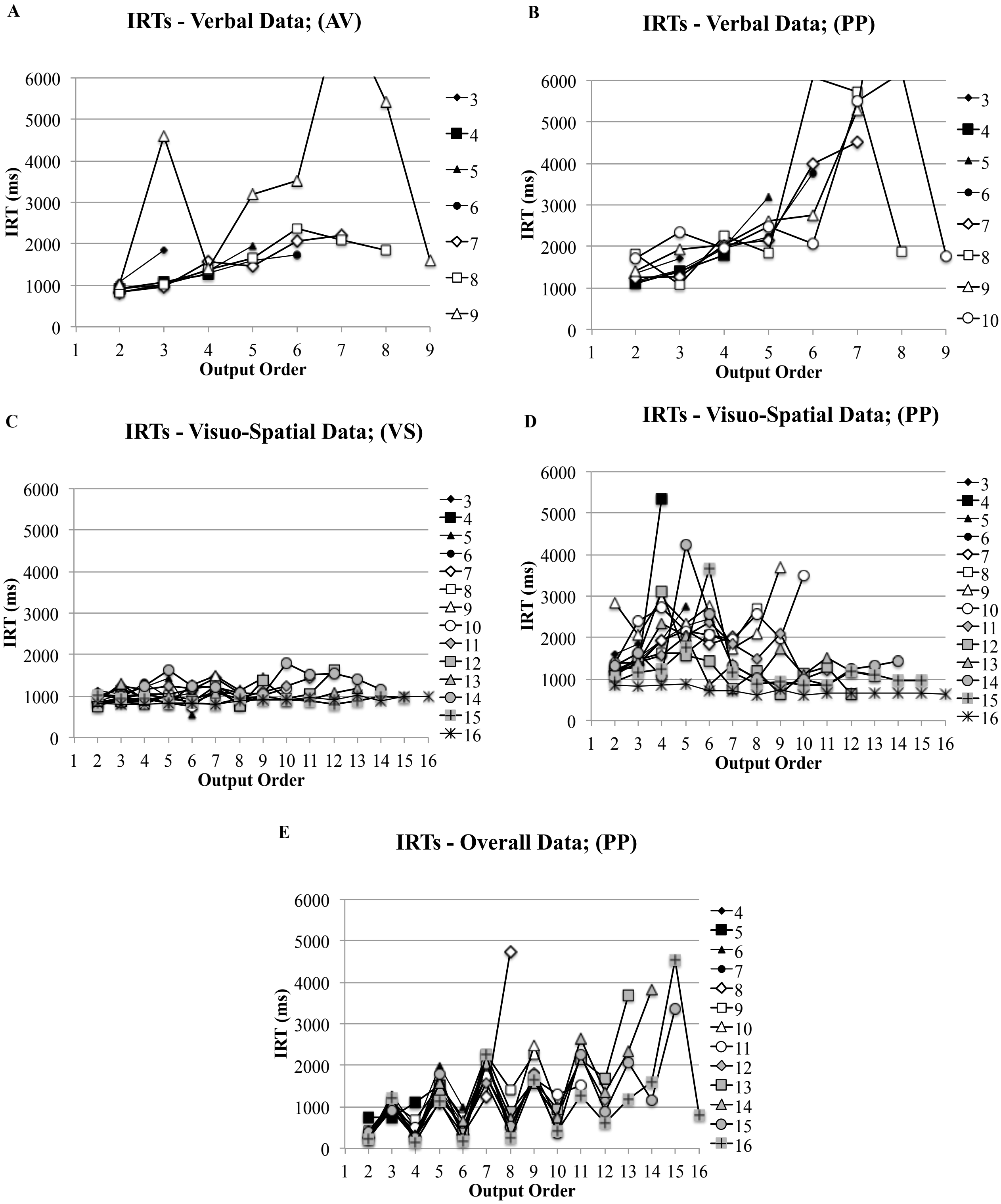

Figure 3.8. Experiment 4: Inter-response times (IRTs) for all data collapsed across the three groups, with the parallel presentation group data further segregated by stimulus domain to enable comparison with the

respective single-modality task. Note: any IRTs above 6000ms were excluded since these were much higher than average. The missing data point in Panel A for output order 7 was of 7732ms, whereas those for Panel B, were 11843ms for output order 8, 11563ms for output order 9 and 19708ms for output order 10.

Figure 3.8 shows the IRTs partitioned on the total number of items recalled across all three groups. The time it takes to output the first item is eliminated since, by definition this is not an IRT. The data for the parallel presentation group was further segmented by modality to enable direct comparison with the respective single-modality group. Murdock and Okada (1970) have shown that in the IFR of verbal materials, the IRTs tend to increase exponentially with increasing outputs, resulting in rapid output of the first few items, which slows down with increasing number of outputs. This can be somewhat seen in the verbal data of the present experiment (see Figure 3.8 Panel A), however, the visuo-spatial data is much flatter. When comparing the single-modality task IRTs with their respective modality data from the parallel presentation group, it is clear that the latter is much nosier than the former.

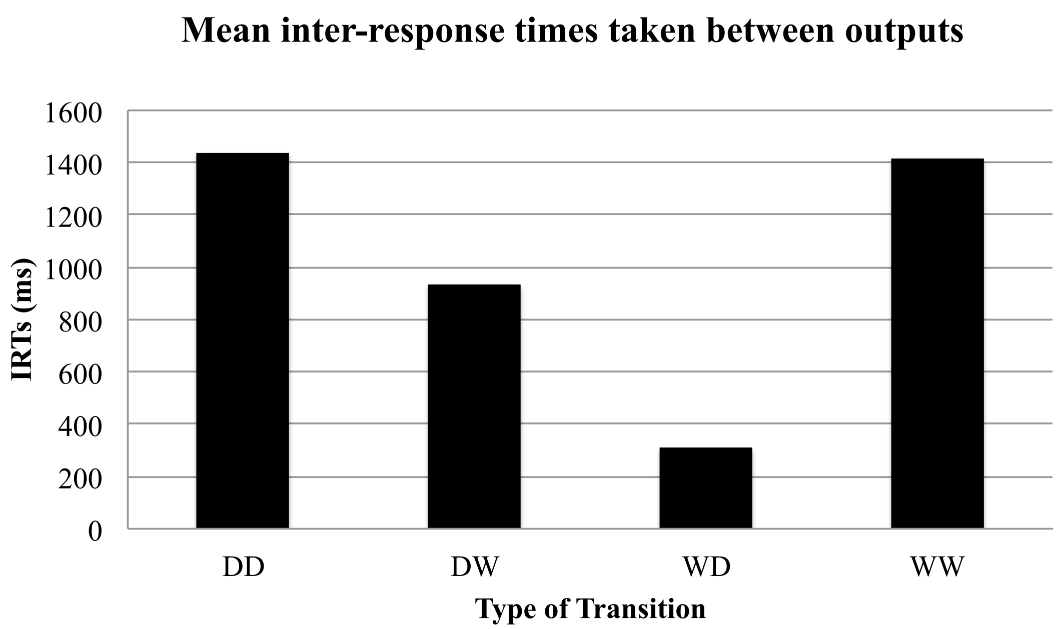

Figure 3.9. Experiment 4. The mean IRTs taken between outputs for each of the four different transitions, where DD stands for two consecutive dots, DW refers to the time taken to output a word preceded by a dot, WD refers to the time taken to output a dot preceded by a word and WW stands for two consecutive words.

As regards the overall IRTs for the parallel presentation group, it is clear that those items output in an even output position have a much shorter IRT than those in odd output positions. This saw-tooth shape curve coupled with the participants' tendency to recall by alternating between words and dots, implies that participants may be outputting in pairs, whereby they prepare to output the dot while they are outputting the word. Alternatively, participants could be retrieving in pairs, whereby both the word and the dot are retrieved together resulting in a slower response time before the odd output, followed by a quicker response of the even output since this was retrieved with the preceding output.

Figure 3.9 shows the mean IRT for the four possible within- and cross-modality transitions. WD transitions have the fastest IRT, followed by DW transitions. There is not much difference between the mean IRT of WW and DD transitions. Paired-samples t-tests showed that there was a significant difference between the mean IRTs for DW and WD transitions, $t(19) = 6.775$, $p < .001$, $d = 2.32$, but a non-significant difference between DD and WW transitions, $t(17) = .438$, $p = .667$, $d = .134$.

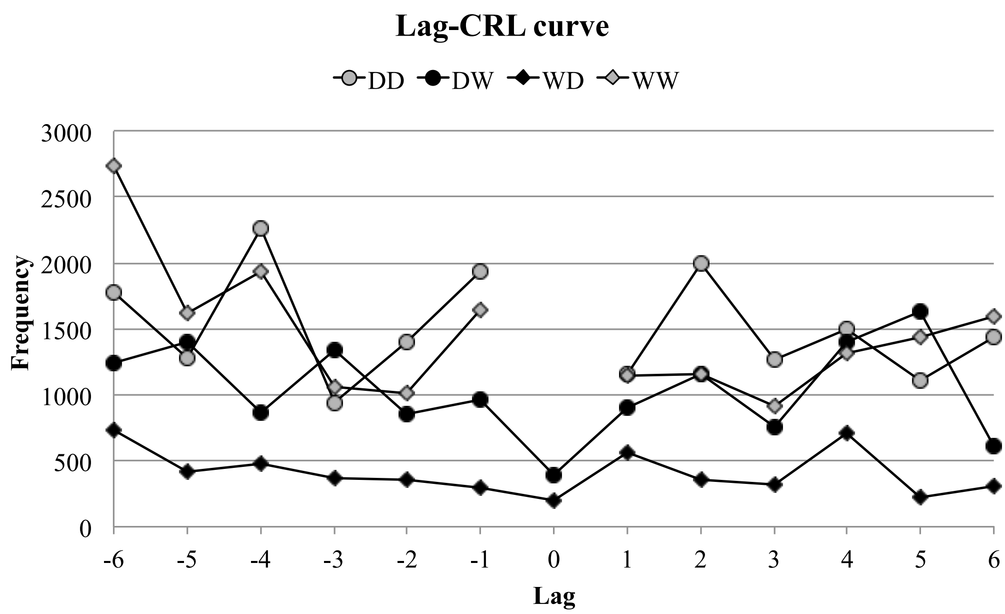

Figure 3.10. Experiment 4. The conditional response latency curve showing the mean inter-response times taken between outputs with lags of between -6 and +6, for each of the four different transitions, where DD stands for two consecutive dots, DW refers to the time taken to output a word preceded by a dot, WD refers to the time taken to output a dot preceded by a word and WW stands for two consecutive words.

Figure 3.10 shows the IRTs for each of the possible across- and within-modality transitions for lags between – and +6, since these were the most frequent. Kahana (2012) terms this the conditional response latency curve (lag-CRL) and typically these show that smaller lags have shorter IRTs than longer ones and therefore the time taken between outputs increases with increasing lag transition. Although the data is fairly noisy, it is clear that IRTs were shortest for 0 lags and that these increased with increasing lag, although this is least pronounced for WD transitions.

DISCUSSION

The three aims of the present experiment were to first confirm previous findings with respect to list length and output order effects in non-verbal stimuli as previously found in Chapter 2. Second, I wanted to test the effects of being presented with two concurrent stimuli from different modalities, that is verbal and visuo-spatial modalities, on the capacity limits of recall. Finally, I wanted to utilise the freedom of IFR to examine the natural or preferred output order when participants were required to recall both auditory-verbal and visuo-spatial stimuli, when these were presented concurrently.

Considering first the evidence regarding the first aim, Experiment 4 confirms the list length and output order effects found in Experiments 1 to 3. The free recall of non-verbal, visuo-spatial dots yield broadly the same results as the IFR of verbal stimuli. First, although participants are less accurate when it comes to selecting visuo-spatial locations, there are clear list length effects in the recall of non-verbal material similar to those in the verbal IFR literature. These were pronounced despite the limited number of list lengths; while previous experiments manipulated list length at approximately 11 levels, there were only 5 list lengths in the present experiment. Second, in both modalities, there was primacy at the shorter list lengths, both primacy and recency at mid-length lists and extended recency at the longest list length.

Third, Experiment 4 confirmed previous findings that regardless of modality, participants tend to initiate recall with the first item if the list is short, but as the list length increases, participants tend to initiate recall with one of the last four presented items. Lastly, Experiment 4 corroborates the findings that even when participants are asked to recall a sequence of visuo-spatial dots in any order that they wish, there is clear evidence of forward ordered recall, resulting in an "ISR-like" recall pattern. When participants initiate recall with the first presented items, there is an increased advantage for the earlier items on the list and reduced recency. Conversely, if participants recall one of the last four presented items first, there is a recall advantage of the later items in the list as well as a decrease in primacy.

The performance of the parallel presentation group showed that overall, there was no evidence of a significant trade-off in accuracy when combining the presentation of verbal and visuo-spatial material. The overall accuracy data showed that the number of items remembered from each modality in the parallel presentation group was almost identical to the number of items remembered when either modality was to be recalled in the respective single-modality groups. For example, when the proportion of responses correct is converted into number of items recalled, at list length 4, participants in the single-modality groups remembered approximately 3.55 words and 2.00 visuo-spatial locations respectively, adding up to a total of 5.55 items. Participants in the dual-modality group remembered on average 5.33 items when presented with 4 words and 4 dots. This shows that immediate memory capacity for concurrently presented words and dots seems to be the equivalent of summing up the immediate memory capacity of each of the single–modality tasks. This is consistent with the Saults and Cowan (2007) results of concurrently presented verbal and visuo-spatial arrays.

To enable a more direct comparison across modalities, the performance of the parallel presentation group was separated into verbal and visuo-spatial performance, and compared to that of the auditory-verbal and visuo-spatial groups respectively. Consistent with the previously described evidence of capacity limits, there was a non-significant difference between the verbal performance of the auditory-verbal group and the parallel presentation group. A corresponding comparison for visuo-spatial performance yielded the same results, although overall, there was a slight non-significant difference in accuracy.

These similar findings between modalities regardless of whether the task required single- or dual-modality recall also extends to the serial position curves, which were similar irrespective of group. Although there were non-significant differences overall, the serial position plots showed that although recency is almost completely unaffected by the parallel presentation condition, primacy is somewhat reduced, and this is more pronounced at list length 16. This is consistent with the Morey and Mall (2012) findings of interleaved mixed-modality lists.

Furthermore, there was no effect of group when comparing the probability of initiating recall with serial position one across modalities. Similarly, the probability of starting with one of the last four presented items on the list was unaffected by whether or not the participants saw a visuo-spatial dot while hearing a spoken word. There is a slight dissimilarity with regard to the verbal data, whereby the probability of initiating recall with one of the last four presented items differed somewhat between the two groups. The tendency to start with one of the last four items on the list is stronger when participants heard spoken words while simultaneously seeing visuo-spatial circles on the screen. Finally, the crossover points shifts to shorter list lengths when participants are presented with a dual-modality task.

As regards the resultant serial position curves conditioned by those trials initiated with either the first item or one of the last four items, both the visuo-spatial and verbal modalities remained consistent and showed similar increased primacy when participants initiated recall with the first presented item, even when SR scoring was used, and increased recency when the first item recalled was one of the last four presented items.

Further analysis on the parallel presentation group’s performance showed that participants tend to output fewer visuo-spatial items in the dual-task condition. However, the number of items recalled as a proportion of all output items does not vary significantly. Furthermore, participants tend to recall the auditory-word first and this is mostly followed by a dot. This was seen both through the analysis of the first three outputs and through lag transitions. The lag transition curve revealed that the majority of transitions were between a word and a dot, and that on the fewer outputs where dots were output first, these were mainly followed by a word. Therefore, it can be concluded that participants were recalling the stimuli presented in parallel in an alternating manner. This is not parsimonious with findings by Broadbent (1958) and Dornbush (1968) with verbal material presented using different channels, where participants naturally output one stream first, followed by the other. It is clear that such findings are not merely a result of a short list length, whereby 2 sets of 3 verbal items are presented, since in the present experiment even at list length 2 (2 words and 2 visuo-spatial dot locations to be remembered), participants chose to recall in an alternating manner rather than by modality.

Additionally, the present data suggests that participants were actively associating a single word with a visuo-spatial dot that was presented concurrently. This can be seen through the constrained order exhibited at output. The large amount of 0 lags show that in a large proportion of responses, participants output the word and visuo-spatial dot of the same serial positions consequently. Additionally, alternating modalities resulted in a greater number of correctly recalled items than simply outputting same-modality items consecutively; this was especially true for visuo-spatial memoranda.

Finally, the inter-response times resulted in a saw-tooth curve which showed that the items recalled in even output order had a much shorter reaction time than those in odd ones. Given that most alternations were word-dot transitions, this could imply one of three things: (1) perhaps word have generally longer IRTs than visuo-spatial dots, (2) participants could be retrieving the dots while simultaneously speaking an auditory-word or (3) participants are retrieving two items of different modalities together, whereby the second item is output much quicker than the previous one because it has already been retrieved with the subsequent item.

Additionally, IRTs showed that word-dot transitions are quicker than any other transition type. This is somewhat surprising given the Wingfield and Byrnes (1972) findings showing that pair-by-pair output of two concurrently presented streams take longer to output than channel-by-channel recall. Perhaps this difference is due to the fact that in the present experiment there were two way of outputting the different modality streams, whereas in the Wingfield and Byrne's data, all responses were verbal. Furthermore, lag transition had an effect on IRT, in that lags of zero had the shortest IRTs, which increased moderately with increasing lag. However, it is important to note that interreponse time data requires a large number of data points for it to be meaningful (e.g. Murdock & Okada, 1970), and due to the list length manipulations in the present experiment, there were limited data points per amount of output items. Additionally, some participants output a large amount of items at list length 16. It is possible that these responses, which were mainly visuo-spatial mouse clicks were guesses and therefore this could impact the reliability of the inter-response time data.

Overall, this experiment was concerned with discerning the capacity and output orders of concurrently presented verbal and visuo-spatial items. When participants were presented with both visuo-spatial and verbal items, the capacity to recall both was very similar to that of participants who were only presented with and required to recall one of the two domains. As regards the way in which the items were output, participants' output showed constrained orders between the two modalities and that the modalities were output in an alternating manner. It is possible that the constrained order, which may be a result of encoding by association of modalities, is due to the fact that these stimuli were presented in parallel, and that this finding may perhaps be a result of an exception rather than the norm. I therefore wanted to test whether staggering the presentation of the two modalities will disrupt the constrained orders and therefore reduce capacity limits.

EXPERIMENT 5

Experiment 5 both replicated Experiment 4 and extended the scope by the inclusion of an alternating group. Consequently, there were four groups: the first three groups were the same as the previous experiment: auditory-verbal group, the visuo-spatial group, the parallel presentation group (synchronous onsets) and the alternating presentation group, in which participants heard spoken words and saw visuo-spatial circles presented in an alternating pattern, such that there was no overlap between the presentations of the two modalities. Each participant saw 50 lists according to which group they were in. For the alternating presentation condition, half the trials were initiated with a word and the other half with a visuo-spatial location.

The aims of Experiment 5 concentrated on the second and third aim of Experiment 4 by focusing on capacity and output order effects. Specifically, I wanted to ensure that the results from Experiment 4 with regards to the capacity and output order in the parallel presentation group could be successfully replicated. The addition of a fourth group allowed for the examination of whether the constrained order could be disrupted if the two modalities were presented sequentially. In Experiment 4, I found a large number of zero lags, whereby participants output an item of a specific serial position (more often a word than a dot), followed by the cross-modality item that was presented concurrently. To ensure that the constrained orders were not due to a special circumstance in which two stimuli are presented simultaneously, the stimuli in Experiment 5 were presented sequentially to ensure that the list was easily perceived to be made up of twelve mixed-modality items rather than six to-be-remembered events.

To enable a detailed analysis of output order effects and reaction time data a single list length was utilised. List length 6 was selected because it had not been previously used in Experiment 4 and more importantly, because Experiments 1 to 3 have shown that at this list length participants tend to shift their recall between starting with the first or last four items presented; resulting in both primacy and recency effects. Another motivation to use list length six was that from the previous experiment, it was clear that outputs greater than six are considerably fewer and tend to be more erroneous and therefore not as useful when testing for constrained order.

In summary, I was expecting to find consistent result patterns with the previous experiments as regards the auditory-verbal, visuo-spatial and parallel presentation groups. More specifically, that there would be summed verbal and visuo-spatial capacities and constrained alternating outputs in the parallel presentation group. Since the purpose of staggering of the stimuli in the alternating presentation group, was to ensure that participants view it as a twelve item list rather than six events, it was possible that this would have an adverse effect on capacities as well as possibly leading to unconstrained orders.

METHOD

Participants. A total number of 80 students from the University of Essex participated in exchange for either course credit or a small payment.

Materials. Materials were the same as that of Experiment 4.

Design. The experiment used a mixed factorial design. The between-subjects independent variable was the performance of free recall when using either verbal stimuli, visuo-spatial stimuli, both stimuli presented in parallel and both stimuli presented in a staggered manner such that there was an auditory-verbal stimuli group, a visuo-spatial stimuli group, the parallel presentation group and the alternating presentation group. Overall, there was one within-subjects independent variable: serial position with 6 levels for the auditory-verbal and visuo-spatial group and 12 levels in the parallel presentation and alternating presentation groups. For the alternating presentation group another dependent variable was used: whether the first item presented was a word or a dot.

The dependent variables were the proportion of items correctly recalled, the proportion of items recalled in the same order as presented, the probability of initiating recall with the first or with one of the last four stimuli and the time taken between responses. For the dual modality groups, there were additional dependent variables: the number of visuo-spatial outputs, the number of items correct as a proportion of actual outputs, the proportion of trials where recall was initiated with a word, the number of times a specific string of three outputs were made, as well as the number of times a specific lag transition was made.

Procedure. Each participant was randomly allocated into one of the four groups: the auditory-verbal stimuli group, the visuo-spatial stimuli group, the parallel presentation group and the alternating presentation group such that each group was made up of 20 participants. Each participant was tested individually and given group-specific instructions. All participants were informed that they would be shown two practice lists of six stimuli (six words and six dots in the parallel presentation and alternating presentation groups), followed by 50 experimental lists of stimuli. The experimental trials were arranged into two blocks; each containing 25 trials. To ensure that all sequences in the experiment were of the same temporal length we ensured that spoken words had a duration of 0.60s. Therefore, all stimuli appeared on the screen for 0.60s, with an inter-stimulus interval of 0.60s. For the alternating presentation group this inter-stimulus interval was filled with another stimulus, which was always a cross-modal item. Additionally, in the alternating presentation group, half of the trials started with a word, while the other half started with a visuo-spatial dot and the order of these trials was randomised. Each trial started with a pre-cue instruction to enable the participants to self-pace the start of each trial.

Following a computer mouse click, participants saw a sequence of six stimuli presented one at a time in the single-modality groups, or twelve stimuli for the parallel presentation and alternating presentation groups, where a dot and a word were presented either simultaneously or in an alternating manner respectively. The procedure for the auditory-verbal, visuo-spatial and parallel presentation groups is identical to that of Experiment 4. Similar to participants in the parallel presentation group, participants in the alternating presentation condition, were instructed to say out loud as many words, and click on the screen to indicate the spatial locations of the dots, in any preferred order. In all groups, participants pressed the "submit" button once they were confident that they have submitted all the responses they could recall and this initiated the next trial.

RESULTS

Capacity and Replication

Overall Accuracy. Similar to Experiment 4, the dual-modality groups' recall performance (parallel and alternating presentation groups) was separated by modality (i.e. verbal and visuo-spatial performance) and compared to the performance of the auditory-verbal and visuo-spatial group respectively as shown in Figure 3.11.

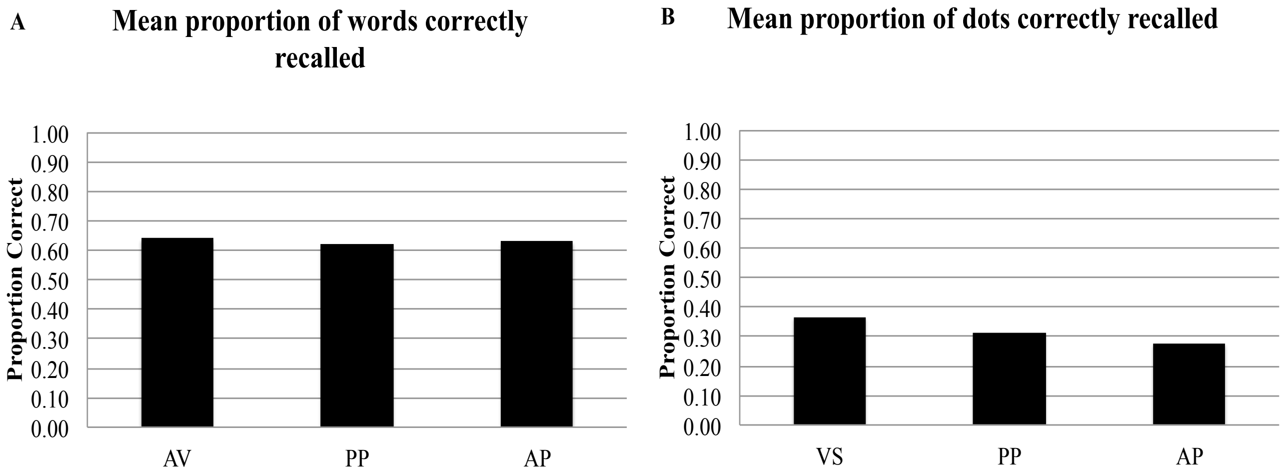

Figure 3.11. Experiment 5: The mean proportion of correctly recalled words (panel A) and dot locations (panel B) respectively, where performance for the dual-modality groups (parallel presentation (PP); alternating presentation (AP)) was segmented by modality to enable comparison with the respective single-modality groups (auditory-verbal (AV); visuo-spatial (VS)).

A between-subjects ANOVA (group: single-vs dual-modality) revealed that there was a non-significant main effect of group on verbal accuracy $F(2,57) = .403$, $MSE = .007$, $\eta^2_p = .014$, $p =$

.670. Conversely, there was a significant main effect of group on non-verbal accuracy $F(2,57) = 7.98$, $MSE = .005$, $\eta^2_p = .219$, $p = .001$. Post-hoc Bonferroni tests showed that there was a significant difference between the non-verbal performance of the alternating group and visuo-spatial group ($p = .001$), all other tests were non-significant (all *p*s > .064). Thus, there is evidence that staggering the presentation of both modalities did not have much of an effect on verbal performance, but it had more of a marked effect on visuo-spatial accuracy.

The number of output dot locations across groups. Figure 3.12 shows the number of total visuo-spatial responses as a proportion of total possible outputs (6000) and the total number of correct outputs made by the visuo-spatial, parallel presentation and alternating presentation groups as a proportion of actual outputs. A between-subjects ANOVA showed that there was a significant main effect of group on the proportion of total outputs made out of the possible 6000 outputs, $F(2,57) = 15.5$, $MSE = .012$, $\eta^2_p = .353$, $p < .001$.

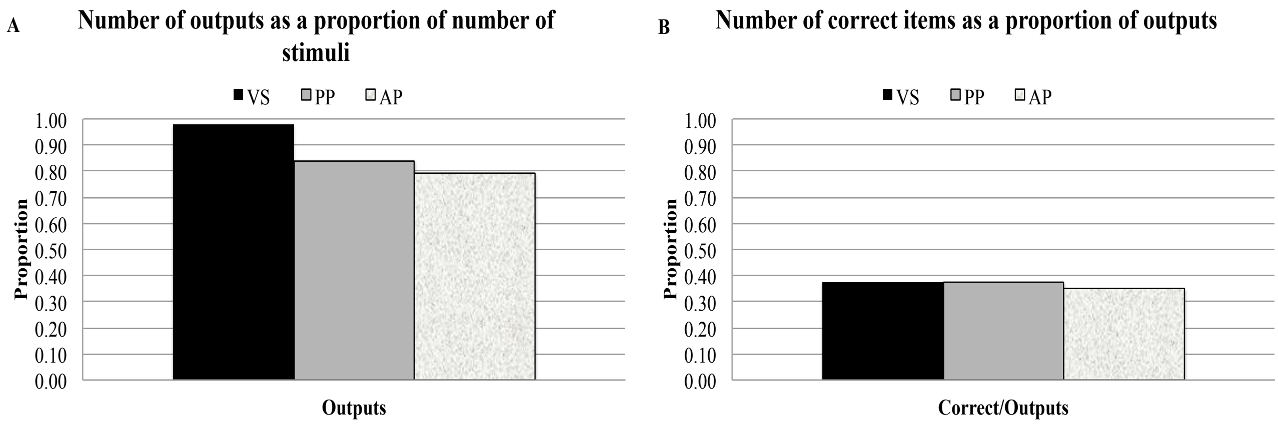

Figure 3.12. Experiment 5: The total number of output visuo-spatial dots as a proportion of all possible outputs (panel A) and the total number of correct responses as a proportion of actual outputs for all three groups (panel B) Note: visuo-spatial (VS); parallel presentation (PP); alternating presentation (AP).

Post-hoc Bonferroni tests showed that there was a significant difference between the means of the visuo-spatial and the alternating presentation groups ($p < .001$) and between the visuo-spatial and the parallel presentation groups ($p = .001$), but not between the two dual-modality groups ($p = .522$). When the visuo-spatial accuracy for the visuo-spatial, parallel presentation and alternating presentation groups was recalculated as a proportion of the total number of outputs made, there was a non-significant main effect of group on accuracy, $F(2,57) = .498$, $MSE = .006$, $\eta^2_p = .017$, $p = .610$.

Serial position curves (SPCs). Figure 3.13 shows the SPCs for each group by modality. Table 3.6 shows two 3 (group: single- vs dual-modality) x 6 (serial position) ANOVAs. These showed that there was a significant main effect of serial position on verbal performance, a non-significant main effect of group and a non-significant interaction.

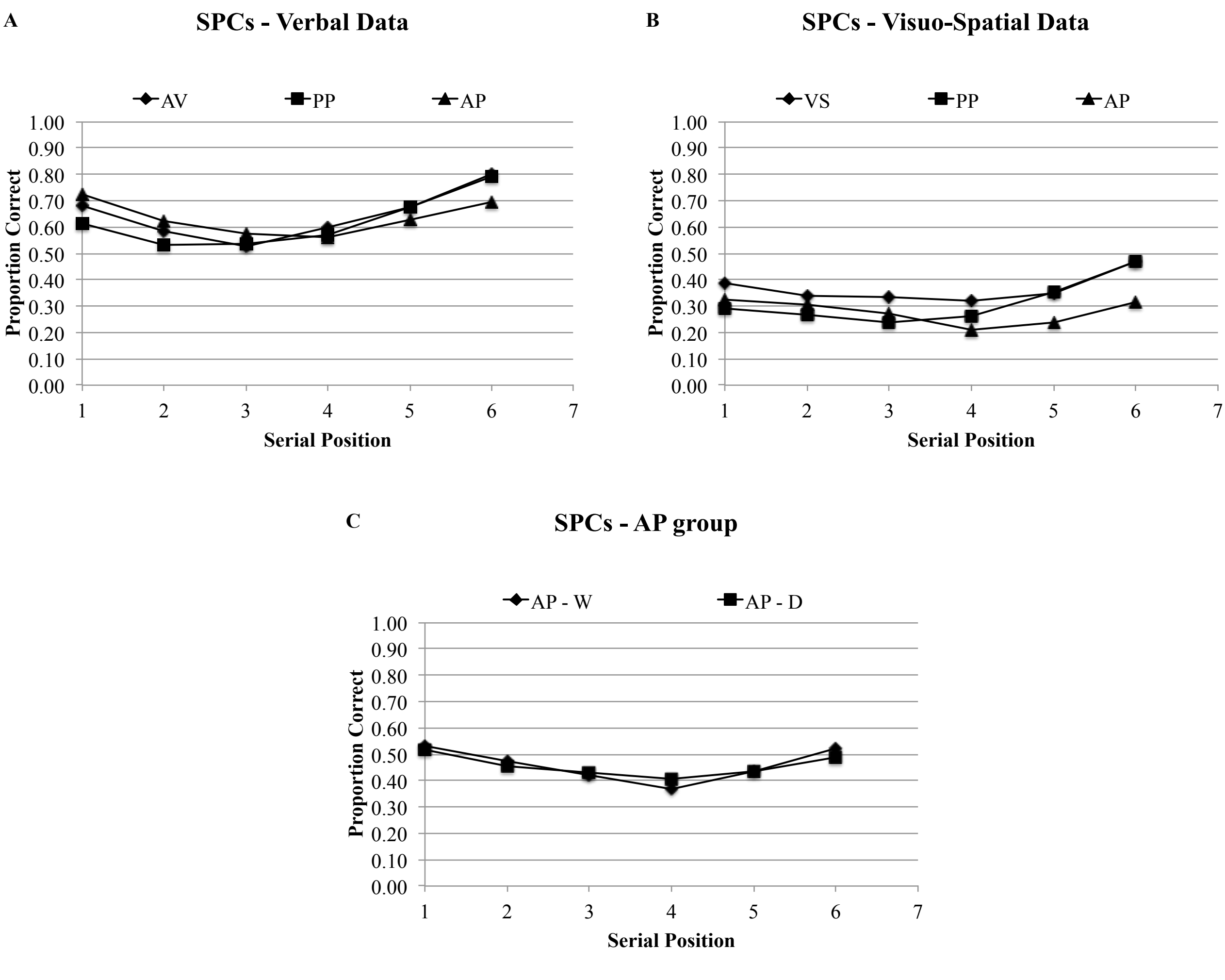

Figure 3.13. Experiment 5: SPCs for the verbal data, taken from the auditory-verbal (AV), parallel presentation (PP) and alternating presentation (AP) groups (panel A) and visuo-spatial data taken from the visuo-spatial (VS), parallel presentation (PP) and alternating presentation (AP) groups (panel B). Panel C separates the data from the alternating presentation group into those trials where the first item was a word (AP – W) or a dot (AP – D).

For the non-verbal data, there was a significant main effect of serial position on non-verbal performance, a main effect of group as well as a significant interaction. Post-hoc Bonferroni corrections showed that the only significant difference was between the visuo-spatial group and the alternating presentation group (*p* = .001).

For the alternating presentation group a repeated-measures 2 (first item: Word, Dot) x 6 (serial position) ANOVA showed that there was a non-significant main effect of which modality item was presented first, a significant main effect of serial position and a non-significant interaction (see Table 3.6). Overall, there is the typical primacy and recency usually found at this list length, since the curves were quadratic. Alternating presentation seems to have somewhat shifted these serial position effects whereby there is less recency in this group, when performance is separated by modality and compared to the specific modality of the other groups; this is more pronounced in the visuo-spatial data.

Table 3.6
Experiment 5: Summary of the ANOVA analyses conducted upon the serial position curves (SPCs) data.

	df	*MSE*	*F*	η^2_p	*p*
Serial Position Curves- Verbal Data					
SP	5,285	.027	14.9	.207	< .001
GP	2,57	.007	.403	.014	.670
SP x GP	10,285	.027	1.45	.048	.158
Serial Position Curves – Visuo-Spatial Data					
SP	5,285	.015	11.5	.168	< .001
GP	2,57	.030	7.98	.219	.001
SP x GP	10,285	.015	2.37	.077	.010
Serial Position Curves – AP group separated by 1st item (Word or Dot)					
1st Item	1,19	.005	.228	.012	.638
SP	5,95	.039	2.78	.127	.022
1st Item x SP	5,95	.005	1.31	.064	.267

The probability of first recall (PFR) data. Similar to Experiment 4, the data from the dual-modality groups were also segmented into verbal and visuo-spatial data respectively and compared to the respective single-modality group. Figure 3.14 shows the PFR data for each modality and performance from the alternating presentation group was further separated by those trials starting with either a word or a dot. The PFR data was analysed by modality through 3 (group: single- and dual-modality - PP and AP) x 6 (serial position) ANOVAs to test for effects of modality on the tendency to start with either the first or last few list items; the summarised statistics of these are in Table 3.7. In summary, in the verbal domain, there was a non-significant main effect of group on starting with the first presented item as well as a non-significant main effect of starting with one of the last four auditory-words. As regards the non-verbal data, there was a non-significant main effect of group on initiating recall with the first presented item. However, there was a significant main effect of group on the probability of initiating recall with one of the last four dots; post-hoc Bonferroni tests showed that there was a significant difference between the means of the parallel and alternating presentations groups ($p = .011$); all other group differences were non-significant (all ps > .420).

Lastly, Table 3.7 shows two within-subjects ANOVAs that were conducted to test whether there was any effect on starting with the first or last four items presented, if the participants saw a dot or a word first in the alternating presentation condition. There was a non-significant main effect of the modality item (whether first item was a word or dot) on the tendency to start with serial position 1 as well as a non-significant main effect of the first item's on initiating recall with one of the last four presented items on the list.

Overall, Figure 3.14 shows that despite the differences in accuracy levels in the verbal and visuo-spatial performance, at list length 6, participants tended to initiate recall with either the first or one of the last four items presented. Furthermore, this tendency is not affected by the modality of the first or last item. However, when participants are presented with a dual-modality task, the tendency to start with the last items is higher, and this is especially seen in the visuo-spatial data.

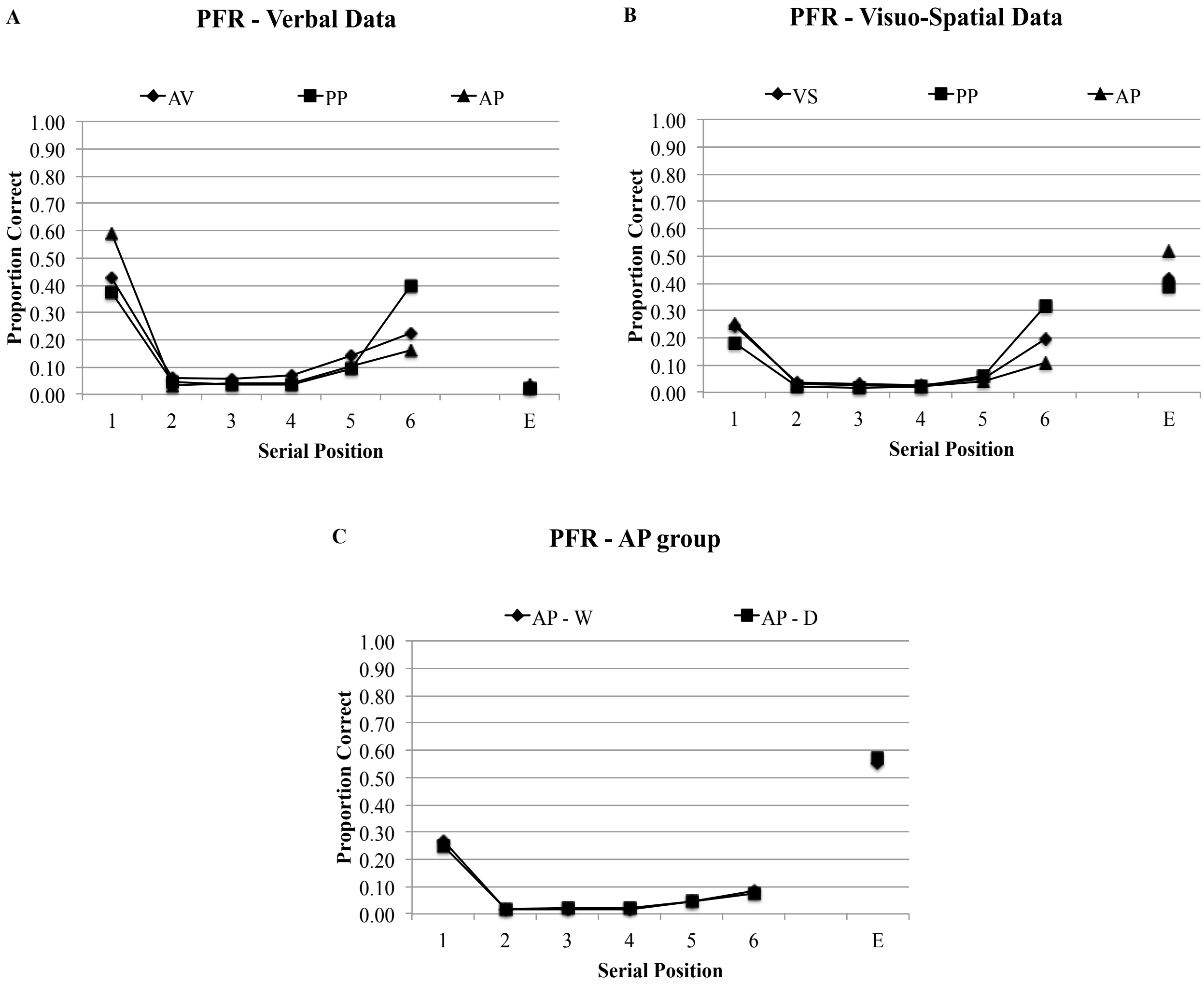

Figure 3.14. Experiment 5: PFR data for the verbal (panel A) domain taken from the auditory-verbal (AV), parallel presentation (PP) and alternating presentation (AP) groups and visuo-spatial (panel B) domain taken from the visuo-spatial (VS), parallel presentation (PP) and alternating presentation (AP) groups respectively. These show the proportion of trials in which recall was initiated with one of the 6 available serial positions or an Error (E) across groups. Panel C separates the data from the alternating presentation group into those trials where the first item was a word (AP – W) or a dot (AP – D).

Table 3.7

Experiment 5: Summary of the ANOVA analyses conducted upon the probability of First Recall (PFR) data

	df	*MSE*	*F*	η^2_p	*p*
PFR (Verbal Data: taken from AV, PP and AP groups)					
PFR = SP1	2,57	.083	3.05	.097	.055
PFR = Last 4	2,54	.092	2.29	.078	.111
PFR (Visuo-spatial Data: taken from AV, PP and AP groups)					
PFR = SP1	2,57	.022	1.53	.051	.225
PFR = Last 4	2,54	.053	4.62	.146	.014
PFR in the AP Group (effect of first modality item presented)					
PFR = SP1	1,19	.006	1.68	.081	.211

PFR = Last 4	1,17	.007	.104	.006	.751

Note: AV stands for auditory-verbal; VS stands for visuo-spatial; PP stands for parallel presentation; AP stands for alternating presentation

The effect of the first recall on the serial position curves. Figure 3.15 (Panels A-B) shows the effect of group on the proportion of items recalled, for both modalities, for those trials where recall was initiated with Serial Position 1 using FR scoring. All of the consequent analysis was separated by stimulus domain. For those trials where recall started with the first presented item a 3 (group: single- vs dual-modality) x 5 (serial positions 2-6) mixed ANOVA was conducted; exact statistics for the main effects and interactions are shown in Appendix 3.8. In the verbal domain, there was a significant main effect of serial position, a non-significant main effect of group and a non-significant interaction. In the visuo-spatial modality, there was a significant main effect of serial position, a significant main effect of group and a non-significant interaction. Post-hoc Bonferroni tests showed that there was a significant difference was between the means of the parallel presentation group and the visuo-spatial group (p = .021); no other tests were significant (all ps > .057). These show that in such trials, there were primacy effects and some recency effects in both modalities albeit less pronounced in the visuo-spatial data.

Figure 3.15 (Panels C-D) shows the same above discussed data scored with SR scoring. The data was analysed again using 3 (group) x 5 (serial position) mixed ANOVA and the exact main effects and interactions can be found in Appendix 3.8. In the verbal modality, there was a significant main effect of serial position, a non-significant main effect of group and a non-significant interaction. In the visuo-spatial modality, there was a significant main effect of serial position, a non-significant main effect of group and a significant interaction. These show that the FR of both verbal and non-verbal stimuli were recalled in an “ISR-like” manner and that this is also found when the output is separated by modality in the dual-modality tasks.

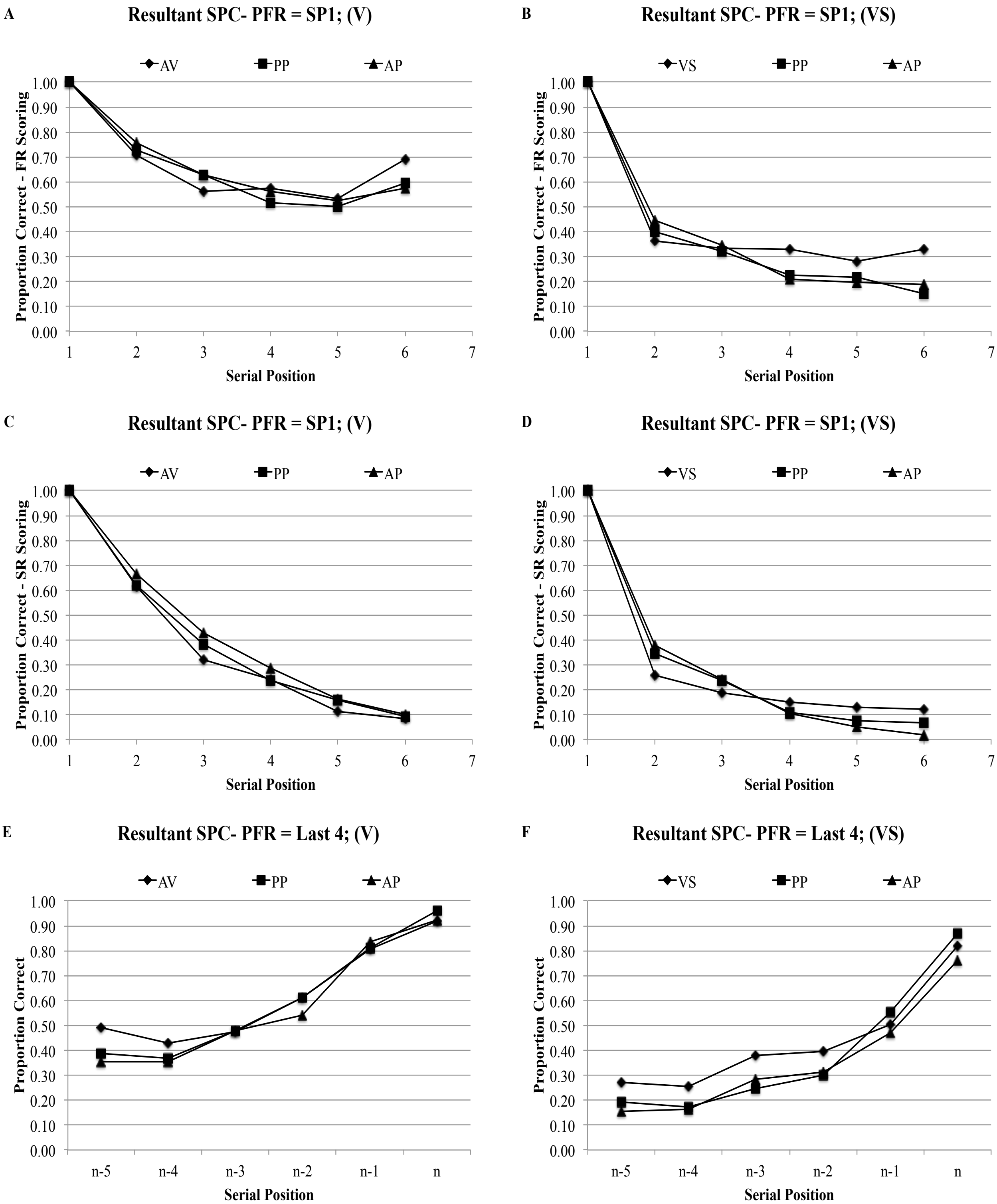

Figure 3.15. Experiment 5: The effect of the first recalled item on the serial position curves, separated by modality with the verbal domain on the left side and the visuo-spatial domain on the right side. Panels A and B show the effect of initiating recall with the first presented item in the list using FR scoring. Panels C and D show the effect of initiating recall with the first list item using SR scoring. Panels E and F show the effect of initiating recall with one of the last four stimuli in the list using FR scoring.

Figure 3.15 (Panels E-F) shows the effects of group on the proportion of visuo-spatial dots and auditory-words recalled in any order for those trials where participants started their recall with one of the last four presented items. These SPCs were analysed by a 3 (group) x 6 (serial position) mixed ANOVAs, one for each modality. The exact statistics for the main effects and interactions can be found in Appendix 3.8. In the verbal modality, there was a significant main effect of serial position, a non-significant main effect of group and a non-significant interaction. In the visuo-spatial modality, there was a significant main effect of serial position, a significant main effect of group and a non-significant interaction. Post-hoc Bonferroni tests showed that the only significant mean difference between the groups was between the alternating presentation and visuo-spatial groups (p = .009); all other tests were non-significant (all ps = 1). These show that when participants initiate recall with one of the last few items on the list, there is a tendency for more pronounced recency effects regardless of the modality.

Detailed Analysis of Output Order in the dual-modality task

First item output by the dual-modality groups. Consistent with the previous experiment, it is clear that on the majority of trials participants initiated recall with a word (parallel presentation group: 870 of 1000 trials were initiated with a word; alternating presentation group: 780 of 1000 trials were initiated with a word). For each dual-modality group, the proportion of trials initiated with a word was compared to a test value of 0.5 (probability of starting with either a word or a dot) using an independent-samples t-test. These showed that the number of trials initiated with a word are significantly higher than expected by chance (both ps < .001). A between-subjects ANOVA (parallel presentation vs alternating presentation) showed that there was a significant main effect of group on the proportion of trials started with a word, $F(1,38) = 4.21$, $MSE = .019$, $\eta^2_p = .100$, $p = .047$. Participants in the alternating presentation group initiated recall with a dot more often than those in the parallel presentation group, and this could be a result of participants seeing the dot before hearing a word in the alternating condition. However, a within-subjects ANOVA showed that for the alternating presentation group, there was a non-significant effect of whether participants were presented with a word or dot first, on the proportion of trials where recall was initiated with a word, $F(1,19) = 1.45$, $MSE = .009$, $\eta^2_p = .071$, $p = .243$.

First three outputs by the dual-modality groups. Since in the previous experiment, participants were likely to alternate between modalities, the first three outputs were analysed to test whether the findings from the previous experiment could be replicated and extended to when participants were presented with alternating presentation. Similar, to the previous experiments, there are eight possible ways in which the first three items in a dual-modality task can be output. Table 3.8A shows the frequency by which a particular set of three items were output for the parallel presentation and alternating presentation group respectively. For the alternating presentation group, the data is further segmented into those trials where the first list item was a word or a dot respectively. It is clear that the preferred output strategy for both groups was to alternate by outputting WDW and that participants are not as keen to alternate by outputting DWD. When the first presented item in the alternating presentation group was a visuo-spatial location, participants were still almost as likely to output WDW as when they were presented with a word first. Table 3.8B shows that consistent with the findings from the previous experiment, participants perform best when they alternate modalities, since they correctly recall more items when they output WDW or DWD. Furthermore, being presented with a word or a dot did not affect the number of items recalled when alternating outputs.

Table 3.8A
Experiment 5: The number of occurrences of each of the eight possible output strategies for the first three outputs of the parallel and alternating presentation group respectively.

	First three outputs								
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW	Total
PP Group	3	4	30	93	52	**667**	21	130	1000
AP Group									

SP1 = D	2		57	60	33	**285**	14	49	500
SP1 = W	4	1	30	66	37	**304**	13	45	500
Total	6	1	87	126	70	**589**	27	94	1000

Table 3.8B
Experiment 5: The average number of list items recalled for each of the eight possible output strategies for the first three outputs of the parallel and alternating presentation group respectively.

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
PP Group	3.67	5.50	5.23	5.90	5.27	**5.65**	4.81	5.54
AP Group								
SP1 = D	2.00		5.53	5.35	5.30	**5.59**	4.36	5.24
SP1 = W	4.00	5.00	5.57	5.68	5.30	**5.62**	4.46	4.98
Average	3.33	5.00	5.54	5.52	5.30	**5.60**	4.41	5.12

Note: W stands for word; D stands for dot. Outputs refer to the modalities of the first three responses, irrespective of whether the response is correct or not

The data shown in Table 3.8B is segregated to show the number of correctly recalled words and dots respectively for both dual-modality groups; this is found in Appendix 3.9. Participants are almost as likely to recall the same amount of words when they alternate as when they output three words consecutively. As regards the number of correctly recalled dots, participants perform best when they recall three consecutive dots (DDD) or two dots followed by a word (DDW). However, these output preferences were very uncommon. Participants are still fairly accurate on the recall of dots when they alternate their outputs.

The effect of PFR = SP1 in the verbal domain on the visuo-spatial domain. Out of the total 1000 trials for each group within Experiment 5, 843 trials in the parallel presentation group and 877 trials in the alternating presentation group were started with a word-dot or dot-word transition. Table 3.9 shows the number of responses where the first word and visuo-spatial dot output, were output consecutively and had identical within-modality serial positions. Overall, it is clear that when participants started with the first item or one of the last four items in one modality, the consecutive cross-modality output often had a matching serial position.

Table 3.9
Experiment 5: The proportion of responses where the first word and first visuo-spatial dot output consecutively had matching within-modality serial position. These were classified into three categories: the probability of starting with the first item, one of the last four items or an error.

		Visuo-Spatial Data			
	PP Group				
		PFR = SP1	PFR = Last 4	PFR = Error	**Total**
Verbal Data	PFR = SP1	**122**	15	150	287
	PFR = Last 4	12	**383**	146	541
	PFR = Error	4	5	6	15
	Total	138	403	302	**843**
	AP Group				
		PFR = SP1	PFR = Last 4	PFR = Error	**Total**
	PFR = SP1	**214**	37	295	546
	PFR = Last 4	18	**150**	124	292
	PFR = Error	11	7	21	39
	Total	243	194	440	**877**

Number of observed chunks. In order to test whether participants were outputting by modality, the number of output chunks were analysed. The average chunk size in the parallel presentation group was of 6.92 chunks whereas in the alternating presentation group the average chunk size was 7.37. Overall, it is clear that participants were not outputting by modality but were more likely to alternate between modalities.

Lag transitions. Appendix 3.10 and Appendix 3.11 summarise the number of correct outputs at all serial positions (*n*) and their respective consequent output item (*n*+1) for both the parallel presentation and alternating presentation groups respectively. As regards the alternating presentation group, these are shown using both within-modality serial position (Appendix 3.10B) to enable comparison with the parallel presentation group and overall serial position (Appendix 3.11). This information was then utilised to calculate lag transitions; the frequency by which a particular lag occurred is summarised in Appendix 3.12 and graphically presented in Figure 3.16. The findings for the parallel presentation group corroborated those previously found in Experiment 4. The most common transition was a WD zero lag transition, whereby participants output a word from serial position *x* followed by a visuo-spatial dot of the same serial position. Although 0 lags outnumbered positive and negative lags, there was still the typical asymmetry, albeit reduced, between positive and negative lags. The frequency of WD and DW transitions is very symmetrical, whereas WW transitions show the typical asymmetry between +1 and -1 lag transitions. Similarly, the alternating presentation group lag transition curve shows that participants tended to output a word of a particular serial position followed by a dot of corresponding within-modality serial position. However, the alternating presentation group curve is less symmetric when using within-modality serial positions and all transitions show the typical asymmetry between positive and negative curves.

As previously mentioned, lag transition data from the alternating presentation group was also calculated using the overall list serial position (i.e. 1 to 12). Given the alternating nature of the stimuli, some lag transitions were not always possible. For example, in a W-D-W-D-W-D-W-D-W-D-W-D sequence it is impossible to have odd (+1, +3, +5 etc.) same-modality lag transitions and even (+2, +4, +6 etc.) cross-modality lag transitions; this also held true when the alternation started with a visuo-spatial dot. Overall, there was an asymmetric lag effect for all four types of transitions and the most common transitions were +1 and -1 lag transitions, implying that participants were very likely to alternate with the cross-modality stimulus having a preceding or consequent serial position. It is also noteworthy that +2 and -2 same-modality lags were more common in the verbal domain than in the visuo-spatial one, and this implies that when participants do not alternate, they are more likely to recall consecutive words than consecutive dots.

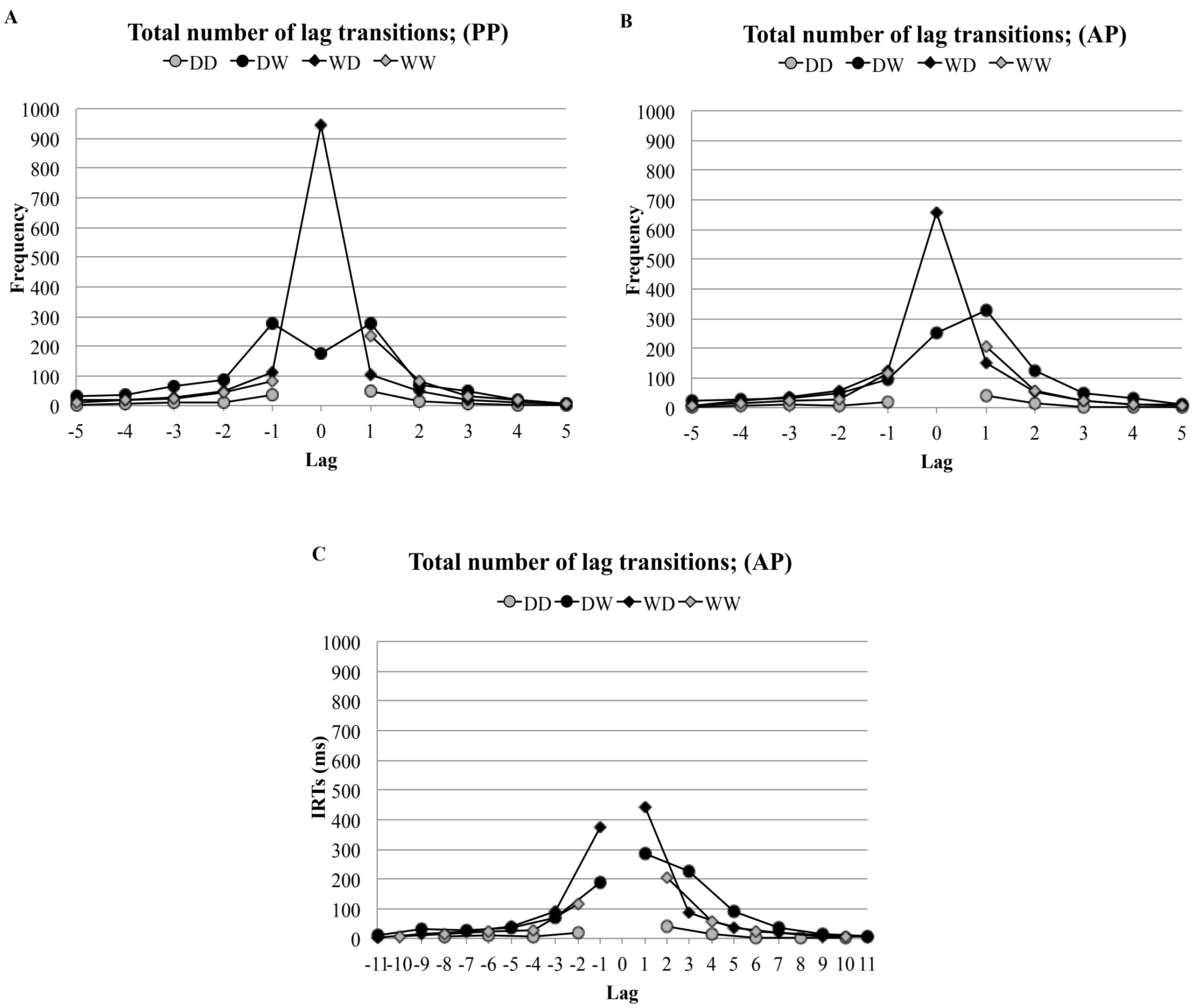

Figure 3.16. Experiment 5: The frequency by which a particular lag transition was made for the parallel presentation (PP - panel A) and alternating presentation (AP - Panels B and C) groups respectively. For the AP group this is represented using the within-modality serial position (panel B) and the overall serial position (panel C). Smaller lags denote transitions between items of close SPs, whereas larger lags denote transitions between items that are further apart in the list.

Inter-response times (IRTs). Figure 3.17 shows the IRTs as a function of the output order of the recalled items, regardless of whether these were correct or not, for the verbal and visuo-spatial domain respectively across all three groups.

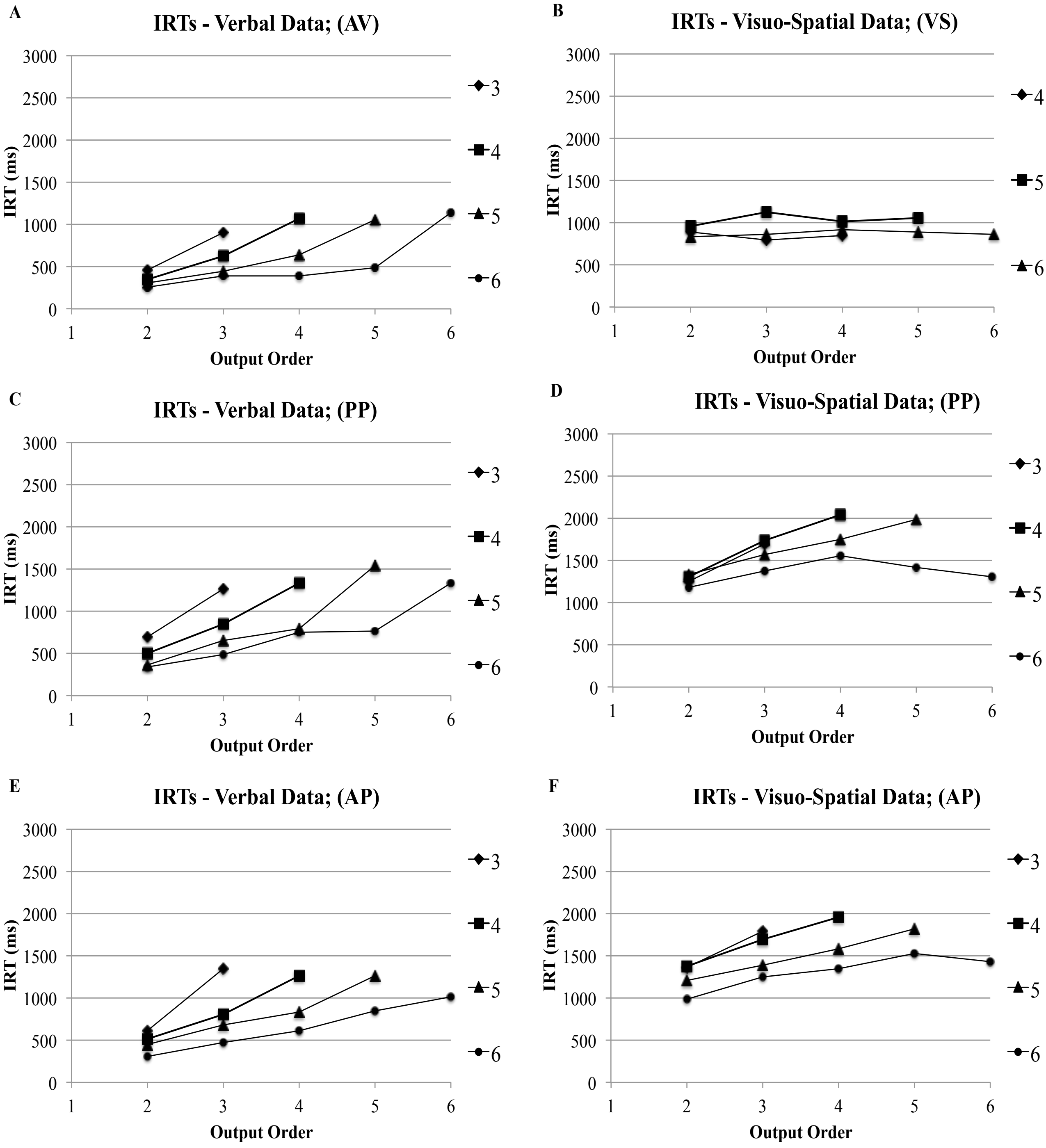

Figure 3.17 Experiment 5: Inter-response times (IRTs) for the verbal (left) and visuo-spatial data (right) collapsed across the three groups, with the parallel presentation (PP) and alternating presentation (AP) groups data segregated by stimulus domain to enable comparison to the respective single-modality group (AV and VS).

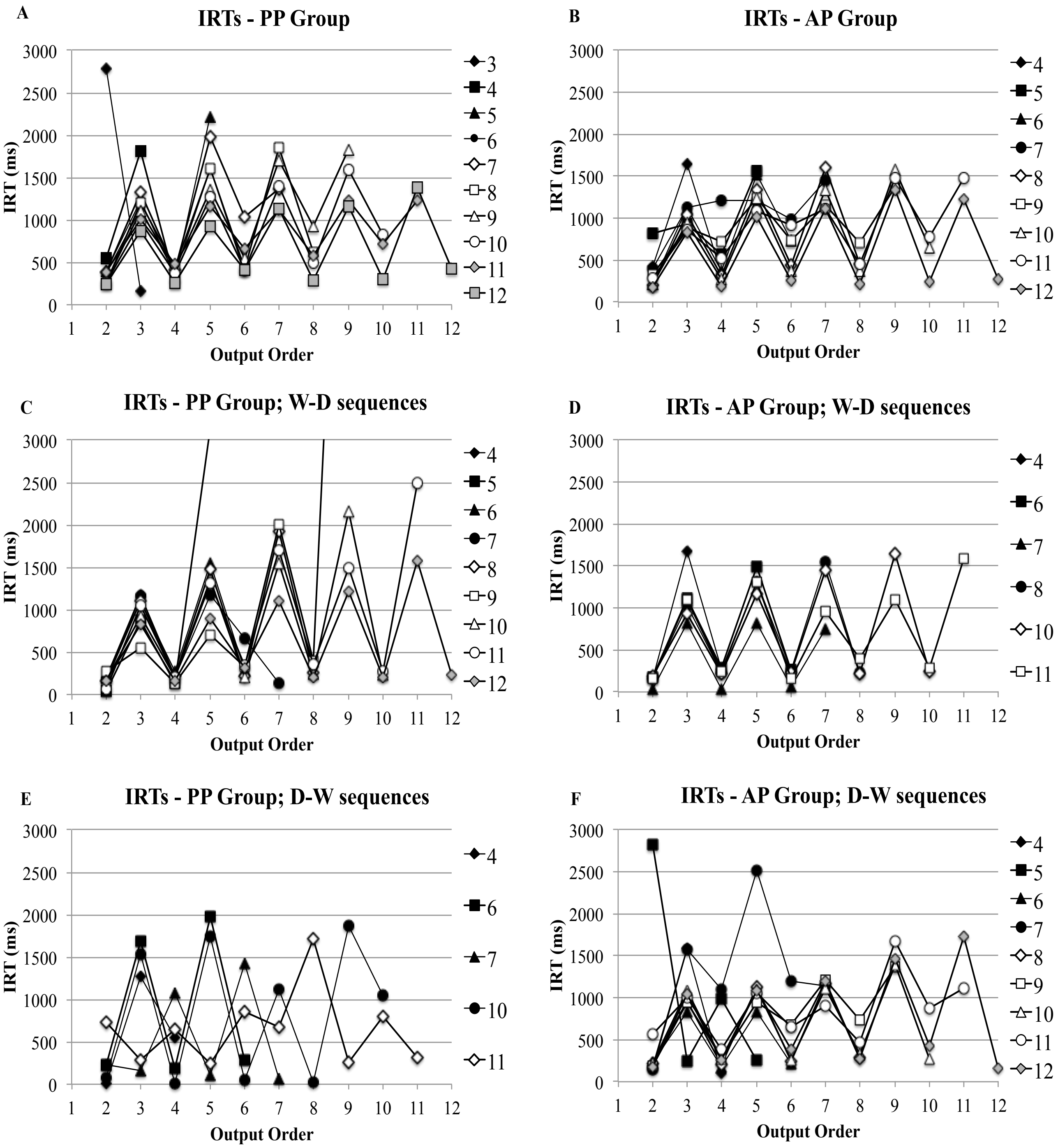

Figure 3.18 Experiment 5: Inter-response times (IRTs) for the dual-modality groups (parallel presentation: PP; alternating presentation: AP). Panels A and B show the time taken to output each item in milliseconds (ms) for each dual-modality group. Panels C and D show the IRTs for those trials where participants consistently recalled in a word-dot sequence for each dual-modality group. Panels E and F show the IRTs for those trials where participants consistently recalled items in a dot-word sequence for each dual-modality group respectively. Note: in Panel C the IRTs for Output Orders 5 and 9 were excluded because they were much higher than average – the exact figures were 3112ms for Output order 5 and 9111ms for output order 9 respectively

Since this experiment was made up of 50 trials of a single list length, per participant, the data is much clearer than that of Experiment 4. Across all three groups, IRTs for the verbal domains show an exponential-like curve whereby IRT increases with increasing outputs. In the visuo-spatial modality, the curves are completely flat in the single-modality group, whereas for the dual-modality group, there is a reduced exponential curve for 3-5 outputs; when participants output 6 items the IRTs decreased for the last few items.

Figure 3.18 shows that similar to the previous experiments, items output in an even output position have a much shorter response time than those in odd output positions resulting in a saw-shaped curve in both groups. This further implies that participants could be associating items of different modalities together, retrieving them concurrently, thus resulting in a longer reaction time for the first item in a pair and outputting them almost simultaneously, with a very small reaction time in between the first and second item output in the pair. Alternatively, participants could be retrieving an item while simultaneously outputting another item of a different modality. Moreover, Figure 3.18 (panels C-F) shows that the method of recall is consistent regardless of whether participants recall the word or the dot first in a pair, although participants usually tend to prefer the former.

Furthermore, Figure 3.19 shows the mean IRT for each of the four possible modality transitions (DD, DW, WD, WW). Consistent with the previous experiment, WD transitions are the fastest, followed by DW transitions. Transitions between same-modality items, take on average approximately 1.2 seconds. A 2 (group: parallel presentation vs alternating presentation) x 4 (transition: DD, DW, WD, WW) mixed ANOVA showed that there was a significant main effect of transition on IRTs, $F(3,114) = 22.6$, $MSE = .456$, $\eta^2_p = .373$, $p < .001$, but a non-significant main effect of group, $F(1,38) = .665$, $MSE = .713$, $\eta^2_p = .017$, $p = .420$, as well as a non-significant interaction, $F(3,114) = .856$, $MSE = .456$, $\eta^2_p = .022$, $p = .466$.

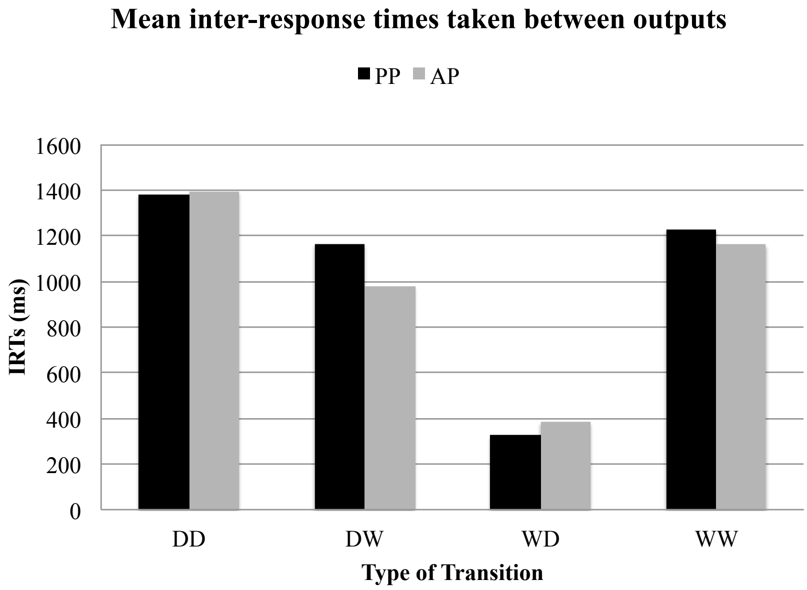

Figure 3.19. Experiment 5. The mean inter-response times taken between outputs for the dual-modality groups (parallel presentation: PP; alternating presentation: AP), for each of the four different transitions, where DD stands for two consecutive dots, DW refers to the time taken to output a word preceded by a dot, WD refers to the time taken to output a dot preceded by a word and WW stands for two consecutive words.

Finally, Figure 3.20 shows the lag-CRL curve whereby the IRTs between successively recalled items are related to their proximity within the list, for each of the four possible transitions. The findings for the parallel presentation group are consistent with the findings from the previous experiment: 0 lags have the shortest IRTs, with IRTs increasing with increasing lag, albeit not to the extent of those found by Murdock and Okada (1970). It is noteworthy that there is hardly any asymmetry between negative and positive lags; this is also seen in the plot for the alternating presentation group. However, +1 and – 1 lags are the shortest, and this directly relates to alternating across-modalities, since lags of +1 or –1 necessarily denoted a cross-modality transition. Overall, cross-modality transitions are shorter than same-modality ones, and transitions between items of close serial positions are quicker than transitions between further apart list items, although this is not as pronounced as in the Murdock and Okada (1970) data.

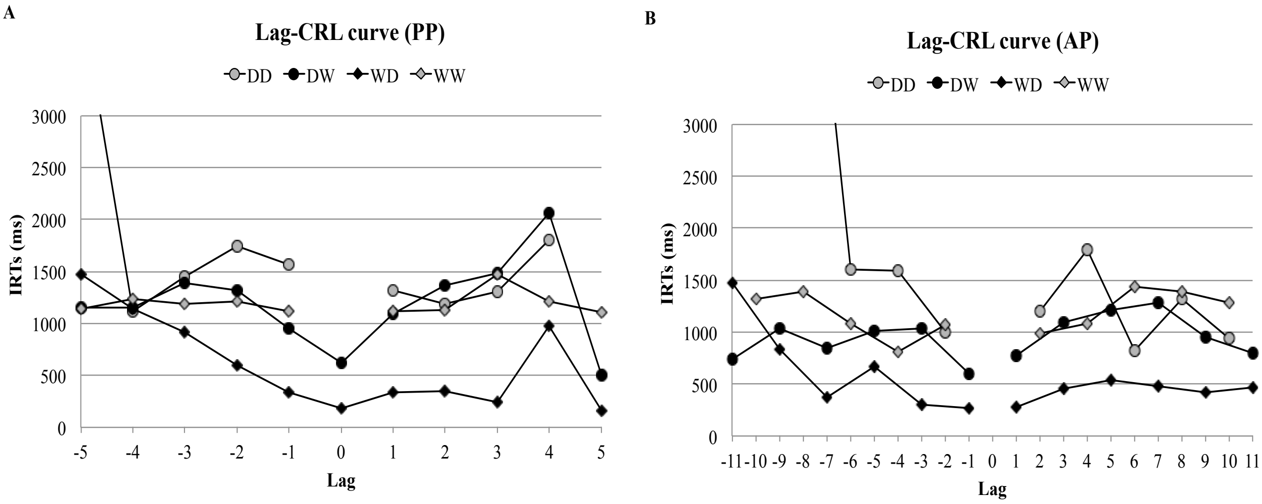

Figure 3.20. Experiment 5. The mean inter-response times taken between outputs with lags of between -6 and +6, for the parallel presentation group (PP) and between -11 and +11 for the alternating presentation (AP) group. This is shown for each of the four different transitions, where DD stands for two consecutive dots, DW refers to the time taken to output a word preceded by a dot, WD refers to the time taken to output a dot preceded by a word and WW stands for two consecutive words. Note: any IRTs above 3000ms were excluded because they were much higher than average. The exact data points in Panel A was of 4120ms for the -5 lag, whereas in panel B the -8 lag had an IRT of 5962ms.

DISCUSSION

The aims of the present experiment were to (1) confirm the findings of Experiment 4 with respect to the concurrent presentation of verbal and non-verbal material, (2) to test whether alternating presentation would have an adverse effect on the domains' capacities and (3) whether the tight constrained output was solely due to the parallel presentation. For this reason, I introduced an alternating method of presentation where the overlap between the two stimuli was completely eliminated. I anticipated that this would not only adversely affect the overall accuracy, but possibly affect the recall pattern as well as the inter-response reaction time data.

As in Experiment 4, the present experiment compared verbal and non-verbal performance in the dual-modality groups (i.e. parallel presentation and alternating presentation groups) with the performance of the auditory-verbal and visuo-spatial group respectively. Consistent with the previous experiment, there was a non-significant decrease in accuracy in the verbal and visuo-spatial data in the parallel presentation group relative to the respective single-modality groups. In the alternating presentation however, there was a significant decrease in the visuo-spatial performance while the verbal performance remained relatively unaffected.

Overall, the serial position curves showed both primacy and recency. There were some subtle differences in the performance of the alternating presentation group, whereby there was a slight reduction in the recency when compared to the parallel presentation group and the single-modality tasks. These findings are consistent with those found by Morey and Mall (2012) in the serial RoO tasks of interleaved verbal and visuo-spatial stimuli.

The probability of first recall curves also showed that in a six item list, there was a tendency to either start with the item in serial position 1 or with one of the last four presented items. More specifically, there were no significant differences between groups on starting with the first presented item. However, there was a significant difference between the parallel presentation group and the alternating presentation group as regards the tendency to initiate recall with one of the last four items in the visuo-spatial modality; there were no differences in the verbal modality. Additionally, the serial position curves and the probability of first recall curves for the alternating presentation remained consistent when separating those trials starting with a word from those starting with a dot.

The resultant serial position curves conditioned by those trials starting with serial position 1 for both FR and SR scoring, showed that when the first output item is the first presented item, there is increased primacy and decreased recency. On those trials where recall is started with one of the last four items, there is decreased primacy and increased recency. Overall, when separating performance by modality, there was a non-significant effect of group in the verbal modality, however in the non-verbal modality, there was a difference in the resultant serial position curves for those trials initiating recall with the first item using FR scoring between the visuo-spatial group and the parallel presentation group, as well as a difference between the alternating presentation group and visuo-spatial group in those trials were recall was initiated with one of the last four presented items.

Critically, in IFR dual-modality tasks participants tended to prefer to start with a word rather than a dot; however, this tendency was somewhat reduced in the alternating presentation group. When analysing the first three outputs and lag transitions, it is clear that participants in the parallel presentation group tend to recall a word followed by a dot of the same serial position and that -1 DW transition lags were as common as +1 ones. Conversely, in the alternating presentation group, there was the typical asymmetry in transition lags, whereby positive lags were more common than negative ones. Given the nature of the lists in the alternating condition, certain lags for across- or same-modality transitions were not possible, for example it was impossible to have +1 WW or DD transitions. Therefore, it may be possible that the WD and DW transition reflects participants tendency to recall temporally contiguous items. It is clear from both groups that the WD strategy not only is the most efficient transition in terms of the time it takes to output, but also a very effective strategy in terms of the number of correctly recalled items.

Finally, and also consistent with the previous experiment, inter-response reaction time data showed that in both dual-modality groups, the even outputs had a much quicker inter-response reaction time than those output in odd ones. Segmenting the reaction time data into those trials were participants were consistently alternating between either a word and a dot, or a dot and a word, showed that even though on the majority of trials participants tend to prefer the former strategy, the saw-tooth curve of the data shows that a slower reaction time is not necessarily inherent to outputting words while a quicker reaction time is associated with outputting dots. This is because even in the case where the dot preceded the word, there was a longer reaction time before the dot and a shorter reaction time before the word. Thus, it is likely that the saw-tooth curve is either the result of either retrieving an associated pair and then outputting the first item of that pair followed by an almost instant output of the item following it or simply that participants prepare to physically output an item while simultaneously outputting an item.

Overall, it can be concluded that when participants are presented with an IFR task comprising of both verbal and visuo-spatial stimuli, they will choose to recall in an alternating manner rather than by modality, regardless of whether the modalities where presented concurrently or sequentially. Finally, whereas each modality's performance was similar to the single-modality groups in the parallel presentation group, there was a slight decline in the visuo-spatial performance of the alternating presentation group as well as some shifts in recency. This asymmetry will be discussed in the subsequent section.

GENERAL DISCUSSION

Overall, there are a number of conclusions that can be drawn from the previously presented experiments. First, both experiments confirm the findings in Chapter 2. When participants are presented with a non-verbal IFR task comprising of sequences of visuo-spatial circles presented in random locations on-screen, they show similar list length and output order effects to those found with verbal material (Ward *et al*., 2010). More specifically, at shorter list lengths, participants tend to start recall with the first presented item, resulting in primacy effects, whereas at longer list lengths, participants tend to start recall with one of the last four items, thus resulting in extended recency effects. Middle-length lists such as the one utilised in Experiment 5 (LL6) tend to show both primacy and recency, as participants tend to use both strategies at this length. Additionally, in both stimulus domains there is a consistent forward order tendency.

The fact that there are similar output order and list length effects in both verbal and non-verbal material suggests that the Ward *et al*. (2010) findings are not a result of a language-specific mechanism but it could be due to either a general mechanism that operates on all stimuli types at all timescales (e.g. Jones, *et al*., 1996, 2006, 2007; Cowan, 1988, 1995, 2005) or that there could be two separate mechanisms, one for verbal and one for visuo-spatial stimuli (Baddeley and Hitch, 1974, 1986, 2007, 2012), that operate in very similar ways. The dual-modality tasks were utilised to help ascertain which one of the two possibilities best accounts for data where both verbal and visuo-spatial modalities are presented and recalled.

THE DUAL-TASK FINDINGS WITHIN DOMAIN-SPECIFIC MODELS

In a domain-specific framework such as the multicomponent WM model of Baddeley (1986, 2007, 2012), when participants are presented with and required to maintain both verbal and visuo-spatial material, it is expected that each modality is stored separately in its respective store. Therefore the assumption can be made that there should be separate and independent capacities for each modality that hold irrespective of whether the other modality store is concurrently being used or not. When presenting participants with concurrent verbal and visuo-spatial stimuli, they were able to recall both modalities to the same degree as other participants who were presented with and had to recall one modality only; this is therefore parsimonious with domain-specific frameworks. However, when presenting both stimuli in a staggered and alternating manner, there was an asymmetric cross-domain interference as found by Depoorter and Vandierendonck (2009) and Morey and Mall (2012), since there was a significant decrease in the accuracy of the visuo-spatial stimuli but not in the verbal accuracy. These findings are therefore problematic for domain-specific models.

The updated versions of the multicomponent model (Baddeley, 2007) have included the episodic buffer which is a domain-general mechanism intended to link information from various stimulus domains. It is possible that, in the case of concurrent presentation, this domain-general mechanism enables the two stimulus domains to be linked to one another and retrieved together as a pair. However, there is no reason why there should be an asymmetry between the recall accuracy of verbal and visuo-spatial material, when they are presented sequentially since they are equally supported by the episodic buffer. Consequently, this asymmetry between the two domains can be explained only if one were to show that the domain-specific stores do not benefit equally from the episodic buffer (Morey & Mall, 2012).

Another potential problem for domain-specific models, is the constrained cross-modal output order, whereby the recall of a specific item was followed by a cross-modality item of the same (in the parallel presentation group) or consequent serial position (in the alternating presentation group). When items are stored independently into separate stores, it would be potentially more efficient to first output one store completely, followed by the output of the other store. Neither Experiment 4 nor Experiment 5, have shown channel-by-channel output. Additionally, the majority of transitions were between temporally contiguous items. As outlined in the first Chapter, one of the major shortcomings of the WM model is that it does not explain how serial order is maintained within the stores, and therefore it is not clear what the WM predictions are in the case of mixed-modality lists.

THE DUAL-TASK FINDINGS WITHIN DOMAIN-GENERAL MODELS

In domain-general frameworks, memory is conceived as an amodal unitary system (e.g. Cowan, 1995; 2005; Jones *et al*. 1996) and therefore it would be expected to have a central capacity for all stimulus types that can be recalled in a constrained manner. In the present findings the capacities seem independent when two different modality stimuli were presented concurrently. However, when the stimuli were presented in an alternating manner, there was a small decrease in visuo-spatial performance, but the verbal performance remained consistent. Within the embedded-processes model (Cowan, 1998, 1995, 2005), it is possible that when stimuli are presented concurrently, they are highly associated with one another and this leads to higher activation, bringing both items to be equally within the focus of attention, and thus resulting in equivalent individual recall accuracy to a single-modality task. The asymmetry in the alternating presentation group can therefore be explained if one assumes that auditory-verbal information has a longer or stronger activation levels than visuo-spatial information (Morey & Mall, 2012) and therefore when these are presented one at a time with no overlap between them, words are more likely to remain within the focus of attention than visuo-spatial dots.

Alternatively, it is possible that since participants are more finely tuned to give consistent attention to language in day-to-day tasks, they are more likely to attend to the verbal than the visuo-spatial material (Logie, Cocchini, Della Sala, & Baddeley, 2004). Perhaps when the two domains overlap, the visuo-spatial material needs to be attended to the same degree as the verbal material since they are presented concurrently. However, when they are presented in an alternating manner, participants naturally attend more to the verbal material than the visuo-spatial stimuli and this results in the asymmetry in the recall performance. Similarly, the perceptual-gestural account (Hughes *et al*., 2009; Jones *et al*., 2006; 2007) can also account for these findings by assuming that speech-based motor processes are more readily accessible since they are more commonly used and therefore more refined than the movement motor processes required to locate items within a very limited space (Morey & Mall, 2012). Additionally, visuo-spatial dots are less distinguishable between each other when compared to auditory-words and perhaps this requires a more elaborate motor plan for the visuo-spatial stimuli than is required for the verbal material. Since motor plans are time critical and movement processes are not as practiced as speech motor processes, this leads to poorer performance in the visuo-spatial domain.

Overall, the present findings are somewhat similar to those by Morey and Mall (2012) and thus do not fully subscribe to either a domain-specific or a domain-general view. However, the present result patterns do seem to fit better within a domain-general approach that at the very least controls serial order. Morey and Mall (2012) and Morey *et al*., (2013) suggest integrating models that focus on domain specificity with those that postulate domain-general processes but state that further empirical work is required for this to be properly established. An important difference between the present experiments and the ones by Morey and Mall (2012) is that in these experiments participants were required to both maintain and recall both types of stimulus. The fact that there is not a very large adverse effect on accuracy when required to recall two modalities as opposed to one implies that immediate memory for the two stimulus domains are separate with little interference between the two. However, it is much harder to explain why recall order is so tightly yoked between modalities and why the preferred output is alternating.

Perhaps, the most elegant answer lies in the fact that participants tend to output in a forwards-order, especially with short-to-medium length lists. The alternation in the parallel presentation is due to participants perceiving the concurrently presented word and dot as one to-be-remembered item and therefore as they tend to output in a forward-ordered manner, they automatically output the two closely together. This tendency is reflected in the alternating presentation, where participants are required to alternate between modalities if they are to recall in a forward-order since this was the inherent structure of the presented list.

What remains unclear is, why do participants prefer to output in a word-dot sequence even when the reverse type of sequence is presented? It is possible that participants are linking the concurrently or sequentially presented auditory-words and visuo-spatial dots together and retrieving them in pairs. This is arguably harder to do in the alternating presentation relative to the parallel presentation, since in the former condition, stimuli did not overlap and thus any binding here would have required post-item processing, by for example, placing a word in a spatial location. In an attempt to answer this question, the last two experiments will present both stimulus domains in a completely randomised serial order, to remove any inherent list structure and further avoid the possibility of binding.

SUMMARY AND CONCLUSIONS

Chapter 3 firstly replicates the list length and output order effects found in Chapter 2.

Secondly, it shows interesting and innovative findings as regards the IFR of concurrently and sequentially presented auditory-words and visuo-spatial dots. Overall, there were relatively independent capacities and constrained recall order and this does not fully subscribe to either a domain-general or a domain-specific theory of immediate memory. However, the present data seem to be more elegantly explained within a domain-general mechanism, which is at least responsible for maintaining serial order. This is because the preferred method of output is to transition between words and dots, with the same or proximate serial positions. This strategy of alternating outputs could be either due to the linking or binding together of two cross-domain items that are then retrieved in pairs even in the alternating condition via post-item processing, or it could simply be the most time-efficient and effective way of recalling mixed-modality lists.

CHAPTER 4

CHAPTER 4

The present Chapter sought to further examine whether the tendency to alternate outputs between the verbal and visuo-spatial stimulus domains would still be present when participants are presented with and instructed to recall, in any order that they liked, mixed-modality lists made up of six auditory-words and six visuo-spatial dots presented in a completely randomised serial order. Chapter 3 offered two possible explanations as to why participants choose to alternate between modalities.

A first possible line of argument is that this tendency to alternate is the result of the innate tendency to recall in a forward ordered manner. If participants have an inherent tendency to recall in forwards order, then as in Chapter 3, when they were presented with two concurrently presented cross-modality stimuli; they would have had to recall the cross-modality items of the same serial position very close together. Additionally, when the auditory-words were interleaved with visuo-spatial dots and vice versa, the inherent structure of the list could have reinforced the tendency to alternate between modalities, although it is unclear why the first item recalled was more likely to be a word rather than a dot, even when the first presented item was indeed a visuo-spatial dot. For this reason, in the following experiments, list structure was completely randomised by presenting auditory-words and visuo-spatial dots in a completely randomised order.

A second possibility is that during list presentation, participants were actively linking or associating a visuo-spatial location with an auditory-word and vice versa. Although this would be relatively easy to do when the two domains were presented concurrently, because it could encourage participants to perceive the two stimuli as a singular multi-modality stimulus, staggering the stimuli's presentation such that they do not overlap could arguably make this harder to achieve. It is still possible however, that knowing the alternating structure of the list could enable post-item processing, such that participants could still associate the two cross-modality items together, by for instance "placing" an auditory-word into a subsequent or preceding visuo-spatial location. Consequently, using randomly structured mixed-modality lists comprising of verbal and visuo-spatial stimuli, should disallow such post-item association, especially in situations where cross-modality items are a number of items apart. Therefore, finding alternating cross-modality item outputs in the IFR of mixed-modality lists, can potentially explain whether the findings in Chapter 3 are the result of some form of binding or whether this is the more spontaneous way of outputting mixed-modality lists.

The Findings from Mixed-Modality Lists

In both the verbal IFR and ISR literature, there have been numerous investigations utilising mixed lists comprising of words from different languages (Lambert, Ignatow, & Krauthamer, 1968; Liepmann & Saegert, 1974; Rose & Carroll, 1974) as well as different types of words such as high-frequency and low-frequency words (Gregg, Montgomery, & Castaño, 1980; Miller & Roodenrys, 2012; Saint-Aubin & LeBlanc, 2005; Watkins, LeCompte, & Kyungmi, 2000), phonologically similar and dissimilar items (Farrell, 2006; Farrell & Lewandowsky, 2003), auditory and visual words (Greene, 1989; Murdock & Walker, 1969; Nilsson, Ohlsson, & Rönnberg, 1977) as well as words in different voices (Hughes *et al*., 2009).

The Modality Effect Across Domains

There are limited studies utilising mixed-lists made up of two stimulus domains in IFR and therefore, I will start by discussing the findings from studies presenting participants with mixed-lists of auditory and visually presented words, since these can be potentially relevant to the presentation of auditory-words and visuo-spatial dots mixed-modality lists. As previously mentioned in Chapter 1, when comparing the immediate recall of visual and auditory-words, there is an advantage for the recall of the last few list items for the auditory presentation of words compared to visual presentation. This is a well-replicated finding in the verbal immediate recall literature and is termed the modality effect (Corballis, 1966; Crowder & Morton, 1969).

This modality effect finding has also been found in the non-verbal domain, where it was found for musical stimuli (Greene & Samuel, 1986), environmental sounds (Rowe & Rowe, 1976) and spatial stimuli (Tremblay *et al*., 2006). Tremblay *et al*. (2006) presented participants with a serial reconstruction of order task, where the stimuli were either spatial sounds emitted from different hidden speakers, or visuo-spatial locations presented using light-emitting diodes. They found that there was more recency for the auditory stimuli compared to the visuo-spatial stimuli, i.e., the modality effect, which was of a similar magnitude to the one found within the verbal domain.

MIXED-MODALITY LISTS: AUDITORY AND VISUAL WORDS

Given that the modality effect can be found using both verbal and non-verbal stimuli, the literature on the immediate recall of mixed-modality lists can potentially be useful for the present chapter including mixed lists of auditory-verbal and visuo-spatial material. Murdock and Walker (1969) were the first researchers to present participants with lists incorporating both auditory and visual items and compared their performance to that of single-modality (either visual and auditory) lists. The mixed-modality lists were made up of ten auditory-words and ten visual words and the order in which the cross-modality items were one of the five possibilities: 10-10, 2-8-10, 5-5-5-5 (Experiment 2), or random (Experiment 2 and 3). In the random condition, there were two sets of lists, whereby a randomised list in one set had its inverse in the other set.

Across three experiments using IFR, Murdock and Walker delineate three main findings. First, they found the typical modality effect, whereby auditory-words were better recalled than visual ones and that this advantage was seen in the recency portion of the serial position curve.

Second, in mixed-modality lists the advantage for auditory items was present yet consistent over all serial positions. Third, and similar to the split-span findings (Broadbent, 1956, 1957a; Dornbush, 1968) discussed in Chapter 3, participants organized their order of recall by mode of presentation, since the average number of cross-modality switches never exceeded two, even when it was possible for participants to make five switches. These findings have been successfully replicated numerous times (Murdock & Carey, 1972; Nilsson *et al*., 1977), both in IFR and ISR (Greene, 1989).

Greene (1989) also controlled for the structure of the mixed-modality lists, and asked participants to recall auditory and visual words in the same order as presented (ISR). Similar to the abovementioned studies in IFR, he found that the recall advantage for auditory items in mixed-modality lists was not found solely for the last few list items but across all serial positions. Furthermore, he found that this advantage for auditory items was also present when the items were acoustically similar or identical and were unaffected by auditory suffixes in the middle of the list. Greene (1989) suggests that auditory items are recalled better since these have two dimensions that make them highly accessible: one that relates to the item's identity and the other that relates to acoustic properties, such as whether the voice was that of a male or female, or loud or quiet.

On the other hand, visual items are recalled less well in mixed-modality lists when compared to single-modality ones. According to Greene (1989) this inhibition of visual items in mixed-modality lists may be a result of 'retrieval competition', whereby the retrieval of visual items is disrupted by the much more highly accessible auditory items. Indeed, it has been shown that whereas visual representations and images decay after about one second (Averbach & Coriell, 1961), auditory and phonological representations remain intact for about three seconds (Darwin, Turvey, & Crowder, 1972). This is also congruent with the modality effect found in the recall of advantage of auditory-spatial versus visuo-spatial materials, whereby the last few auditory-spatial stimuli on the list benefit from the prolonged trace that is not available in the visuo-spatial domain.

THE CURRENT EXPERIMENTS

There were three specific aims of Experiment 6 and 7, which were related to output order, capacity and the role of encoding and retrieval in dual-modality tasks. These aims will help the thesis achieve its broader aim, to inform the debate of whether there are domain-general or domain-specific memory retrieval mechanisms as regards different stimulus domains.

The first aim of the current experiments was to examine whether the tendency to alternate between verbal and visuo-spatial material (as found in Chapter 3) when presenting participants with both stimulus domains either concurrently or in alternation, would still be found when utilising completely randomised lists. As previously discussed, in randomised lists of auditory and visual verbal lists, participants tend to organize their outputs via modality. However, Experiments 4 and 5 have already shown, somewhat surprisingly, that participants do not output by modality, when the cross-modality stimuli are presented simultaneously or in alternation.

One possible explanation for this could be that these cross-domain stimuli were being associated to one another, potentially resulting in a visuo-spatial dot and an auditory-word being encoded and retrieved as a pair. Although this is a possibility, it is certainly more difficult to do so in alternating lists, where the stimuli do not overlap. However, completely randomising the order in which six auditory-words and six visuo-spatial items are presented within the list will decrease the opportunity for cross-modal associations that were possible in the previous experiments. A second possible line of argument could be that the tendency to output two modalities in alternation is a by-product of the participants' tendency to recall in a forward ordered manner. Chapter 2 has shown that participants prefer to output in an "ISR-like" manner, even when this is not a task requirement. When the to-be-recalled list consists of two cross-modality items that are presented simultaneously and thus share the same serial position, in order to recall in forwards order, participants are required to output the items of the same serial position together. When the lists consist of alternating visuo-spatial dots and auditory-words, participants necessarily have to alternate to recall in forwards order due to the inherent list structure.

The second aim of the current experiments was to examine verbal and visuo-spatial capacities, when the respective stimuli are randomly presented within the same list, and to then compare these to the performance of the respective single-modality task. Whereas parallel presentation resulted in slight yet non-significant decrease for both the words and visuo-spatial dots, alternating presentation resulted in a marked significant decrease for the visuo-spatial domain, while the verbal domain remained relatively unaffected. If participants were indeed encoding and retrieving a word and a visuo-spatial dot as a pair, then preventing this through list randomisation could potentially have a much more adverse effect on the visuo-spatial domain.

The third aim of the current chapter was to help delineate the role of encoding and retrieval in the IFR performance of mixed-modality lists. Greene (1969) suggests that in mixed-modality lists, visual words are inhibited because of the higher accessibility of auditory stimuli, which therefore results in a lower performance for the visual stimuli. In this chapter I examine the possible reasons why there is a decrement in the performance, particularly in the visuo-spatial domain, in dual-modality tasks as compared to single-modality ones. Three main reasons for this are considered: perhaps participants' recall performance decreases in the dual-tasks because they (1) have twice as many items to encode, (2) have twice as many items to output and this leads to heightened output interference, whereby the recall of words interferes with that for visuo-spatial items or (3) participants do not attempt to output as many items due to response bias.

Overall, these three aims help to achieve the general aim of the thesis, that is, to delineate whether the similar list length and output order effects for the verbal and visuo-spatial domain found in Ward *et al*. (2010) and Chapter 2 are a result of two domain-specific mechanisms that operate in similar ways (e.g. Working Memory model) or whether they are a result of a domain-general mechanisms that operate on all stimuli at all timescales (e.g. Embedded-Processes model, O-OER, Perceptual-Gestural account).

I will now re-use the analogy of the recording devices used in Chapter 3, to explain the implications of the possible findings from Experiment 6 and 7. If the domain–specific stores are akin to a silent video-camera to track visuo-spatial items and an audio-reel tape recorder to capture the auditory material, then in a randomised mixed-modality list, the more efficient way of retrieval would be to output one device followed by the other, especially when there is no structure that could lend itself to systematic output (i.e. output one item from each store). Even if the stores are capable of switching output systematically, since they are completely independent, it is possible for one store to output from one temporal context (e.g. start of list) while the other outputs from another one (e.g. end of list). In the data this would be reflected in unconstrained orders and large transition lags. Furthermore, in this scenario, there is no reason why the output of one should interfere with that of the cross-modality leading to the asymmetry found in the previous Chapter.

Alternatively, the domain-general mechanism can be likened to a multimedia modern-day video camera that is able to start recall from any temporal context and moves in a forward order. In the previous experiments, it was hard to identify which analogy works best, due to the possibility that the alternating output could be the result of an inherent tendency to recall in a forward ordered manner. Consequently, if participants recall randomised mixed-modality lists, in a forward ordered manner, then a domain-general framework is better placed to explain the findings.

The findings as to whether the decrease in recall performance in accuracy is due to encoding demands or output interference will also help inform the domain-specific versus domain-general approach. In the case of a domain-specific approach, at encoding, items within each modality are placed and maintained in their respective domain-specific store. If at test, participants are instructed to recall one modality only, then only one store needs to be outputted; this should therefore result in comparable performance to single-modality tasks. As regards a domain-general approach, items are recorded in the order they are presented in, and at test the “video camera” would need to "rewind" to the beginning of the trial and replay events. When only one modality is required, additional processing is required to inhibit those items that do not need to be outputted and this may lead to a decrement in performance.

EXPERIMENT 6

This experiment compared the IFR of verbal and non-verbal material when these were presented individually (i.e. single-modality lists) to the IFR of mixed-modality lists. All participants were presented with 50 lists, made up of either six auditory-words, six visuo-spatial dot sequences, or twelve randomly presented auditory-words and visuo-spatial locations (six items per modality). Similar to Experiment 5, there was no overlap in the presentation of the stimuli. There were three participants group, the auditory-verbal group, the visuo-spatial group and the randomised presentation group.

The main aim of the present experiment was to test whether participants would still prefer to output the IFR of dual-modality lists in an alternating manner as previously found in Chapter 3, when the order of the twelve list items is completely randomised and therefore does not have any inherent structure. If the tendency to alternate in the previous experiment was simply due to the list structure at presentation, then there should be a reduced number of alternations in this experiment. Alternatively, the lack of inherent structure may also result in a channel-by-channel output similar to that found in the FR of mixed-lists consisting auditory and visual words (Murdock &Walker, 1969).

Since there was a small yet significant decrease in the FR accuracy of the visuo-spatial dot locations in the alternating presentation group of Experiment 5, I expected to also find a significant decrease in accuracy for the visuo-spatial performance of the randomised presentation group. By contrast, the FR accuracy for the verbal domain was expected to have a slight yet non-significant decrease, if at all, in the dual-modality task.

METHOD

Participants. A total number of 60 students from the University of Essex participated in exchange for either course credit or a small payment.

Materials. Materials were the same as that of Experiment 5.

Design. The experiment used a mixed factorial design. The between-subjects independent variable was the performance of free recall when using verbal stimuli, visuo-spatial stimuli and both stimuli such that there was an auditory-verbal stimuli group, a visuo-spatial stimuli group, and a randomised presentation group. Overall, there was one within-subjects independent variable: serial position with six levels for the auditory-verbal and visuo-spatial group and twelve levels in the randomised presentation group. For the randomised presentation group another dependent variable was used: whether the first item presented was a word or a dot.

The dependent variables were the proportion of items correctly recalled, the proportion of items recalled in the same order as presented, the probability of initiating recall with the first or with one of the last four stimuli and inter-response times. For the dual-modality group, there were additional dependent variables: the proportion of trials where recall was initiated with a word, the proportion of outputs where participants switched from one modality to the other, and the inter-response times between outputs.

Procedure. Each participant was randomly allocated into one of the three groups: the auditory-verbal stimuli group, the visuo-spatial stimuli group and the randomised presentation group such that each group was made up of 20 participants. Each participant was tested individually and given group-specific instructions. All participants were informed that they would be shown two practice lists of six stimuli (six words and six dots in the randomised presentation group), followed by 50 experimental lists of stimuli separated into two blocks. As in Experiment 5, I wanted to ensure that all sequences in the experiment were of the same temporal length. Therefore, for all participants, each trial was made up of twelve randomly assigned auditory-words and visuo-spatial dot locations (six per modality), which were presented for 0.60s. In the case of the single-modality groups (auditory-verbal and visuo-spatial groups), participants were presented with only the group-specific stimuli according to the modality they were assigned to (auditory-words for auditory-verbal group and visuo-spatial dots for the visuo-spatial group), with the other modality stimuli, (i.e. not presented stimuli) acting as inter-stimulus intervals. For the randomised presentation group, all twelve stimuli were presented one at a time for 0.60s, with no inter-stimulus interval. Each trial started with a precue instruction to enable the participants to initiate the stimuli presentation whenever they were ready to do so. Following a computer mouse click, participants saw a sequence of six stimuli presented one at a time in the single-modality groups, or twelve stimuli for the randomised presentation group, where the serial order in which the six words and six dots were presented was randomised. The procedure for the auditory-verbal and visuo-spatial groups is identical to that of Experiments 4 and 5. Similar to participants in the dual-modality groups of Experiment 4 and 5, participants in the randomised presentation condition, were instructed to recall as many items as they could by saying the words out loud, and clicking on the screen to indicate the spatial locations of the dots, in any preferred order. In all groups, participants pressed the “submit” button once they were confident that they have submitted all the responses they could recall and this initiated the next trial.

RESULTS

Capacity and Replication

Overall Accuracy. To analyse overall accuracy, a between-subjects ANOVA with group as a factor (with 4 levels: auditory-verbal, visuo-spatial and randomised presentation) was conducted and revealed that there was a significant main effect of group on overall accuracy, $F(2,57) = 95.0$, $MSE = .005$, $\eta^2_p = .769$, $p < .001$. Bonferroni post-hoc tests showed that there were significant differences between all three groups (all *p*s < .001).To enable within-modality comparison, the performance for the randomised presentation group was segmented into verbal and visuo-spatial performance and each of these were compared to the performance of the relevant single-modality group. Figure 4.1 shows the mean proportion of words (panel A) and visuo-spatial dots (panel B) correctly recalled for the single-modality groups and the respective modality of the dual-modality group.

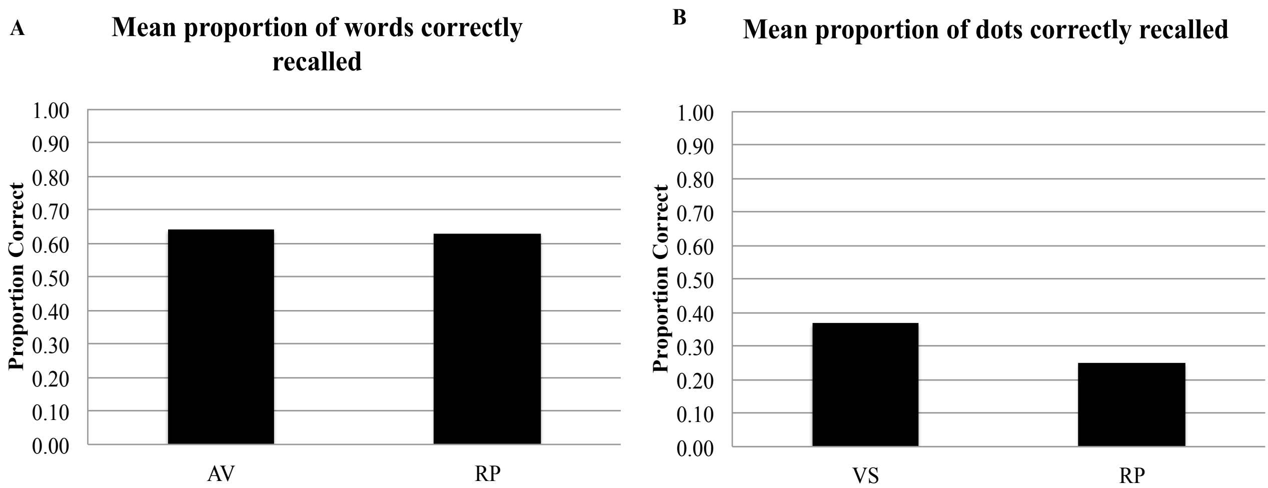

Figure 4.1. Experiment 6: Mean proportion of words recalled in the auditory-verbal (AV) and randomised presentation (RP) groups (panel A) and the mean proportion of dot locations recalled in the visuo-spatial (VS) and randomised presentation (RP) group (panel B).

Two between-subjects ANOVAs (group: single-vs dual-modality) showed that there was a non-significant main effect of group on verbal accuracy between the two groups $F(1,38) = .087$, $MSE = .008$, $\eta^2_p = .002$, $p = .769$, but there was a significant main effect of group on visuo-spatial performance $F(1,38) = 12.3$, $MSE = .004$, $\eta^2_p = .244$, $p = .001$. These therefore show that when participants are required to remember both modalities, visuo-spatial performance is more adversely affected then the words; whereas verbal performance dropped from .64 to .63 (see Figure 4.1 Panel A), visuo-spatial performance dropped from .32 to .25 (see Figure 4.1 Panel B).

The number of outputted dot locations across groups. Figure 4.2 shows the number of total outputs as a proportion of total possible outputs (6000) and the total number of correct outputs as a proportion of actual outputs made by the visuo-spatial and randomised presentation group respectively. An independent samples *t*-test revealed a significant main effect of group on the proportion of total outputs made out of a possible 6,000, $t(1,38) = 5.11$, $p < .001$, $d = 1.62$. The overall accuracy was recalculated as a proportion of total number of outputs made; whereas in the visuo-spatial group participants correctly recalled 33.7% of all outputs, the randomised presentation group correctly recalled 30.6% of all outputs. An independent samples *t*-test conducted on the number of correctly recalled items as a proportion of total outputs showed that there was a non-significant differences between groups, $t(38) = 1.52$, $p = .136$, $d = .482$.

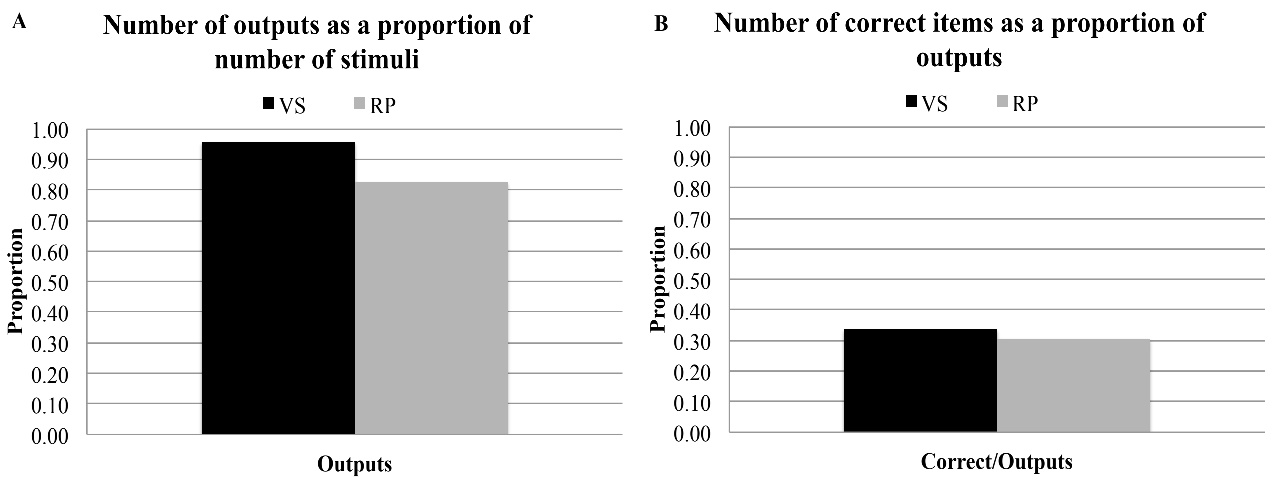

Figure 4.2. Experiment 6: The total number of outputted dots as a proportion of all possible outputs (panel A) and the total number of correct responses as a proportion of actual outputs (panel B) for the visuo-spatial (VS) and randomised presentation (RP) groups.

Serial Position Curves (SPCs). Figure 4.3 shows the SPCs for each of the three groups for the verbal and visuo-spatial domain, whereas Table 4.1 shows two 2 (group: single- vs dual-modality) x 6 (serial position) mixed ANOVAs conducted on the verbal and visuo-spatial data respectively. For the verbal data there was a non-significant main effect of group, a significant main effect of serial position and a non-significant interaction.

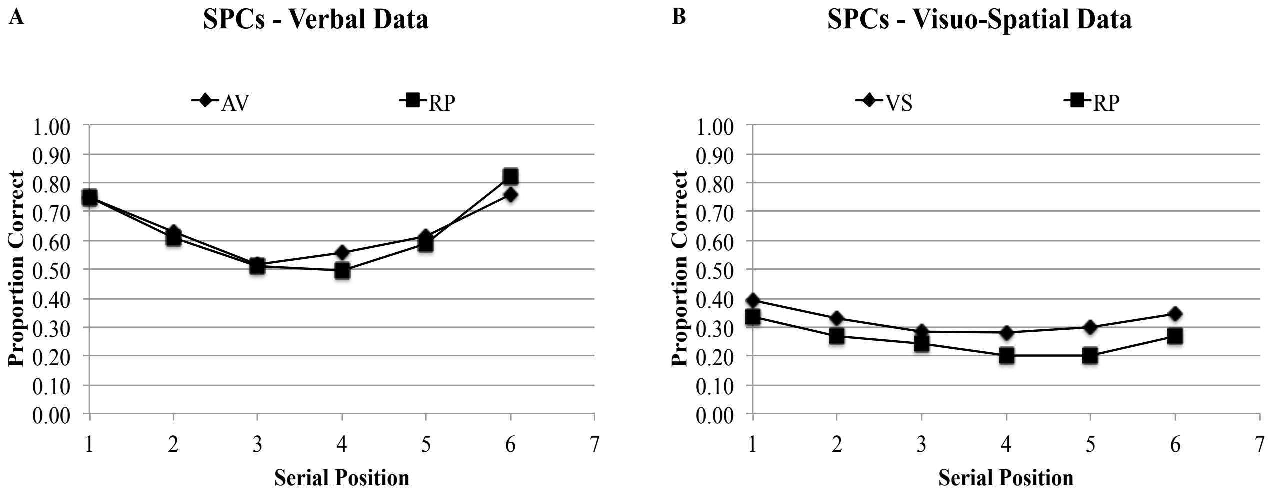

Figure 4.3. Experiment 6: SPCs for the verbal data, taken from the auditory-verbal (AV) and randomised presentation (RP) groups (panel A) and visuo-spatial data from the visuo-spatial (VS) and randomised presentation (RP) groups (panel B).

The statistics conducted upon the visuo-spatial data showed that there was a significant main effect of group, a significant main effect of serial position and a non-significant interaction. Overall, the SPCs for the verbal stimuli are almost identical in shape, with both primacy and recency effects, leading to a bow shaped curve. The shape of the visuo-spatial stimuli is flatter and it is clear that the reduction in the overall accuracy in the randomised presentation group has resulted to overall equal reduction in accuracy across all serial positions.

Table 4.1

Experiment 6: Summary of the ANOVA analyses conducted upon the serial position curves (SPCs) data.

	df	*MSE*	*F*	η^2_p	*p*

Serial Position Curves- Verbal Data					
GP	1,38	.050	.087	.002	.769
SP	5,190	.013	39.3	.508	< .001
GP x SP	5,190	.013	1.19	.030	.315
Serial Position Curves – Visuo-Spatial Data					
GP	1,38	.023	12.3	.244	.001
SP	5,190	.008	10.4	.215	< .001
GP x SP	5,190	.008	.551	.014	.737

The probability of first recall (PFR) data. Figure 4.4 shows the proportion of trials in which items from different serial positions were recalled first for each of the three groups. A between-subjects ANOVA showed that there was a significant main effect of group on starting with the first presented item $F(2,57) = 6.63$, $MSE = .037$, $\eta^2_p = .189$, $p = .003$. Bonferroni post-hoc tests showed that there was a significant difference between the auditory-verbal and visuo-spatial group ($p = .002$); all other differences were non-significant.

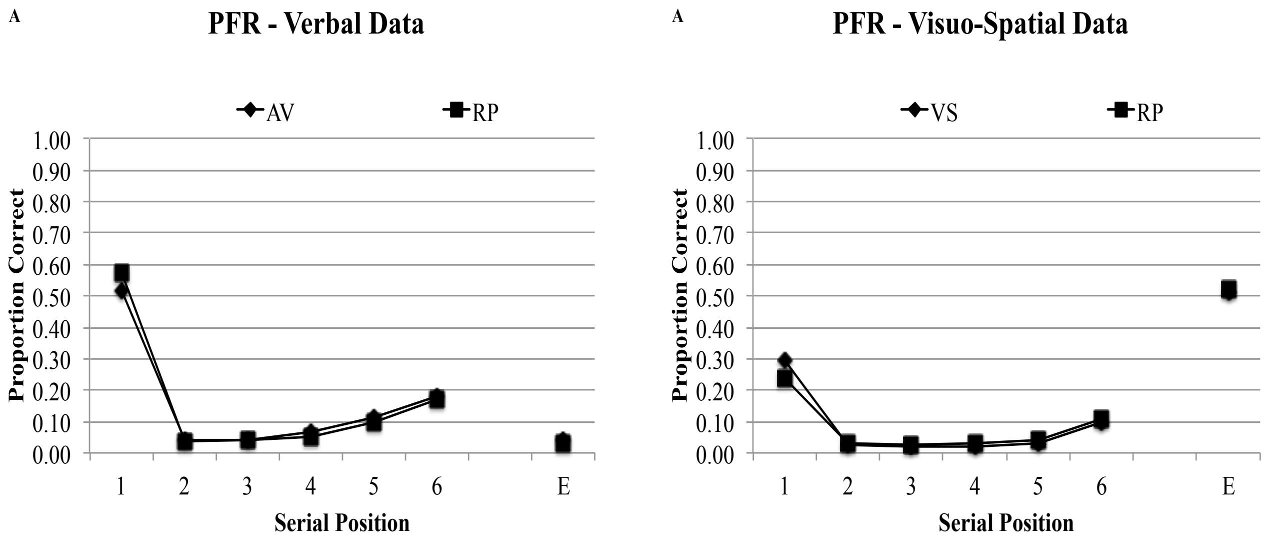

Figure 4.4. Experiment 6: Probability of first Recall (PFR) data for the verbal (panel A) domain taken from the auditory-verbal (AV) and randomised presentation (RP) groups and visuo-spatial (panel B) domain, taken from the visuo-spatial (VS) and randomised presentation (RP) respectively. These show the proportion of trials in which recall was initiated with one of the 6 available serial positions or an Error (E) across groups.

Additionally, another between-subjects ANOVA revealed that there was also a significant main effect of group on starting with one of the last four items on the list $F(2,54) = 5.07$, $MSE = .059$, $\eta^2_p = .158$, $p = .010$. Bonferroni post-hoc tests showed that there were significant differences between the randomised presentation and the visuo-spatial group (p = .038) and between the auditory-verbal and visuo-spatial groups (p = .015). To enable within-modality comparison, the data was further segmented into verbal and visuo-spatial data respectively. These were analysed through two between-subjects ANOVAs, one per modality (auditory-verbal and randomised presentation; visuo-spatial and randomised presentation) and the exact statistics are shown in Table 4.2. In the verbal domain, there was a non-significant main effect of group on starting with either the first presented word or with one of the last four presented words. Similarly, in the visuo-spatial modality, there was a non-significant main effect of group on either initiating recall with the first presented dot or with one of the last four dots in the sequence.

Table 4.2
Experiment 6: Summary of the ANOVA analyses conducted upon the Probability of First Recall (PFR) data for both verbal and visuo-spatial data

	df	*MSE*	*F*	η^2_p	*p*
PFR- Verbal Data					
PFR = SP1	1,38	.058	.503	.013	.483
PFR = Last 4	1,37	.061	.656	.017	.423
PFR – Visuo-Spatial Data					
PFR = SP1	1,38	.020	1.71	.043	.199
PFR = Last 4	1,36	.023	.152	.004	.699

Overall, the PFR data is consistent with Experiment 5, whereby when presented with six items to remember, participants tend to either initiate recall with either serial position 1, or one of the last few presented items. This tendency was fairly consistent when drawing within-modality comparisons across groups.

The effect of the first recall on the serial position curves. Figure 4.5 shows the effect of group on the proportion of items recalled, for those trials where recall was initiated with either the first presented item using both FR scoring (panels A-B) and SR scoring (panels C-D) or one of the last four presented items (panels E-F). For both modalities a 2 (group: single- vs dual-modality) x 5 (serial position 2-6) mixed ANOVA was conducted upon the those trials were recall was initiated with the first presented item using FR scoring; exact statistics for the main effects and interactions are shown in Appendix 4.1. For the verbal data there was a non-significant main effect of group, a significant main effect of serial position and a non-significant interaction. The curves show highly elevated recall accuracy for the first three items as well as good performance on the last item, resulting in both primacy and recency. For the visuo-spatial data there was a significant main effect of group, a significant main effect of serial position and a non-significant interaction. Unlike the resultant SPCs for the verbal domain, the visuo-spatial data is not as bowed, and this reflects the difference in overall accuracy between the two domains.

An additional 2 (group: single- vs dual-modality) x 5 (serial position 2-6) mixed ANOVA was conducted for each modality, upon those trials were recall was initiated with the first presented item using SR scoring (see Appendix 4.1 for exact statistics). Similar to when using FR scoring, for the verbal data there was a non-significant main effect of group, a significant main effect of serial position and a non-significant interaction. Furthermore, the SPCs for both groups are identical and both show that participants tend to recall a list of six words in strict forwards order, even when this is not a task requirement. With regard to the visuo-spatial data, there was a significant main effect of group, a significant main effect of serial position and a non-significant interaction. Although the SPCs for the visuo-spatial domain show evidence of forward serial order even when this is not a task requirement, this is not as strong as in the verbal modality.

Finally, two 2 (group: single- vs dual-modality) x 6 (serial position) mixed ANOVA were conducted, one for each modality, on those trials were recall was initiated with one of the last four presented items; exact statistics for the main effects and interactions are shown in Appendix 4.1. As regards the verbal data, there was a non-significant main effect of group, a significant main effect of serial position and a significant interaction. For the visuo-spatial data there was a non-significant main effect of group, a significant main effect of serial position and a non-

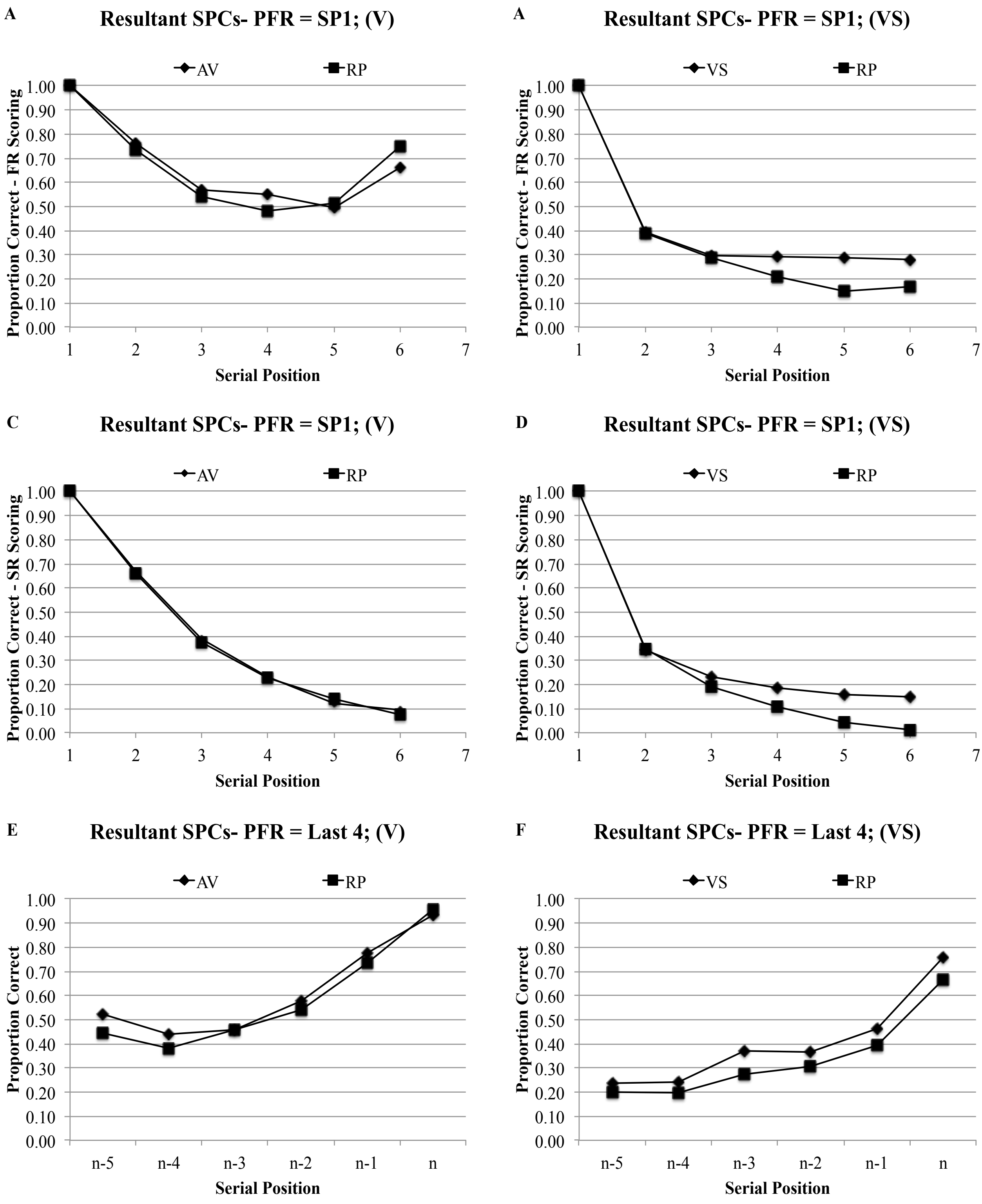

Figure 4.5. Experiment 6: The effect of the first recalled item on the serial position curves, separated by modality with the verbal domain on the left side and the visuo-spatial domain on the right side. Panels A and B show the effect of initiating recall with the first presented item in the list using FR scoring. Panels C and D show the effect of initiating recall with the first list item using SR scoring. Panels E and F show the effect of initiating recall with one of the last four stimuli in the list.

significant interaction. The SPCs for the verbal data are very similar across groups, showing that when participants start recall with one of the last four items, they tend to perform better on the later list items, thus leading to extended recency and reduced primacy. Additionally, there is slightly more primacy in the single-modality condition compared to the randomised presentation group. As regards the SPCs for the visuo-spatial data, there are similar extended recency effects and no primacy. It is noteworthy that the curve for the randomised presentation shows reduction throughout all serial positions and this reflects the decrease in overall accuracy in the dual-modality group.

Detailed Analysis of Output Order in the dual-modality task

First item outputted by the randomised presentation group. Half of the 1000 trials in the randomised presentation group started with a word, while the other half starting with a dot. Consistent with previous experiments, participants initiated output with a word (712 trials) more often than a dot (288 trials). A within-subjects ANOVA confirmed that the proportion of trials in which recall was initiated with a word was not significantly affected by whether the first presented item was a word or a dot, $F(1,19) = 2.57$, $MSE = .009$, $\eta^2_p = .119$, $p = .126$.

First three outputs by the randomised presentation group. Since in previous experiments participants showed a tendency to alternate between modalities, the first three outputs should be indicative of whether participants are alternating between modalities. There are eight various ways in which the first list items can be presented and outputted. Consequently, Table 4.3A shows the number of times a particular set of three outputs were outputted for each of the different combinations of possible presented items. Overall, the most preferred strategy is to alternate modalities by saying word-dot-word (WDW), and the next preferred strategy was to simply output three words consecutively (WWW). The tendency to alternate with dot-word-dot (DWD) is also quite common; however, participants are much less keen to output three dots consecutively. Although this data confirms that participants tend to output in an alternating manner, it does not reveal whether alternating is the most effective strategy in terms of recall accuracy.

Table 4.3B shows the average number of items correctly recalled for each particular output strategy. Overall, participants recall the most items correctly when they alternate with WDW, followed by when they output DWD and WDD. Appendix 4.2 separates this data further by modality by showing the number of words and dots correctly recalled for each of the particular output strategy. As regards the words, when participants started their output with three consecutive words, they recalled more words overall. When comparing those instances where two words and a dot were outputted (DWW, WDW and WWD), it is clear that alternating modalities results in a higher number of correctly recalled words. In those strategies where two dots and a word where outputted (DDW, DWD and WDD), participants were more likely to recall more words correctly when outputting WDD. The highest number of correctly recalled dot locations was when participants chose to output three consecutive dots. It is noteworthy however, that even when participants choose to output three dots first, they are not likely to correctly recall all of them, and this contrasts with the words, where participants are almost always correct on the first three outputted words. When comparing all three strategies where two dots were outputted with a word (DDW, DWD and WDD), it is clear that participants perform better when they alternate modalities; this is also true when participants choose to output two dots and a word (DWW, WDW and WWD).

Table 4.3A
Experiment 6: The number of occurrences of each of the eight possible output strategies for the first three outputs of the randomised presentation group.

	First three outputs								
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW	Total
First three items									
DDD	5	4	7	7	7	**24**	13	19	86

DDW	1	2	27	9	6	**56**	9	33	143
DWD	1		19	10	12	**42**	10	28	122
DWW	3	6	17	14	10	**56**	13	30	149
WDD	3	7	35	8	19	**38**	13	26	149
WDW	2	1	16	11	11	**46**	10	25	122
WWD	4	4	25	11	14	**39**	12	34	143
WWW	2	5	15	6	9	**22**	3	24	86
Total	21	29	161	76	88	**323**	83	219	**1000**

Table 4.3B

Experiment 6: The average number of list items recalled for each of the eight possible output strategies for the first three outputs of the randomised presentation group.

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
First three items								
DDD	5.40	5.50	5.43	5.14	5.14	**6.13**	5.46	5.47
DDW	4.00	4.00	5.37	4.78	6.17	**5.59**	4.33	5.64
DWD	5.00		5.05	5.40	5.83	**5.67**	5.00	5.11
DWW	5.00	3.67	4.12	4.79	5.00	**5.79**	5.23	4.93
WDD	4.67	6.14	5.26	3.75	4.74	**5.26**	4.85	5.12
WDW	2.50	4.00	5.25	4.73	5.73	**5.24**	4.90	5.08
WWD	5.75	5.25	5.88	5.00	4.71	**5.49**	4.92	5.06
WWW	6.50	5.60	5.60	5.33	5.78	**6.05**	4.33	5.17
Average	5.05	5.10	5.27	4.86	5.27	**5.60**	4.96	5.19

Note: W stands for word; D stands for dot. Outputs refer to the modalities of the first three responses, irrespective of whether the response is correct or not.

The effect of PFR = SP1 in the verbal domain on the visuo-spatial domain. Table 4.4 shows the number of responses where the first word and visuo-spatial dot outputted, were outputted consecutively and had identical within-modality serial positions; there were 648 such trials from a total of 1000 trials (64.8%). Overall, it is clear that when participants started with the first item or one of the last four items in one modality, the consecutive cross-modality output often had a matching serial position; this is relatively reduced from the equivalent occurrences in Experiment 4 (72.9%) and 5 (PP: 84.3%; AP: 87.7%).

Table 4.4

Experiment 6: The proportion of responses where the first word and first visuo-spatial dot outputted consecutively had matching within-modality serial position. These were classified into three categories: the probability of starting with the first item, one of the last four items or an error.

		Visuo-Spatial Data			
		PFR = SP1	PFR = Last 4	PFR = Error	**Total**
Verbal Data	PFR = SP1	**129**	69	192	390
	PFR = Last 4	34	**95**	107	236
	PFR = Error	8	4	10	22
	Total	171	168	309	**648**

Expected versus Observed Chunks. Each randomised mixed-modality list was made up of a number of same-modality chunks varying between two and twelve chunks, where two chunks meant six items of the same modality were followed by six items of the other modality and twelve chunks meant consistent alternations between modalities. Figure 4.6 shows the average number of observed chunks outputted for each number of expected chunks, as prescribed by the list structure.

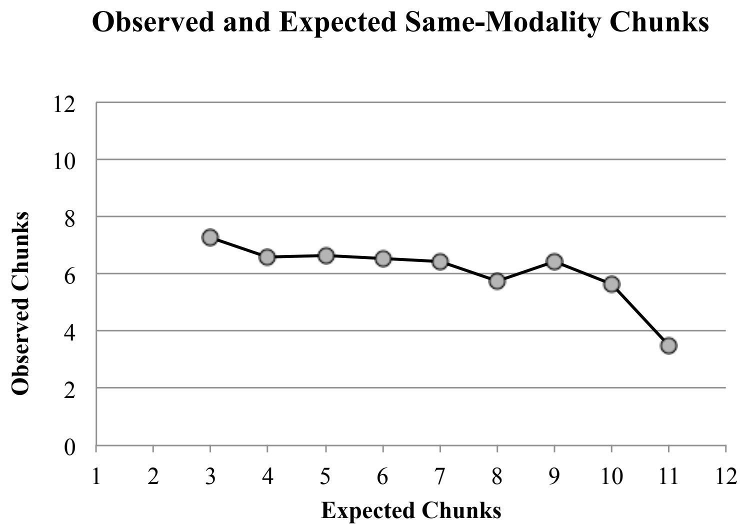

Figure 4.6. Experiment 6: The frequency by which a particular lag transition was made. Smaller lags denote transitions between items of close serial positions, whereas larger lags denote transitions between items that are further apart in the list.

Overall, it is clear that participants are not outputting by modality since chunk size is consistently greater than two; instead average chunk size is between six to eight chunks. Given that the average number of outputted items was 9.23 items, it is clear that there was a high level of alternations within the data.

Lag transitions. Appendix 4.3 summarises the number of correct outputs at all possible serial positions (*n*) and their respective consequent outputted item (*n* + 1). This information was then used to summarise the number of times a particular lag transition occurred, for each of the 4 possible modality transitions; this is summarised in Appendix 4.4 and graphically presented in Figure 4.7. Overall, the cross-modality transitions were much higher than the within-modality transitions (1654 vs 1050), implying that participants are more likely to alternate between modalities than they are to output consecutive same-modality items.

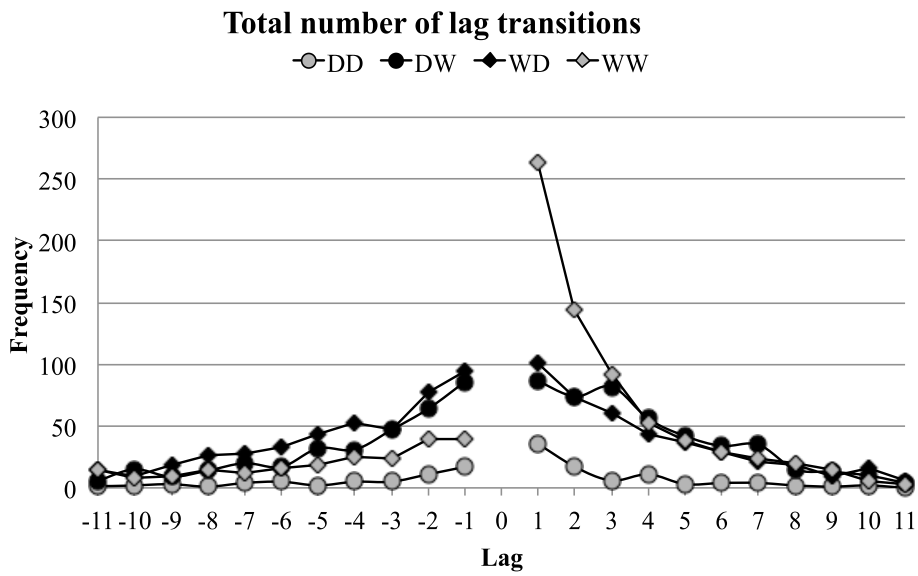

Figure 4.7. Experiment 6: The frequency by which a particular lag transition was made. Smaller lags denote transitions between items of close serial positions, whereas larger lags denote transitions between items that are further apart in the list.

Additionally, it is noteworthy that the WW transitions (908) heavily outnumbered the DD transitions (142), where participants were more likely to output two words consecutively rather than two consecutive dots. Overall, participants are more likely to recall consecutive items from temporally close serial positions, resulting in a heightened frequency of smaller lags. Furthermore, +1 and +2 lags are most likely to be WW transitions and whereas there is a marked asymmetric lag recency effect in same-modality transitions, this is not as pronounced in the cross-modality transitions. Whereas the tendency to go in backwards order is markedly reduced for within-modality transitions, participants are more likely to go in backwards order across modalities.

Inter-response times (IRTs). Figure 4.8 shows the inter-response time data partitioned on the total number of items recalled for all three groups. The data for the randomised presentation group was further segmented by modality to enable comparison with the respective single-modality group. Similar to the findings from the previous chapter, when recalling words in the single-modality group, IRTs increase with increasing output order (from very fast, <500ms for early outputs to 1000ms for later outputs) whereas IRTs for the visuo-spatial responses remain consistent, and fairly slow (> 1000ms at all outputs) regardless of the number of items outputted. For the randomised presentation group, it is clear that consistent with previous experiments, within-modality IRTs are longer in the dual-modality group relative to the single-modality one, perhaps reflecting the time taken to output both modalities. Moreover, when looking at the IRTs of twelve-item lists, even outputs are much shorter than odd outputs, although overall even outputs in the present experiment were considerably higher than in previous experiments.

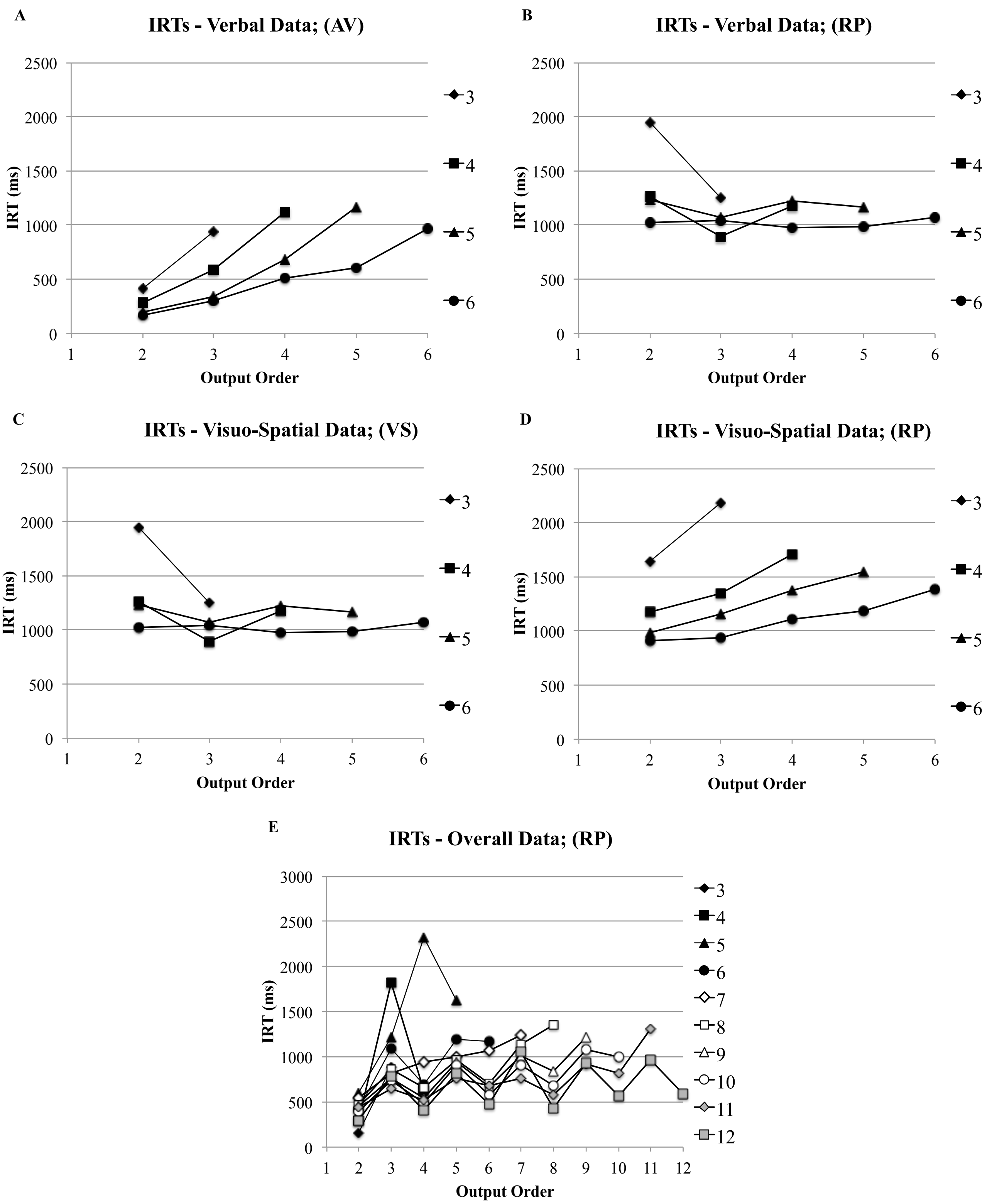

Figure 4.8. Experiment 6: Inter-response times (IRTs) for all data collapsed across the three groups, with the randomised presentation group data further segregated by stimulus domain. Note: AV stands for Auditory-Verbal group; VS stands for Visuo-Spatial group; RP stands for Randomised Presentation group.

Furthermore, Figure 4.9 shows the average response time for each of the four possible modality transitions. It is clear that the WD transitions are the fastest. However, different to the previous experiments, there is not much difference between the IRTs of the WD and DW transitions, with the latter only taking on average a few milliseconds longer; this was confirmed via a paired-samples t-test, $t(19) = .102$, $p = .920$, $d = .024$. Similar to the previous experiments, same-modality transitions are longer, taking on average about one second between outputs; there was a non-significant difference between DD and WW transitions, $t(19) = 1.90$, $p = .073$, $d =$

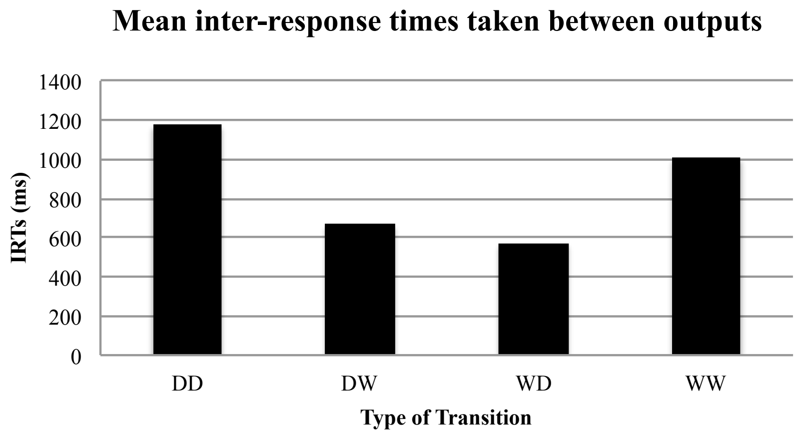

Figure 4.9. Experiment 6. The mean inter-response times taken between outputs for each of the four different transitions, where DD stands for two consecutive dots, DW refers to the time taken to output a word preceded by a dot, WD refers to the time taken to output a dot preceded by a word and WW stands for two consecutive words.

.065.

Figure 4.10 shows the IRTs taken for each of the four possible transitions across all lags. It is clear that in alternating transitions there is no effect of lag on IRTs, since these IRTs remained fairly consistent across lags. Furthermore, alternating lags are consistently shorter than consecutive same-modality outputs.

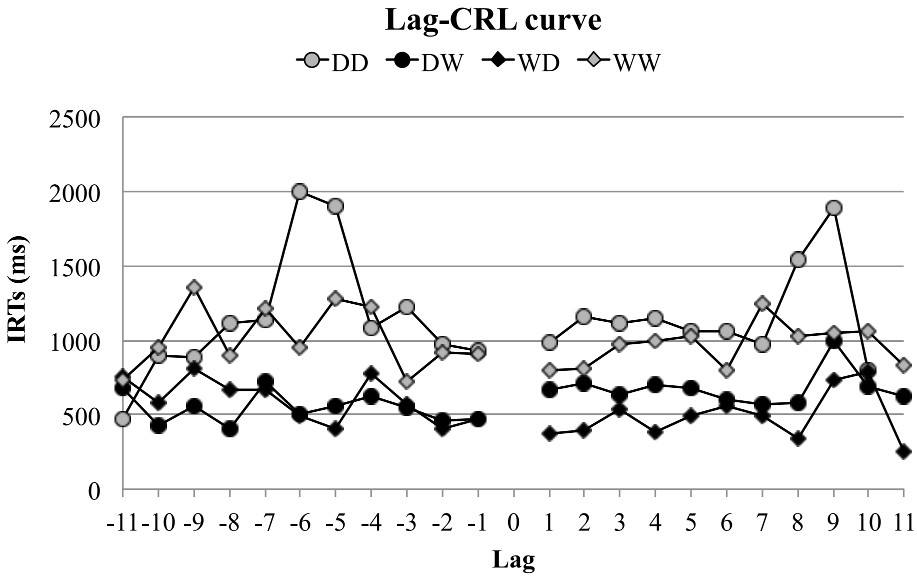

Figure 4.10. Experiment 6. The mean inter-response times taken between outputs with lags of between -11 and +11, for each of the four different transitions, where DD stands for two consecutive dots, DW refers to the time taken to output a word preceded by a dot, WD refers to the time taken to output a dot preceded by a word and WW stands for two consecutive words.

DISCUSSION

Experiment 6 examined the effect of presenting mixed lists of verbal and non-verbal stimuli on capacity and output orders, when these cross-modality stimuli are not presented concurrently and therefore the order in which stimuli are presented is completely randomised. There were seven salient findings from this experiment. First, when comparing within-modality performance for each group, the verbal accuracy was superior to that of visuo-spatial accuracy. Whereas there was a very small decrease in accuracy in the verbal domain between the single- and dual-modality tasks, there was a marked difference in visuo-spatial accuracy. Second, serial position curves showed pronounced primacy and recency for the verbal stimuli; this was also found, albeit reduced for the visuo-spatial data. Third, it is clear that in both domains participants tended to initiate their recall with either the first item or last four items on the list. If participants start with the first presented item they tend to continue outputting in forwards order, whereas if they start recall with one of the last four list items they are likely to continue recalling the other end items on the list. Consistent with the experiments in the previous chapter, when presented with mixed-modality lists, participants tended to start recall with a word more often than with a visuo-spatial dot.

Fourth, there was a reduction on the number of visuo-spatial outputs between the single- and dual-modality groups and this, coupled with the reduction of correct outputs implies that participants output less because they know less at test. Therefore, it is possible to conclude that the reduction of outputs is not merely a result of response bias. Fifth, the first three outputs showed that participants were more likely to alternate between modalities, and that they were more likely to recall more items correctly when they alternate. The overall transitions further confirmed that participants tend to alternate between modalities more often than consecutively outputting two items of the same modality. Sixth, lag transitions showed that participants tend to recall items that are temporally contiguous and that although participants are more likely to go forward than backwards, negative lags were more common in cross-modality transitions than in consecutive same-modality outputs.

Finally, the IRTs showed that participants are more likely to output the even outputs faster than the odd outputs and this could merely be a strategy to minimise the time taken to output all recalled items. This could be achieved by directing the cursor to a recalled spatial location while verbally outputting a word. Furthermore, IRTs showed that WD and DW transitions were considerably shorter than same-modality transitions, and that the lag transition does not have much of an effect on the IRTs.

Overall, Experiment 6 shows that when participants are presented with and have to recall a mixed-modality lists consisting of randomly presented auditory-verbal and visuo-spatial material, the asymmetry in the stimulus domains performance found in Experiment 5, was still present albeit more pronounced. Additionally, removing the inherent list structure through randomised presentation did not eliminate the tendency to alternate outputs across modalities. As in the previous experiments, Experiment 6 showed that the tendency to output WDW was both the most common output strategy and the most effective in terms of the number of correctly recalled list items. It is also noticeable however, that the tendency to output three consecutive words heavily outweighs the tendency to output three visuo-spatial locations. Given the low accuracy rate in the visuo-spatial domain, it is possible that this is reflective of the task difficulty, such that participants are discouraged to start their output with visuo-spatial locations, if they are perceived to be the harder items to recall.

Consequently, I decided that a better analysis of output orders in the visuo-spatial domain necessitated a higher accuracy rate, which is more comparable to the verbal IFR accuracy. Therefore, Experiment 7 utilised an easier test of visuo-spatial IFR in order to aid with the interpretation of the findings from Experiment 6. For this reason, further interpretation of these findings within the broader context of the thesis is withheld until the discussion of Experiment 7.

EXPERIMENT 7

The aims of Experiment 7 were two-fold. The first aim was to replicate the findings from Experiment 6 with a greater focus on output order. Although the dot locations task used in Experiments 3 to 5 is a fairer comparison to the FR of verbal material, it is clear that the accuracy for the visuo-spatial domain is fairly poor when using the strict dot criterion, with the highest ever overall performance of 37%, whereas the FR of verbal materials usually yields an accuracy of between 60-65%. This is consistent with previous comparisons of verbal and visuo-spatial FR (Gmeindl *et al.*, 2011) and SR tasks (Davis, Rane, & Hiscock, 2013), where verbal performance is often superior to its visuo-spatial counterpart. However, as a consequence of a low accuracy level for the visuo-spatial domain, there are also fewer dot-related transitions, especially those between pairs of consecutive dots.

For this reason, I sought to use a task that would yield higher accuracy for the visuo-spatial domain to ensure that the fewer dot-dot transitions were not solely due to the large number of dot location errors. I noted that in the first direct comparison of verbal and visuo-spatial FR within this thesis (Experiment 2), at list length 6, FR accuracy was of 59% for the verbal domain and 64% for the visuo-spatial domain. Consequently, to seek equivalent IFR performance between modalities, the dot location task was replaced with the rectangle locations task from Experiments 1 and 2. Since the output order was the most important point of interest in this experiment, I expected more accurate transitions, which would therefore give a much clearer picture of how participants output mixed-modality responses in a dual-modality task.

The second aim of Experiment 7, was to test whether the decrease in the accuracy of the visuo-spatial recall in the dual-tasks of the previous experiments was due to the increase in the number of to-be–encoded items or whether this is due to the additional output interference at retrieval (given that the single-modality group recall a maximum of six items, whereas the dual-modality group recall a maximum of twelve).

A total of three groups of participants were tested. There was a precued group, who were presented with and were required to recall only one modality in any one trial. Additionally, there was a postcued group who saw twelve randomised stimuli (six auditory-words and six visuo-spatial rectangles), but were informed at test which stimulus domain they were required to recall. Finally, there was a randomised presentation group akin to the one in Experiment 6, where participants were presented with twelve mixed-modality stimuli, and at test, were required to recall as many stimuli as they could. If the decrease in recall accuracy in the visuo-spatial domain is due to output interference, then the participants in the randomised presentation group were expected to correctly recall fewer items than the precued and postcued groups, since they have twelve items to output in total, as opposed to six in the latter groups. By contrast, if the decrease is due to the number of items at encoding, then participants in both the postcued and randomised presentation conditions should both have comparable performance levels, as each were presented with twelve items and therefore the number of outputs should not have an effect on their IFR performance.

Overall, Experiment 7 aimed to further the results from Experiment 6, in elucidating participants' output orders by utilising a task that is known to yield a higher accuracy rate than the dots task and also help ascertain whether the decrease in the visuo-spatial performance is due to the increased items at encoding or retrieval.

METHOD

Participants. A total number of 60 students from the University of Essex participated in exchange for either course credit or a small payment.

Materials. Materials were the same as that of Experiment 6 for the verbal stimuli. With regard to the visuo-spatial stimuli, the same materials from Experiment 2 were used.

Design. The experiment used a mixed factorial design. The between-subjects independent variable was the performance of free recall when participants were presented with either verbal or visuo-spatial stimuli only (precued group), when participants were presented with both modalities and were told at test which one they had to recall (postcued group) and when participants were presented with both modalities and were asked to recall both at test (randomised presentation group). Overall, there was one within-subjects independent variable: serial position with six levels for the precued group and twelve levels in the postcued group and the randomised presentation group.

The dependent variables were the proportion of items correctly recalled, the proportion of items recalled in the same order as presented, and the probability of initiating recall with the first or with one of the last four stimuli. Where participants were asked to recall both modalities in the randomised presentation group, there were additional dependent variables: the proportion of trials where recall was initiated with a word, the proportion of outputs where participants switched from one modality to the other, and the inter-response times between outputs.

Procedure. Each participant was randomly allocated into one of the three groups: the precued group, the postcued group and the randomised presentation group, such that each group was made up of 20 participants. Each participant was tested individually and given group-specific instructions. All participants were informed that they would be shown two practice lists of six stimuli in the precued group (either six auditory-words or visuo-spatial rectangles) and twelve stimuli in the postcued and randomised presentation group (six auditory-words and six visuo-spatial rectangles, randomly presented). The practice trials were followed by 80 experimental lists of stimuli separated into two blocks of 40 trials each. For the precued group, half of the trials were auditory-verbal trials and the other half were visuo-spatial trials, where the order of different modality trials was randomised. To ensure that the presented sequences in this experiment were of the same temporal length, the same method of allocation of stimuli used in Experiment 6 was utilised in Experiment 7.

For the precued group, participants were presented with either auditory-words or visuo-spatial rectangles. At the start of each trial, participants were presented with an auditory cue followed by either a blank screen, indicating that the trial was going to be an auditory-verbal free recall, or a randomised set of 36 rectangles presented in different locations on the screen, specifying that the trial was going to be a visuo-spatial free recall test. As in Experiment 6, each stimulus was presented for 0.60s, with the other modality stimuli acting as inter-stimuli intervals. For the postcued and the randomised presentation groups, each trial also started with an auditory cue, followed by a randomised set of 36 visuo-spatial rectangles placed in various screen locations. Participants in both these groups were presented with both auditory-words and visuo-spatial rectangles, presented in a random order for 0.60s, with no inter-stimulus interval.

Across all groups, in visuo-spatial trials, participants were presented with a random set of 36 visuo-spatial rectangles presented in different screen locations, and at test, six of them turned black one at a time. In auditory-verbal trials, all words were spoken through a headset. Similar to previous experiments, the cursor was locked at the right hand edge of the screen during stimuli presentation. Once all items were presented, participants heard an auditory cue, after which they were required to recall the relevant items in any order that they liked. Whereas participants in the precued and randomised presentation group were required to recall as many items as they could in any order that they liked, at test, the postcued group were asked to either recall just the words or the visuo-spatial locations. This was indicated through the set of 36 presented rectangles; if the rectangles remained on the screen after the cue, then participants had to recall the visuo-spatial locations. Conversely, if the rectangles disappeared, then the participants had to recall the words. To make verbal responses, participants were asked to say out loud as many words as they could remember, in any order that they liked; these where recorded through a microphone for offline scoring. To make visuo-spatial responses, participants were asked to indicate which rectangles had previously turned black by clicking on them in any preferred order. Once the participants were satisfied that they had completed their recall, they pressed the “submit” button which started the next trial.

RESULTS

Capacity and Replication

Overall Accuracy. Figure 4.11 shows the mean proportion of words and rectangle locations correctly recalled in each of the three groups. A 3 (group: precued, postcued and randomised presentation) x 2 (stimulus: verbal and visuo-spatial) mixed ANOVA revealed that there was a significant main effect of group $F(2,57) = 12.8$, $MSE = .016$, $\eta^2_p = .310$, $p < .001$ and a significant main effect of stimulus $F(1,57) = 13.1$, $MSE = .007$, $\eta^2_p = .187$, $p = .001$, on overall performance, as well as a significant interaction $F(2,57) = 5.52$, $MSE = .007$, $\eta^2_p = .162$, $p = .006$. Bonferroni post-hoc tests showed that there were significant differences between the precued and the postcued group and between the precued and the randomised presentation group (all *p*s $< .001$), but not between the postcued and the randomised presentation group ($p > .999$).

Since there was a significant main effect of stimulus type, each of the three groups' performance were segmented into verbal and visuo-spatial performance respectively to enable within-modality comparison. Paired-sample *t*-tests were conducted to test for differences between the verbal and visuo-spatial recall performance for each group. There was a non-significant difference between the verbal and visuo-spatial performance in the precued group, $t(19) = .333$, $p = .743$, $d = .078$, showing that in the current experiment, both modalities had similar baselines in the control condition. There was a significant difference between the recall accuracy of two modalities in both the postcued condition, $t(19) = 2.14$, $p = .045$, $d = .583$ and the randomised presentation group, $t(19) = 4.158$, $p = .001$, $d = .975$, implying that the recall for the two modalities was affected differently when participants were presented with two stimuli.

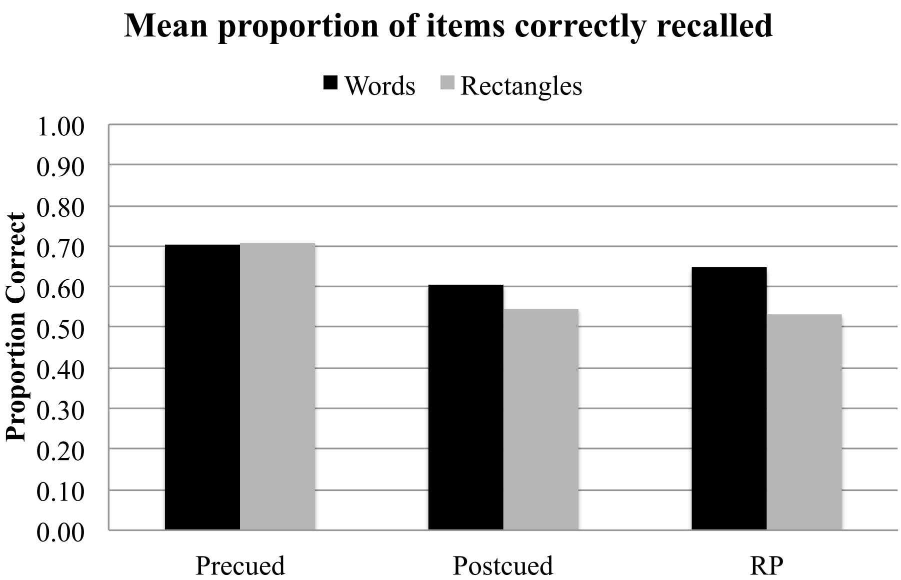

Figure 4.11. Experiment 7: Mean proportion of items correctly recalled for each of the three groups segregated by modality for the verbal and visuo-spatial domains respectively.

Furthermore, there was a significant main effect of group on verbal performance, $F(2,57) = 5.66$, $MSE = .008$, $\eta^2_p = .166$, $p = .006$. Bonferroni tests showed that there was a significant difference between the precued and the postcued groups ($p = .004$); there were no other significant differences between groups. As regards the visuo-spatial modality, there was also a significant main effect of group, $F(2,57) = 13.6$, $MSE = .014$, $\eta^2_p = .323$, $p < .001$. Bonferroni post-hoc tests revealed that there was a significant difference between the precued and postcued group as well as between the precued and the randomised presentation group (all *p*s <.001) but no significant difference between the postcued and randomised presentation group (p = 1.00). Therefore, overall accuracy drops for both stimulus types when participants are required to remember both modalities, despite the fact that in the postcued group participants were only required to output one modality.

The number of outputted rectangle locations across groups. Figure 4.12 shows the number of outputs as a proportion of total possible outputs (4,800 for the precued and the postcued group and 9,600 for the randomised presentation group) as well as the correct number of outputs as a proportion of actual outputted items. It is noteworthy that the number of outputs is highest for the precued group, with the participants in the postcued and randomised presentation groups outputting fewer yet similar amounts of items.

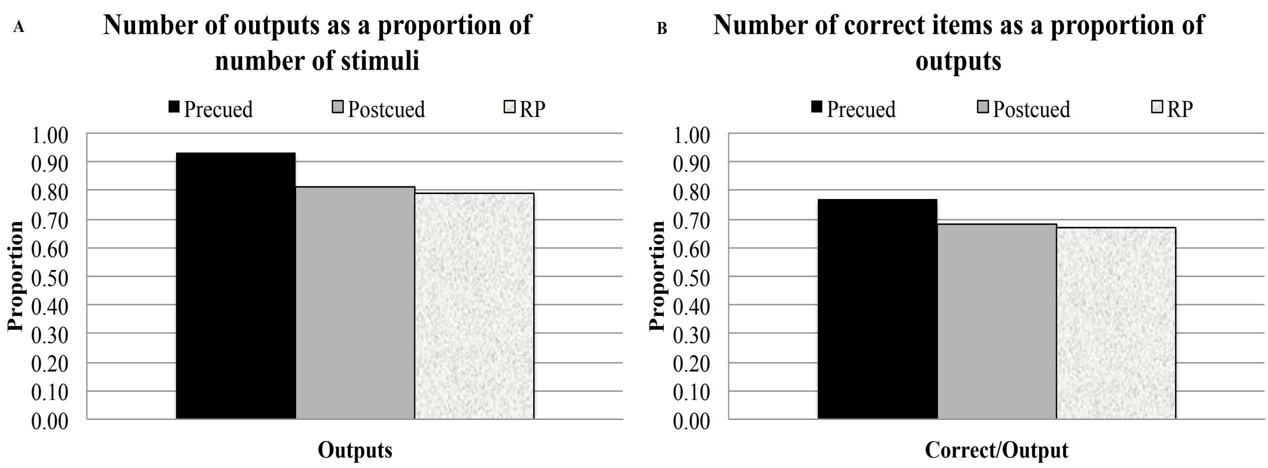

Figure 4.12. Experiment 7: The total number of outputted rectangles as a proportion of all possible outputs and the total number of correct responses as a proportion of actual outputs for all three groups.

A between-subjects ANOVA showed that there was a significant main effect of group on the number of outputted rectangles as a proportion of all possible outputs, $F(2,57) = 6.06$, MSE = .016, $\eta^2_p = .188$, $p = .003$ and post-hoc Bonferroni tests, showed that there were mean significant differences between the precued and the postcued groups (p = .019) and between the precued and the randomised presentation groups (*p* = .004). This pattern of results holds also for the number of items recalled as a proportion of the number of outputs, where there was a significant main effect of group on the proportion of correct items, $F(2,57) = 4.77$, $MSE = .012$, $\eta^2_p = .143$, $p = .012$ and post-hoc Bonferroni tests, showed that there were mean significant differences between the precued and the postcued groups ($p = .031$) and between the pre-cued and the randomised presentation groups ($p = .028$).

Serial Position Curves (SPCs). Figure 4.13 (panel A) shows all serial position curves for each group separated by modality, which are then plotted for each separate group in panels B, C and D. To enable comparison panels E and F show the SPCs for each of the three groups for the verbal and visuo-spatial modality respectively. Table 4.5 shows the exact statistics for two 3 (group: precued, postcued and randomised presentation) x 6 (serial position) mixed ANOVAs that were conducted on the verbal and visuo-spatial data respectively.

For the verbal data, there was a significant main effect of group, a significant main effect of serial position, and a significant interaction. Bonferroni post-hoc corrections showed that there was only one significant difference between the groups: that between the precued and the postcued groups ($p = .004$). As regards the visuo-spatial data, there was a significant main effect of group, a significant main effect of serial position, and a significant interaction. Bonferroni post-hoc corrections showed that there were significant differences between the precued and the randomised presentation group and between the precued and the postcued group (both *p*s $<.001$). Overall, the SPCs for the verbal data show that bowed curves for all three groups, but whereas recency remained consistent across groups, primacy was affected, with the precued group showing the most primacy and the postcued group showing the least primacy. Conversely, the SPCs for the visuo-spatial data is much flatter and that the differences between the groups reflects the reduction of overall accuracy across groups.

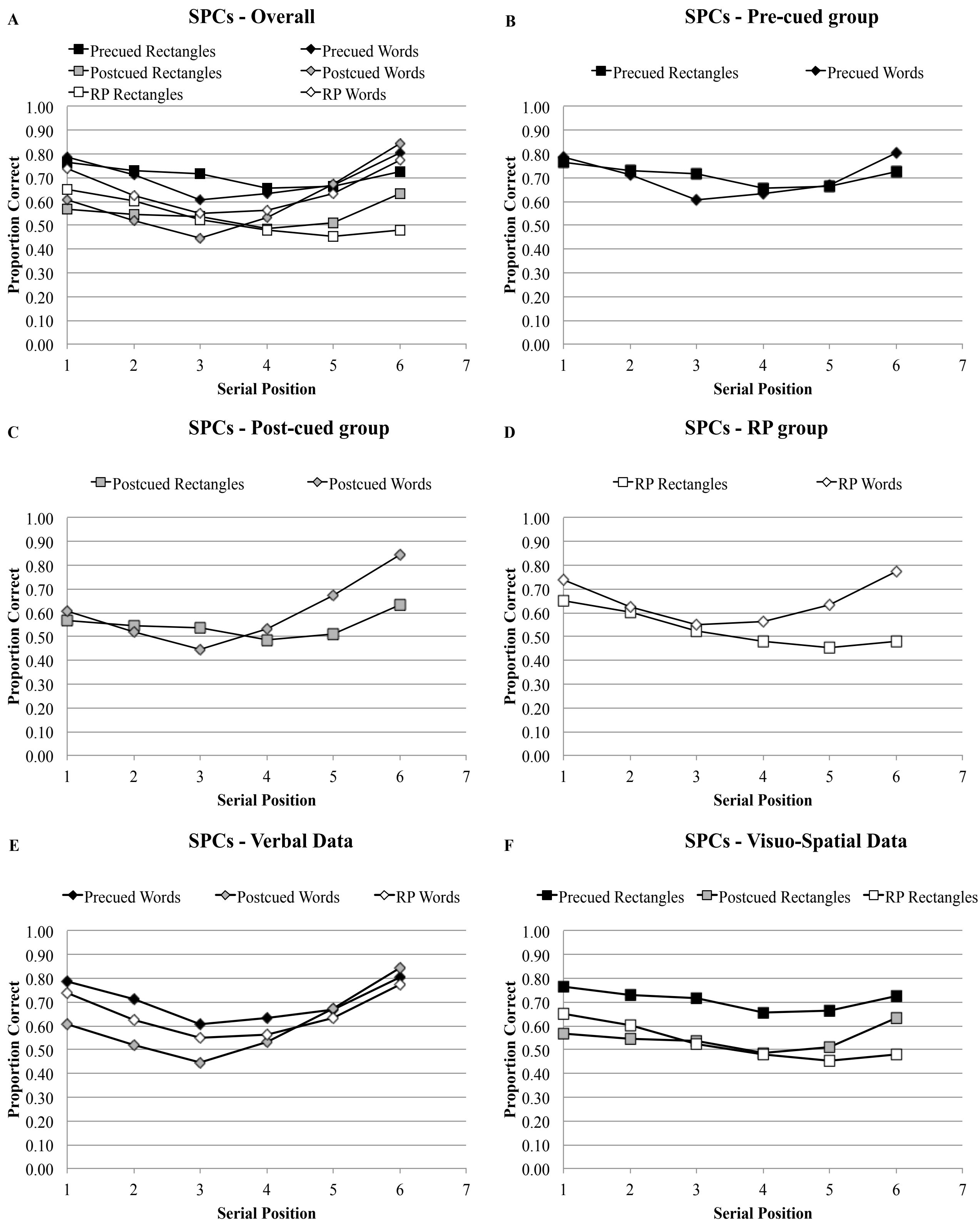

Figure 4.13. Experiment 7: SPCs for all three groups separated by modality. Panel A shows all SPCs, whereas Panels B, C, and D show the verbal and visuo-spatial curve for each group respectively. Panels E and F show the SPCs across groups separated by the verbal and visuo-spatial modality respectively.

Table 4.5

Experiment 7: Summary of the ANOVA analyses conducted upon the serial position curves (SPCs) data.

	df	*MSE*	*F*	η^2_p	*p*
Serial Position Curves- Verbal Data					
GP	2,57	.051	5.66	.116	.006
SP	5,285	.020	29.0	.337	< .001
GP x SP	10,285	.020	2.91	.093	.002
Serial Position Curves – Visuo-Spatial Data					
GP	2,57	.086	13.6	.323	< .001
SP	5,285	.013	10.3	.153	< .001
GP x SP	10,285	.013	2.82	.090	.002

The probability of first recall (PFR) data. Figure 4.14 shows the proportion of trials in which items from different serial positions were recalled first for each of the three groups. Table 4.6 shows the exact statistics for a 3 (group: precued, postcued, randomised presentation) x 2 (stimuli: verbal and visuo-spatial) ANOVA conducted on the probability of starting recall with the first presented item (PFR = SP1). This revealed that there was a non-significant main effect of group, a significant main effect of stimuli, and a non-significant interaction.

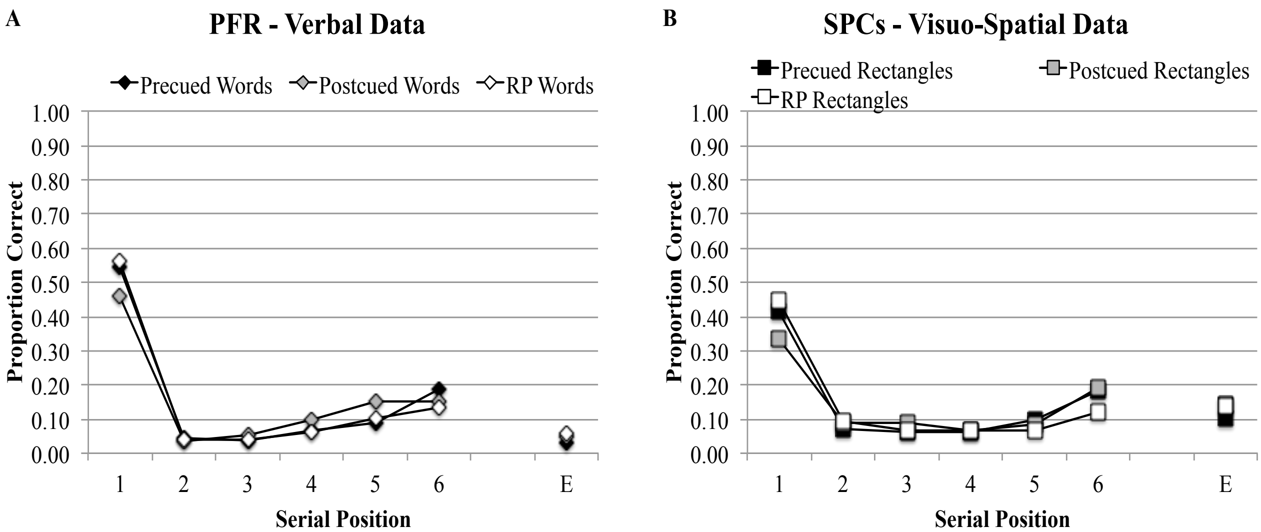

Figure 4.14. Experiment 7: Probability of first Recall (PFR) data for the verbal (panel A) and visuo-spatial (panel B) modalities respectively across all three groups, where black markers represent the Precued group, grey markers represent the Postcued group, and open markers represent the randomised presentation (RP) group. These PFR curves show the proportion of trials in which recall was initiated with one of the six available serial positions or an Error (E) across groups.

Another 3 (group: precued, postcued, randomised presentation) x 2 (stimuli) ANOVA on the probability of initiating recall with one of the last four items in the list showed that there was a non-significant main effect of group, a non-significant main effect of stimuli, and a non-significant interaction (see Table 4.6 for exact statistics). The data was further segregated by modality and analysed by two between-subjects ANOVA; the exact statistics are shown in the bottom half of Table 4.6. For both modalities, there was a non-significant main effect of group on starting recall with either the first presented item or one of the last four items on the list. Overall, the probability of initiating recall with the first list item was affected by whether the item outputted is a word or a visuo-spatial location. However, the probability of starting with either the first or last few list items did not vary significantly across the three groups, despite having different task requirements.

Table 4.6
Experiment 7: Summary of the ANOVA analyses conducted upon the Probability of First Recall (PFR) data overall and when segregated by verbal and visuo-spatial modality respectively

	df	*MSE*	*F*	η^2_p	*p*
Overall					
PFR = SP1					
GP	2,57	.088	1.40	.047	.255
ST	1,57	.043	10.7	.159	.002
GP x ST	2,57	.043	.005	< .001	.995
PFR = Last 4					
GP	2,57	.099	1.29	.043	.284
ST	1,57	.044	.008	< .001	.931
GP x ST	2,57	.044	.167	.006	.847
PFR- Verbal Data					
PFR = SP1	2,57	.088	.674	.023	.514
PFR = Last 4	2,57	.092	.757	.026	.474
PFR – Visuo-Spatial Data					
PFR = SP1	2,57	.044	1.48	.049	.236
PFR = Last 4	2,57	.050	1.29	.043	.238

Note: ST refers to Stimulus Type

The effect of the first recall on the serial position curves. Figure 4.15 (panels A and

B) shows the effect of group on the proportion of items recalled for both modalities, for those trials where recall was initiated with Serial Position 1 using FR scoring. Appendix 4.5 shows the exact statistics for a 3 (group: precued, postcued randomised presentation) x 5 (serial position: 2-6) mixed ANOVA for the verbal and visuo-spatial modality respectively. For the verbal modality there was a non-significant main effect of group, a significant main effect of serial position and a non-significant interaction. As regards the visuo-spatial data, there was a significant main effect of group, a significant main effect of serial position and a non-significant interaction. Bonferroni post-hoc tests showed that there were mean significant differences between the precued and the postcued group (p =.005) and between the precued and the randomised presentation group ($p <$ .001). Overall, when participants start recall with the first presented item, this leads to extended primacy effects, with very little or no recency.

Panels C and D of Figure 4.15 show the effect of group on the proportion of items recalled for both modalities, for those trials where participants started recall with the first presented item using SR scoring. Similar, to the previous data, a 3 x 5 mixed ANOVA was conducted for each modality and the exact statistics are shown in Appendix 4.5. In the verbal domain, there was a non-significant main effect of group, a significant main effect of serial position and a non-significant interaction. For the visuo-spatial data, there was a significant main effect of group, a significant main effect of serial position and a non-significant interaction. Bonferroni post-hoc tests showed that there was a significant difference between the means of the precued and the postcued groups only (p = .027); all other differences were non-significant. Overall, when participants start recall with the first presented item, they tend to continue recall in forwards order leading to extended primacy effects and no recency.

Panels E and F of Figure 4.15 show the effect of group on the proportion of items recalled for both modalities respectively, for those trials were recall was initiated with one of the last four presented items. These were analysed through a 3 (group: precued, postcued randomised presentation) x 6 (serial position) mixed ANOVA for each of the two modalities (see Appendix 4.5).

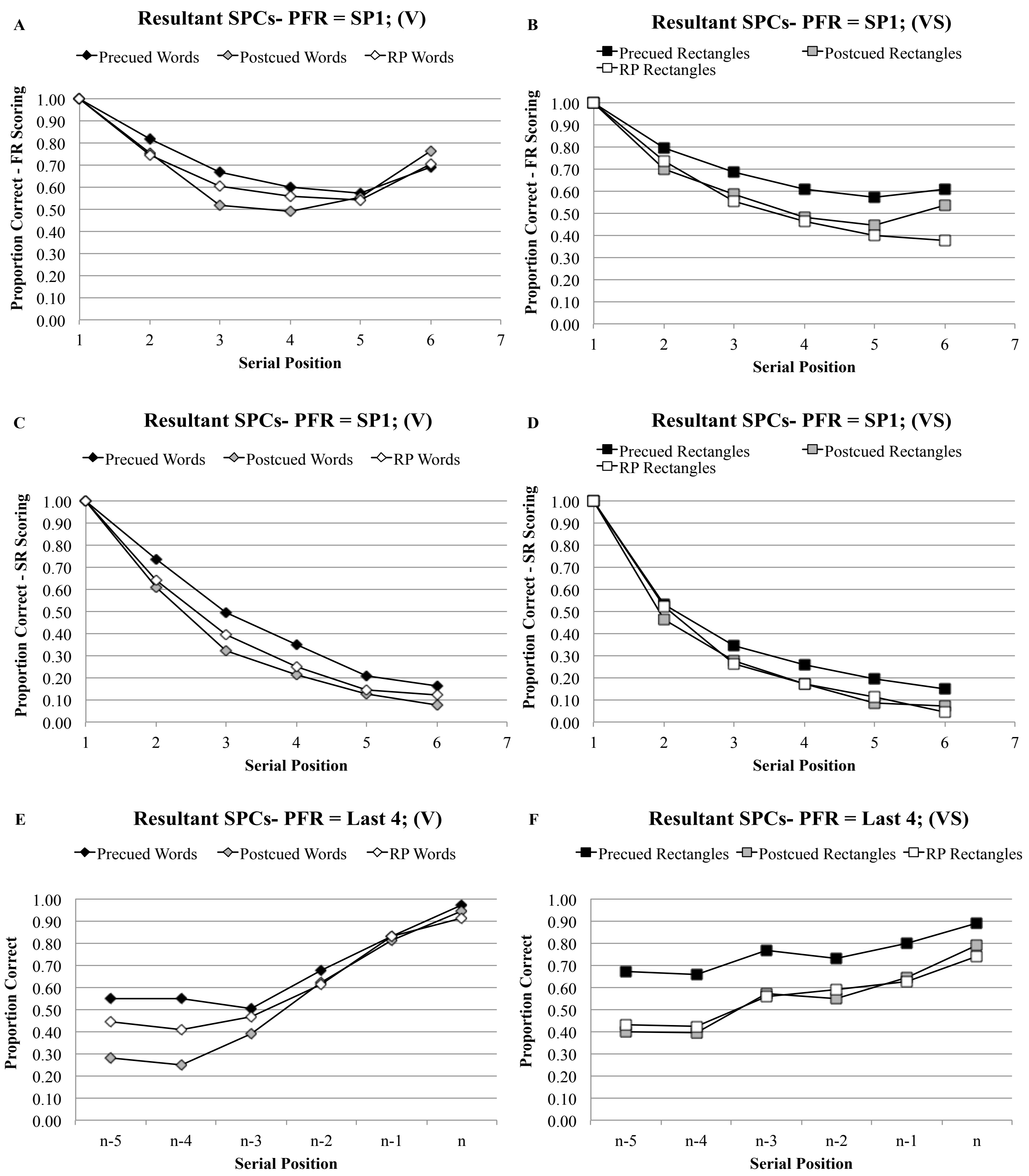

Figure 4.15. Experiment 7: The effect of the first recalled item on the serial position curves, separated by verbal and visuo-spatial modality respectively, across all three groups. Panels A and B show the effect of initiating recall with the first presented item in the list using FR scoring, Panels C and D show the effect of initiating recall with the first list item using SR scoring. Panels E and F shows the effect of initiating recall with one of the last four stimuli in the list using FR scoring.

As regards the verbal data, there was a significant main effect of group, a significant main effect of serial position and a significant interaction. Post-hoc Bonferroni tests revealed that there was a mean significant difference between the precued and postcued group (p = .014), but all other differences were non-significant. For the visuo-spatial data there was a significant main effect of group, a significant main effect of serial position and a non-significant interaction. Post-hoc Bonferroni tests showed that there were mean significant differences between the precued and postcued groups and between the precued and randomised presentation groups. (both ps < .001). Overall, when participants initiate recall with one of the last four items on the list, this leads to more extended recency effects and reduced primacy effects.

Detailed Analysis of Output Order in the dual-modality task

First item outputted by the randomised presentation group. Consistent with the previous experiments, of the 1600 trials in total, participants started with a word (1274 times) more often than starting with a visuo-spatial location (326 times). However, a within-subjects ANOVA showed that there was a significant main effect of whether the first presented item was a verbal or visuo-spatial item on the proportion of trials where participants started recall with a word, $F(1,19) = 6.03$, $MSE = .003$, $\eta^2_p = .241$, $p = .024$.

First three outputs by the randomised presentation group. Table 4.7A shows the number of times a particular string of three items was outputted, whereas Table 4.7B shows the total number of items recalled for each of the eight possible strategies of outputting three items in the randomised presentation group. Participants were more likely to output three words consecutively, but the second most popular tendency was to alternate between a word and a visuo-spatial location. Furthermore, alternating between modalities results in a better recall overall, and participants are more likely to remember more words if the first three outputs are

WRW and more likely to remember more visuo-spatial rectangle locations if the first three outputs are RWR.

Table 4.7A
Experiment 7: The number of occurrences of each of the eight possible output strategies for the first three outputs of the randomised presentation group.

	First three outputs								
	RRR	RRW	RWR	RWW	WRR	WRW	WWR	WWW	Total
First three items									
RRR	8	1	9	15	8	**37**	16	46	140
RRW	12		17	17	4	**51**	27	78	206
RWR	18	3	26	16	10	**72**	27	62	234
RWW	21	2	9	6	7	**65**	27	83	220
WRR	19	4	15	3	13	**65**	19	82	220
WRW	19	3	7	17	15	**79**	23	71	234
WWR	15	1	7	15	4	**63**	25	76	206
WWW	9	1	4	7	8	**44**	22	45	140
Total	121	15	94	96	69	**476**	186	543	1600

Table 4.7B
Experiment 7: The average number of list items recalled for each of the eight possible output strategies for the first three outputs of the randomised presentation group.

	First three outputs							
	RRR	RRW	RWR	RWW	WRR	WRW	WWR	WWW
First three items								
RRR	6.63	8.00	7.44	7.20	5.50	**7.57**	6.75	6.89
RRW	5.58		6.71	7.47	9.25	**7.76**	7.67	6.87
RWR	6.06	8.33	7.65	7.31	7.90	**7.36**	7.04	6.74
RWW	5.57	8.00	7.78	7.17	6.86	**7.40**	7.74	6.53
WRR	5.58	7.00	7.80	6.67	7.38	**7.37**	6.79	6.83
WRW	5.95	6.00	8.14	7.29	8.20	**7.54**	7.65	6.73
WWR	7.00	3.00	6.86	7.67	7.75	**7.48**	8.32	6.22
WWW	6.22	8.00	5.50	6.86	7.38	**7.61**	7.68	6.51
Average	6.00	7.07	7.38	7.31	7.49	**7.50**	7.51	6.66

Note: R stands for rectangle; W stands for word. Outputs refer to the modalities of the first three responses, irrespective of whether the response is correct or not.

The effect of PFR = SP1 in the verbal domain on the visuo-spatial domain. Table 4.8 shows the number of responses where the first word and visuo-spatial location outputted, were outputted consecutively and had identical within-modality serial positions; these made up 504 trials from a total of 1600 (i.e. 31.5%). Overall, it is clear that when participants started with the first item or one of the last four items in one modality, the consecutive cross-modality output often had a matching serial position. However, it is noticeable that the number of trials initiated with either a word-rectangle or rectangle-word transition is relatively reduced from previous experiments, and that the number of transitions to or from an erroneous response have also been reduced drastically (e.g. from 30.9% of trials in Experiment 6 to 3.69% in Experiment 7).

Table 4.8
Experiment 7: The proportion of responses where the first word and first visuo-spatial location outputted consecutively had matching within-modality serial position. These were classified into three categories: the probability of starting with the first item, one of the last four items or an error.

		Visuo-Spatial Data			
		PFR = SP1	PFR = Last 4	PFR = Error	Total
Verbal Data	PFR = SP1	**192**	46	24	262
	PFR = Last 4	59	**126**	27	212
	PFR = Error	14	8	8	30
	Total	265	180	59	**504**

Expected versus observed chunks. Similar to Experiment 6, each randomised mixed-modality list was made up of a number of same-modality chunks varying between two and

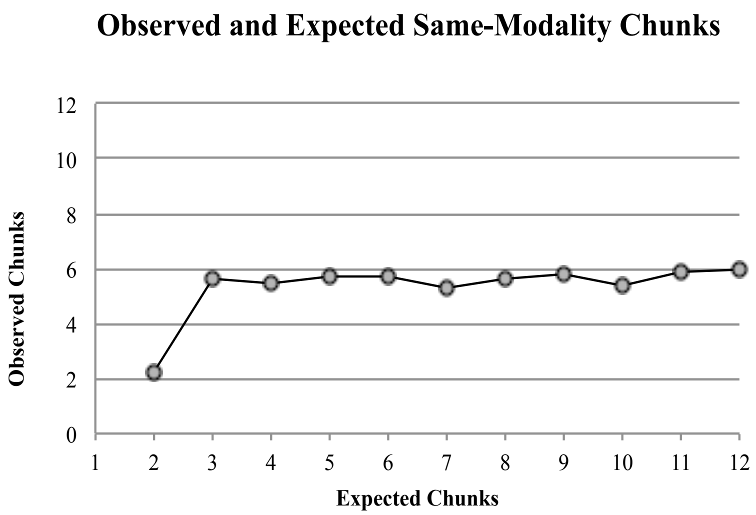

Figure 4.16. Experiment 7: The total number of outputted rectangles as a proportion of all possible outputs and the total number of correct responses as a proportion of actual outputs for all three groups.

twelve chunks, where two chunks meant six items of the same modality were followed by six items of the other modality and twelve chunks meant consistent alternations between modalities. Figure 4.16 shows the average number of observed chunks outputted for each number of input chunks, as dictated by the list structure. Overall, it is clear that when participants are presented with all items chunked by modality (i.e. six words and six locations or vice versa), they tend to output by modality. Otherwise if the presented list is made up of three chunks or greater, average chunk size is around six chunks. Given that the average number of outputted items was nine items, it is clear that there was a high level of alternations within the data.

Lag transitions. Appendix 4.6 shows the total number of transitions from each of the possible serial positions (*n*) to the next outputted item (*n* + 1). This data was used to calculate lags of between + and -11, which are shown in Appendix 4.7 and graphically presented in Figure 4.17. Consistent with Experiment 6, cross-modality transitions where much more frequent than within-modality transitions and WW transitions also outnumbered RR transitions.

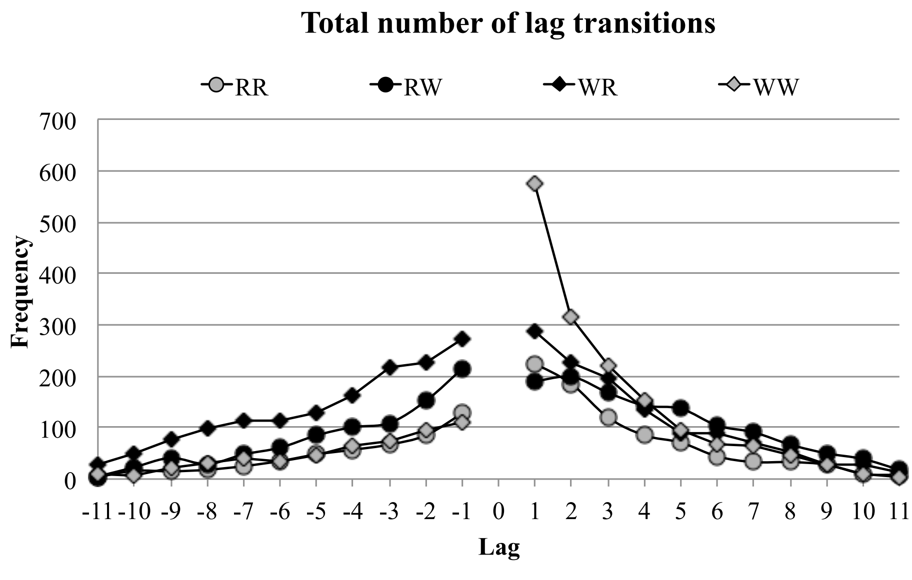

Figure 4.17. Experiment 7: The frequency by which a particular lag transition was made. Smaller lags denote transitions between items of close serial positions, whereas larger lags denote transitions between items that are further apart in the list.

Overall, there was a typical asymmetric lag, with positive lags being more frequent than negative ones, but this was less pronounced for cross-modalities transitions. Furthermore, +1 lags were predominantly WW transitions and negative lags were more frequent when transitioning between modalities, rather than recalling consecutive items from within the same modality.

Inter-response Times (IRTs). Figure 4.18 presents the IRTs for the randomised presentation group which show an albeit reduced saw-tooth shaped curve, whereby those items outputted in an even output position had a shorter inter-response time than those outputted in odd numbers. This pattern is mostly seen where participants outputted between seven and twelve list items and seems to break down with the last few outputted items.

Figure 4.19 shows the mean time taken to respond when transitioning either between items of the same modality (either WW or RR) or between items from different modalities (either RW or WR). There is a clear asymmetry between across- and within-modality transitions, in that, the former are much shorter than the latter. Similar to the previous experiment, paired-

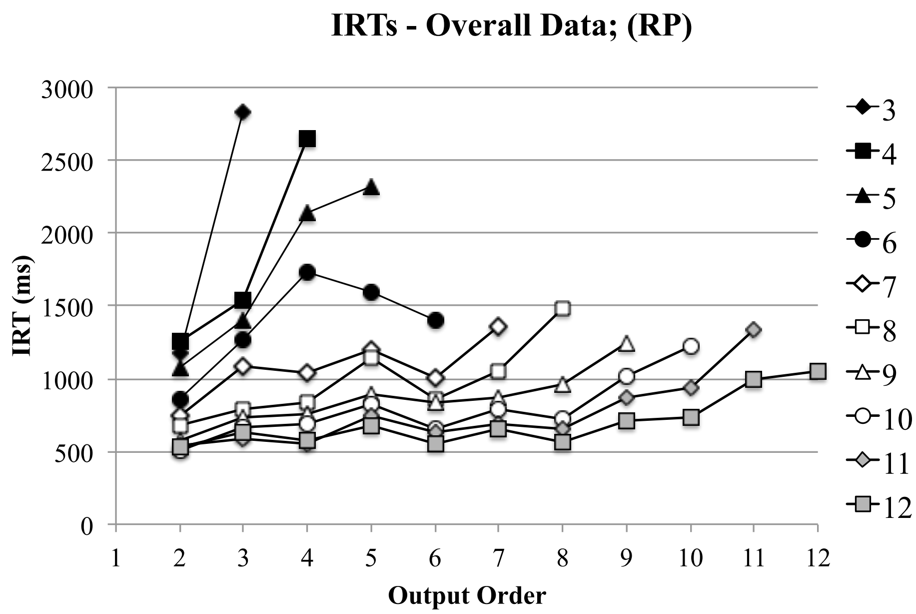

Figure 4.18. Experiment 7: Inter-response times (IRTs) for the Randomised Presentation Group.

samples *t*-test showed that there was a non-significant difference between RW and WR transitions, $t(19) = 1.17$, $p = .256$, $d = .350$ and between RR and WW transitions, $t(19) = 1.78$, p

= .091, d = .386.

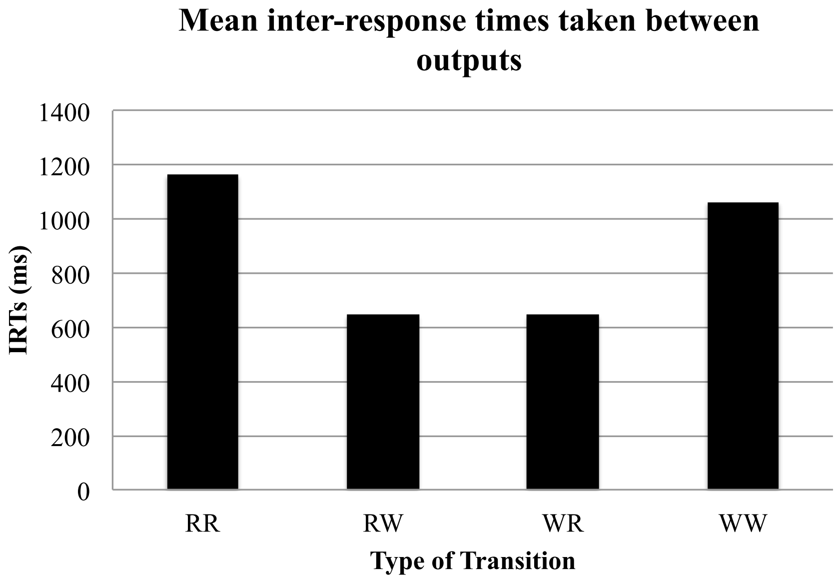

Figure 4.19. Experiment 7. The mean inter-response times taken between outputs for each of the four different transitions, where RR stands for two consecutive rectangles, RW refers to the time taken to output a word preceded by a rectangle, WR refers to the time taken to output a rectangle preceded by a word and WW stands for two consecutive words.

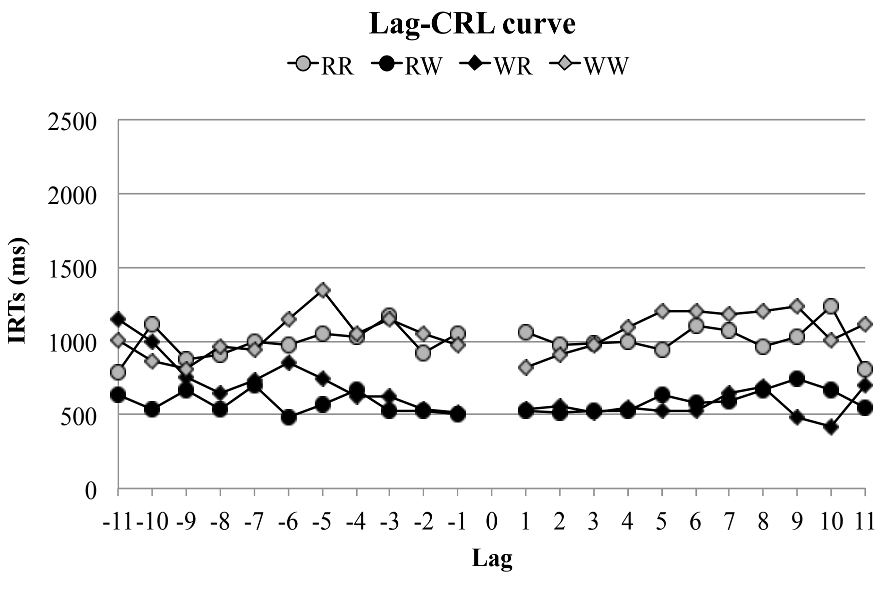

Figure 4.20. Experiment 7. The mean inter-response times taken between outputs with lags of between -11 and +11, for each of the four different transitions, where RR stands for two consecutive rectangle locations, RW refers to the time taken to output a word preceded by a location, WR refers to the time taken to output a rectangle location preceded by a word and WW stands for two consecutive words.

Finally, Figure 4.20 shows the IRTs for each of the possible lag transitions. Overall, there is no effect of lag since the IRT curves are relatively flat. More importantly, RW and WR remain roughly consistent across lags and are shorter than RR and WW transitions.

DISCUSSION

The aims of Experiment 7 were two-fold: first, it was essential to replicate the findings of Experiment 6 using easier to remember visuo-spatial stimuli in order to have similar accuracy levels for both verbal and visuo-spatial domain, allowing for better analysis. The second aim was to test whether the decrease in the visuo-spatial accuracy in the randomised presentation conditions was due to difficulty at encoding or retrieval.

As regards the first aim, the present experiment corroborated the findings from Experiment 6. Firstly, while there was a marked significant difference in visuo-spatial accuracy, there was a small yet non-significant decrease in the recall accuracy of the verbal domain. Secondly, it was clear that in both domains participants tended to initiate their recall with either the first item or one of the last four items on the list. When participants initiate recall with the first presented item they tend to continue outputting in forwards order leading to primacy effects, whereas if they start recall with one of the last four list items, they continue recalling the other end items on the list, leading to recency effects. Third, participants output fewer visuo-spatial items when they are presented with two modalities during presentation and are less accurate in their responses.

Fourth, the first three outputs showed that participants are more likely to start with a word and proceed by alternating between modalities. This tendency is not only a common strategy but also the most effective one, since recall is best when participants alternate between modalities. Fifth, participants tend to recall items from temporally close serial positions and are more likely to go forward than backwards, especially when transitioning between items of the same modality; negative lags were more common in cross-modality transitions than in consecutive same-modality outputs. Finally, the IRTs showed that WR and RW transitions were considerably shorter than same-modality transitions, implying that choosing to alternate outputs results in faster outputs and potentially better recall. Additionally, the IRTs remained relatively consistent across lag transitions, meaning that retrieving items from serial positions that are further apart does not require a longer time between outputs.

As regards the second aim of the present Experiment, participants in the precued group performed better than the postcued and randomised presentation groups. Whereas the former group were presented with one modality, the latter groups were presented with two. Therefore, both the postcued and the randomised presentation group were required to encode both modalities but the main difference between them was that the latter group had to retrieve and recall all presented items, whereas the former were told at test which modality to output. The results showed that the performance of the postcued group was similar to that of the randomised presentation group, despite recalling only six of the twelve presented items. This suggests that the dual-task deficits are due to the increased difficulties associated with encoding twelve (rather than six) items, and are thus not due to differences in output interference.

GENERAL DISCUSSION

There have been very limited investigations examining the immediate recall of mixed-modality lists including both verbal and visuo-spatial items, that were presented in a completely randomised order. For this reason, I have previously summarised and discussed research that has examined the IFR and ISR (e.g. Greene, 1989; Murdock & Walker, 1969; Murdock & Carey, 1972) of mixed-modality lists including auditory and visual words. These studies have shown that whereas a direct comparison of recall performance of auditory and visual words resulted in a recall advantage for the last few items in auditory-verbal lists, in mixed-list presentation, the recall advantage for the auditory-words was consistently higher across all serial positions.

Furthermore, participants ordered their output by modality, by first outputting all items from one modality followed by the items from the other modality.

In Experiment 6, similar to Experiments 4 and 5, visuo-spatial performance was much lower than its verbal counterpart in the single-modality task. Additionally, when mixed-lists were used, such that stimuli did not overlap at all during presentation (alternating or randomised presentation), there was a significant decrease in the visuo-spatial domain that contrasted with the slight yet non-significant decrease in the verbal performance. Furthermore, participants did not output by modality but chose to alternate between words and visuo-spatial dots.

In Experiment 7, the rounded rectangles tasks from Experiment 2 was utilised to ensure that the verbal and visuo-spatial performance in the single-modality task was equated. Recall accuracy on the rectangles task is considerably higher than the dots task, because it aids in creating more stable representations that are present both at encoding and retrieval. Furthermore, the grid of possible rectangles enables fine-grained discrimination of near neighbours because each rectangle is a reference point for others. Despite this, the recall accuracy asymmetry between the verbal and visuo-spatial domain was still present, whereby in the dual-modality tasks as there was a much more marked and significant decrease from the single-modality tasks in the visuo-spatial domain than its verbal counterpart.

THE ROLE OF ENCODING AND RETRIEVAL

Experiment 7 showed that when participants are presented with a twelve-item mixed-modality list and at test, asked to recall either all of the presented items, or the items from one modality only, performance is similar regardless of condition, with performance in the postcued condition being slightly poorer than that of the randomised group. This therefore implies, that participants' decrease in the recall accuracy of the visuo-spatial stimuli is not due to output interference, since if this were the case, participants recalling one modality instead of two would have a much higher performance than those who always have to output two modalities.

When participants were presented with and had to recall one modality only, participants made more outputs and were correct more often. Overall, it is clear that what participants' output reflects what they know, since Experiment 4 onwards showed that the number of correct items as a proportion of actual visuo-spatial outputs made tend to be very similar in single- and dual-modality tasks. What participants know at test is clearly reduced by having to encode two modalities as opposed to one.

The Present Findings within Domain-Specific Models

The main potential problems for domain-specific models of memory, such as the Working Memory model (Baddeley, 1986, 2000, 2007, 2012), from the findings in Chapter 3 apply equally here. First, and similar to the findings from Experiment 5, when the stimuli within a mixed-modality list did not overlap during presentation, (and therefore ensuring that participants perceive it as a twelve-item list), there was an asymmetric cross-domain interference due to a significant decrease in the accuracy of the visuo-spatial stimuli but not in the verbal domain. These findings are therefore problematic for domain-specific models, which would predict independent capacities for the two domains. Using the analogy of the recording devices, there is no reason why the silent video camera should work less well merely because the tape recorder is also being used.

A second potential problem for domain-specific models is the fact that output was not organised by modality in the randomised presentation group, and this was consistent with Experiment 4 and 5. As detailed in the previous chapter, when items are stored in independent and separate stores (e.g. phonological loop and visuo-spatial sketch pad, in the WM model), one might think it would be far more efficient to first output one store completely followed by the other. Furthermore, more often than not, consecutive cross-modality outputs were temporally contiguous and this cannot be fully explained within a domain-specific framework. There is also no theoretical explanation why participants prefer to output words first, even in instances where the first item presented is a visuo-spatial location.

Third, although the role of the episodic buffer would enable the linking of items from different stimulus domains together to form chunks, it still cannot explain the asymmetry between the recall of verbal and visuo-spatial stimuli in mixed-modality lists, unless one would assume that the visuo-spatial sketch pad is less supported by the episodic buffer. Furthermore, because it is unclear whether the episodic buffer is able to reconstruct order, it is uncertain how the different chunks are then recalled in a forward order, i.e. how the overall list structure is maintained.

Finally, the findings from the postcued group are also problematic for domain-specific frameworks of memory. If at encoding items enter their domain-specific stores respectively, and at test only one needs to be outputted, there is no reason why there should be a deficit in the recall performance of either modality, and yet, in the postcued group there was a marked decrease in both the IFR performance of words and visuo-spatial rectangles.

THE PRESENT FINDINGS WITHIN DOMAIN-GENERAL MODELS

The present findings also have similar implications for domain-general models as those previously found in Experiment 5. The pervasive asymmetry between the recall performance of the verbal and visuo-spatial domain, even when the single-task baselines were equated can be explained through the fact that auditory traces last approximately two seconds longer than visual ones (Kahana, 2012). Additionally, verbal material varies across more dimensions (e.g. semantic, phonological, etc.) than does visuo-spatial material, which is much less discriminable. If this is the case, then it is conceivable for auditory stimuli to have longer and potentially stronger activation levels, and therefore auditory-words are more likely to remain within the focus of attention (Cowan, 1995, 2005). Alternatively, since auditory-verbal material is more commonly encountered than the identification of visuo-spatial items within a small space, it is also possible that speech-based motor processes are more refined and readily accessible than its movement-based motor counterpart (Hughes *et al*., 2009; Jones *et al*., 2006; 2007).

The findings from the postcued group in Experiment 7, can be somewhat explained through domain-general frameworks. Using the analogy of the multimodal video camera, during presentation, list items are encoded one after the other and at test, participants are instructed to recall either the auditory-words or the visuo-spatial location, however, regardless of modality, they need to “rewind” back to the context of the start of the list to enable them to replay the required events. If auditory-words have longer and/or stronger activation than visuo-spatial items, then when only the visuo-spatial items of a mixed-modality list need to be recalled, the highly activated auditory-words are harder to inhibit and this therefore hinders the recall of visuo-spatial items. When the words need to be recalled, the visuo-spatial items have to be inhibited, but because the latter are more transient, the words, while still adversely affected, are not affected to the same degree as the visuo-spatial items.

ON THE LINKING OF VERBAL AND VISUO-SPATIAL STIMULI

The previous Chapter pondered whether some form of active linking or binding was occurring when participants were presented with and had to recall mixed-modality lists, when the two stimulus domains were presented either concurrently or in alternation. This was because data from Experiment 4 and 5 revealed a dominant tendency to output mixed-modality lists in alternation, with word-dot being the most prevalent and also the quickest response. It is possible that at encoding, the dots were linked to the words (e.g. by "placing" them into a visuo-spatial location) and then retrieved together at test. It is more conceivable for this to be the case when two cross-modality stimuli are presented simultaneously, as it is possible for participants to view both stimuli as forming one independent to-be-remembered event. However, this is somewhat less likely to happen when list items occur in alternation and do not overlap, although one could suppose participants are able to continue to process words and actively associate them with visuo-spatial locations. Additionally, the fact that participants output word-dot even when they were presented with dot-word, implied that if any binding were indeed happening, this would require some form of active post-item processing that "places" a later word in a previously presented visuo-spatial location.

The purpose of using the randomised presentation lists was to ensure that these one-to-one word-to-dot binding would be greatly disrupted, not least because there would be likely uneven numbers of words and visuo-spatial locations at different points in the stimulus presentation. However, the tendency to output in cross-modality alternation was still present, albeit reduced. When solely considering the first three outputs of the dual-tasks groups, it is clear that whereas WDW outputs made up 66.7% and 58.9% of all responses for the parallel and alternating presentation groups in Experiment 5, this tendency is halved down to 32.3% and 29.8% in the randomised presentation conditions of Experiment 6 and 7 respectively. Furthermore, when analysing the number of occurrences where the first consecutive word and visuo-spatial location had the same within-modality position, it is clear that although such outputs were common even in the randomised presentation group (and this would explain the temporal contiguity effects found), they are much less reduced than the ones found in Experiment 4 and 5. For example, whereas in Experiment 5, participants initiated recall with either a word-dot or a dot-word transition in 84.3% of trials in the parallel presentation group and in 87.7% in the alternating presentation group, in Experiment 6 and 7 such outputs made up 64.8% and 31.5% of trials respectively.

Consequently, it seems highly unlikely that participants in the randomised presentation groups were binding the auditory-words and visuo-spatial locations together as one object. Furthermore, the strong alternating tendency found in Chapter 3, might not be necessarily due to binding either. As previously discussed, it is possible that participants' tendency to recall in forwards order, which has been shown to be present in both the verbal and visuo-spatial domains, is very strong and in both the parallel and alternating presentation, participants could not recall in forwards order unless they alternate between outputs.

THE ROLE OF ALTERNATION

Considering that the tendency to alternate between stimulus domains in Experiment 6 and 7 is highly unlikely to be due to the linking of cross-modality items, why are participants still alternating in the randomised presentation condition? Findings from both split-span findings, where participants were asked to recall concurrently presented verbal stimuli, either to different ears or in different voices (Broadbent, 1956; 1957a; Dornbush, 1968; Wingfield & Byrnes, 1972), and from mixed-modality lists consisting of auditory and visual items (Murdock & Carey, 1972; Murdock & Walker, 1979), have repeatedly shown that participants tend to categorize their output either by ear, by voice or by modality.

Somewhat surprisingly, the present data has never shown such channel-by-channel recall and there is only limited evidence that same-modality items were often grouped together. For instance, in both Experiments 6 and 7, participants outputted nine items on average (not necessarily correctly) and regardless of the number of chunks within the presented list, participants grouped these items into between 5 and 6 chunks. Therefore, it is clear that participants were not outputting by modality, although that is not to say that participants are unable to do so. In Experiment 7, when the presented lists contained two chunks (i.e. it was made up of six items from one modality followed by six items from the other modality), the average number of observed chunks was also two, implying that participants outputted in a similar way to that presented.

When dictating the participants' output strategy, Wingfield and Byrnes (1972), who separated items by channel by presenting words in a male and female voice, found that channel-by-channel recall was superior to pair-by-pair strategy. This was not the case, in the present findings, since across Experiments 4 to 7, outputting the first three outputs in alternation, especially when starting with the word (i.e. WDW), resulted in equivalent and sometimes even superior accuracy then when outputting three same-modality items consecutively. It is therefore apparent that alternation is not only the widely preferred recall method, because participants spontaneously do it in IFR, but also seems to be the strategy that yields the higher recall accuracy.

Wingfield and Byrnes (1972) argued that in their study, pair-by-pair recall was inferior due to temporal decay, since reaction time data showed that channel-by-channel recall was much faster than pair-by-pair recall. Experiments 4 to 7 showed opposite findings, whereby, same-modality transitions where much slower than cross-modality ones and perhaps this is why alternating outputs result in higher accuracy. Perhaps the main distinction between the present Experiments and previous split-span and mixed-modality experiments is the mode of output of the stimuli. In the outlined literature, regardless of whether the stimuli were presented in different presentation modes, different voices, or to different ears, there was only one way to output the recall: they either spoke or wrote down the recalled words. In the present experiment series, participants spoke their words and clicked on the visuo-spatial locations, thereby allowing participants to output both modalities (potentially) simultaneously. Conversely, participants in the split-span and mixed-modality lists studies could never overlap any of their responses, since this was physically impossible.

Consequently, when required to output spoken words and visuo-spatial locations, participants recognise that the faster way to do so is by outputting the word while simultaneously preparing the mouse to output the visuo-spatial location. Because this mode of output is much faster, the representations of the items are more likely to remain intact or within the focus of attention and this result in higher accuracy, compared to when outputting a string of same-modality items.

SUMMARY AND CONCLUSIONS

Chapter 4 showed that when participants are presented with randomised lists of auditory-verbal and visuo-spatial locations, they do not output in a channel-by-channel manner. On the contrary, they are more likely to output in an alternating manner. However, this tendency to alternate is almost halved when compared to the previous experiments were participants saw concurrently presented or alternating words and visuo-spatial dots. Therefore, this tendency does not seem to be the product of the associating or binding an auditory-word to a visuo-spatial location, but rather a tendency to output as many items as possible in order to maximise recall. Furthermore, presenting participants with mixed-modality lists and then postcueing them as to which items need to be output yields broadly similar findings to when participants are presented with and required to recall both stimulus domains. This implies that the decrement between single- and dual-modality tasks especially with regard to the visuo-spatial domain, is due to participants knowing less at test, due to the larger number of to-be-encoded items. Overall, these findings seem to be more parsimonious with a domain-general view of memory that encodes all types of stimuli at all timescales; this will be further discussed in Chapter 5.

CHAPTER 5

CHAPTER 5

The present thesis has provided novel empirical data comparing the IFR of verbal and visuo-spatial material, in both single- and dual-modality tasks. It has informed our understanding of the similarities and differences between the two domains, as well as the relationship between them. My findings show: similar list length and output order effects in the IFR of verbal and visuo-spatial material; at least partially independent capacities and extremely constrained output order in mixed-modality dual-modality tasks where a verbal item is presented concurrently with a visuo-spatial item; and an asymmetry between the stimulus domains' capacities and constrained outputs in sequential mixed-modality lists.

I begin with a summary of the main thesis questions, followed by a summary of the specific findings from each Chapter, then move to more general findings from the thesis and how these can be explained using existing theories and models of immediate memory. I propose one possible interpretation of the findings followed by propositions for future research within the field.

SUMMARY OF THE MAIN THESIS QUESTIONS

There were three main questions within the present thesis. First, I wanted to delineate the similarities and differences between the verbal and visuo-spatial modalities, by equating the methods used to test them. The earlier work comparing the two domains (e.g. Broadbent & Broadbent, 1981; Phillips & Christie, 1977a), focused on the differences between them. These differences were exaggerated by the use of different methods of testing (IFR and ISR in the verbal domain; same-different judgement task and ISR in the visuo-spatial domain). Research performed in the last decade however (e.g. Farrand *et al.*, 2001; Guérard and Tremblay, 2008; Ward *et al.*, 2005), has expounded on a number of similarities between the two modalities by comparing the ISR of verbal and non-verbal material. However, the IFR of visuo-spatial items has been left relatively unexplored (Bonanni *et al*., 2007; Gmeindl *et al*., 2011). This is somewhat surprising given that IFR can be exceedingly helpful to ascertain how participants spontaneously choose to recall, and provides unconstrained data that can elucidate capacity, list length effects and chosen output orders.

Second, and more specifically, I wanted to test whether list length and output order effects found in the IFR of words (Ward *et al.*, 2010), can also be found in the IFR of visuo-spatial items; that is, whether participants show a tendency to start with the first list item in short lists and with one of the last four presented items at longer lists. Similar output order effects in both domains imply that the tendency to start with the first presented item in short lists, is not limited to a language-specific mechanism, but rather it could be either the result of two domain-specific memory stores that operate in quasi-identical ways or a general episodic memory mechanism that operates on all stimuli at all timescales.

Consequently, the third and final aim of the thesis was to determine whether a modality-specific (e.g. Working Memory model, Baddeley, 1986, 2007, 2012) or a modality-general (e.g. Embedded Processes model, Cowan, 1988, 1995, 2005; Perceptual Gestural account, Hughes *et al*., 2009; Jones *et al*., 2006, 2007) approach to immediate memory is better placed to explain the output order, list length and capacity effects found in verbal and visuo-spatial single- and dual-modality tasks.

SUMMARY OF THE MAIN FINDINGS

This thesis presents seven experiments that have been conducted in order to answer these three main questions. Chapter 2 examined whether the list length and output order effects found in the IFR of words (Ward *et al.*, 2010) could also be found in the IFR of visuo-spatial items. Experiment 1 utilised a visuo-spatial task, akin to a computerised Corsi block task, where at test, participants were asked to select the subset of rectangles that had previously turned black, in any order that they liked. This visuo-spatial task yielded similar list length and output order effects to those found in the verbal domain: accuracy decreased with increasing list length and participants outputted visuo-spatial locations in an "ISR-like" manner, even when this was not a task requirement. Experiment 2 replicated these findings while directly comparing verbal and visuo-spatial IFR. Experiment 3 further equated the visuo-spatial IFR task to its verbal counterpart using the dots task, which eliminated the recognition element of the rectangles task and there were comparable list length and output order effects in both stimulus domains. I argued that the list length and output order effects observed by Ward *et al*. (2010) do not necessitate a language-based retrieval mechanism and that the similarities between verbal and visuo-spatial IFR could reflect either two separate domain-specific retrieval mechanisms that operate in very similar ways, or a domain-general mechanism that operates on all stimuli at all timescales.

Chapter 3 analysed and compared the capacity and output order effects in the verbal and visuo-spatial domains in single- and dual-modality tasks to ascertain whether the list length and output order effects found in Chapter 2 are better explained by either a domain-specific or domain-general framework. Experiment 4 showed that when participants were presented concurrently with auditory-words and visuo-spatial dots, there were summed capacities and extremely constrained output order in the dual-modality task, in that participants showed a strong tendency to alternate between modalities. Experiment 5 replicated these findings with regards to parallel presentation, but also showed that removing the temporal overlap of stimuli by alternating modalities at presentation, resulted in similar constrained outputs but in an asymmetry between the domains' capacity. Whereas the verbal recall accuracy remained relatively consistent in the dual-modality task, visuo-spatial performance saw a significant decrease. I argued that neither a domain-general or domain-specific framework fully accounts for these results and therefore sought to examine the issue of constrained output orders when cross-modality items could not be linked or bound together.

Chapter 4 further examined the issues raised in Chapter 3 by ensuring that the constrained and alternating outputs in the dual-modality task were not due to the linking of two cross-modality items together (potentially encouraged by list structure). Additionally, it also examined whether the asymmetry between the verbal and visuo-spatial capacities was due to the increased number of items requiring encoding or whether this was due to output interference at test. Experiment 6 showed that when recalling mixed-modality lists consisting of randomly presented auditory-words and visuo-spatial dots, there was an asymmetry between the domains' capacities and participants were still alternating by modality, albeit at a reduced rate. Experiment 7 showed that the asymmetry between domains is due to an increased number of to-be-encoded items, rather than output interference, since postcueing participants as to which modality needed to be recalled, resulted in almost equivalent performance to when participants were required to output both modalities. I concluded that the tendency to alternate between domains is due to the ease with which participants can output the different cross-domain responses, which in turn leads to faster output and higher recall accuracy.

SIMILARITIES AND DIFFERENCES ACROSS MODALITIES

The seven experiments in the current thesis provide an extensive comparison between verbal and visuo-spatial IFR, which enables for a better test of similarities and differences between the two modalities.

SIMILARITIES BETWEEN VERBAL AND VISUO-SPATIAL MEMORY

There were four main similarities between the two stimulus domains. First, I found that in both IFR tasks, recall accuracy decreased with increasing list length (list length effect).

Second, there were similarities in how the serial position curves varied with list length. In both IFR tasks, at short lists, the serial position curves were relatively flat, but as list length increased, there were increased primacy and recency effects leading to bowed curves, with the longer list lengths showing extended recency effects.

Third, there were also similarities in the probability of first recall data, where in both modalities, participants tended to initiate recall with the first presented item on the short lists, but this tendency decreased with increasing list length, such that, at the longer list lengths, participants' correct modal response was one of the last four stimulus items on the list. Finally, the resultant serial position curves were greatly affected by initial recall. For both modalities, when the first item recalled was the first presented item, there was increased primacy and reduced recency. Conversely, when the first recalled item was one of the last four presented items, there was greater recency and reduced primacy. Consequently, the number of similarities between the verbal and visuo-spatial domains in IFR tasks, support the Ward *et al*. (2005) claims that using closely equated methodologies across domains result in a greater number of similarities than when the methodologies are not fully equated.

DIFFERENCES BETWEEN VERBAL AND VISUO-SPATIAL MEMORY

Although there are a number of similarities between the IFR of verbal and visuo-spatial stimuli, there are also at least four differences. First, when the IFR tasks were fully equated by using the dots FR task (Experiments 3-6), there was a marked difference between the overall accuracy of the two modalities. Whereas in the verbal domain, short lists lengths yield ceiling level performances, the visuo-spatial performance for short lists was below that of ceiling levels. Second, in the visuo-spatial domain, the primacy and recency effects were relatively weaker to those of their verbal counterpart. Gmeindl *et al*. (2011) offer two possible explanations for this: (1) perhaps verbal items are better bound to their temporal context than the visuo-spatial ones;

(2) alternatively, in the visuo-spatial domain, output order may be affected by the spatial proximity of the list items, such that participants output spatially close items successively thus superseding temporal order (but see Gmeindl, Nelson & Wiggin, 2011). However, there may be two additional reasons for these reduced effects: first, verbal items are inherently richer stimuli than the visuo-spatial dots, in that, the former vary along more dimensions than the latter (e.g. semantic, orthographic, phonological) and second, the verbal stimuli benefit from phonological recoding and rehearsal whereas the visuo-spatial items do not.

The third difference between verbal and visuo-spatial IFR, is that in Experiments 2 and 3, articulatory suppression had an adverse effect on the verbal stimulus domain, but not on the visuo-spatial one. Articulatory suppression in the verbal domain reduced the overall accuracy, resulted in steeper primacy and recency effects and reduced the tendency to initiate recall with the first presented list item, whereas the visuo-spatial domain remained unaffected. This suggests that visuo-spatial IFR is not mediated by verbal recoding, whereas verbal IFR benefits from phonological recoding. In the Working Memory model (Baddeley, 1986, 2000, 2007), the Phonological Loop is thought to be responsible for such phonological recoding thus contributing to the tendency to recall in a forward-ordered manner in IFR. However, this forward ordered tendency was also found, albeit at a reduced rate, when visually presented words presented under articulatory suppression were recalled (Experiments 2 and 3; Spurgeon *et al*., 2014a), when such items are assumed to not go through the phonological loop. An alternative interpretation is that the mental representation of visual words is stronger when it also includes phonological features, and this therefore makes them more discriminable at test. A third possible interpretation is that in order to be able to generate streams of ordered visual items, verbal recoding needs to occur (Jones, 2003). A fourth alternative interpretation using Farrell's (2012) clustering account is that, because words are grouped together within temporal clusters, preventing co-articulation of words within a group results into a smaller group size and therefore lower accuracy.

The fourth and final difference between the verbal and visuo-spatial domain, was found in the dual-modality tasks. There was a marked asymmetry between the two domains, such that, there was a significant decrease in the recall accuracy of the visuo-spatial items in the dual-modality task utilising sequential presentation, when compared to the single-modality task. A possible interpretation for this could be that auditory-verbal information has stronger activation levels than visuo-spatial information due to the former being inherently richer (Morey & Mall, 2012). A second possible interpretation is that since verbal material is more commonly processed in day-to-day activities than visuo-spatial locations in a restricted visual field, participants attended to verbal stimuli more than the visuo-spatial items (Hughes *et al*., 2009; Jones *et al*., 2006, 2007; Logie *et al*., 2004).

Overall, although there are a few differences between the IFR of verbal and visuo-spatial material, it is clear that there are also a number of gross similarities especially pertaining to the output order effects of both domains. More specifically, in both stimulus domains, participants tend to initiate their recall by outputting the first list item in short lists, whereas at longer lists, participants start their recall with one of the last four presented items on the list. I will now focus on the tendency to initiate the IFR of a short list of words or visuo-spatial items with the first list item.

THE TENDENCY TO START RECALL WITH THE FIRST LIST ITEM

When systematically manipulating list length in a verbal IFR task, Ward *et al*. (2010) showed that participants who were presented with short lists of words, typically recalled the items in a forward-ordered "ISR-like" manner. In my thesis, these list length and output order effects were replicated in the verbal domain and extended to the visuo-spatial domain, such that in the IFR of both stimulus types, participants showed a tendency to start at the start in short lists and with one of the last four list items in longer lists. Furthermore, in both stimulus domains, the first recalled item had predictive quality as regards the subsequently recalled items. When participants start with the first presented item, they continue recalling early list items resulting in greater primacy and reduced recency. Conversely, when participants start with one of the last four presented items, they proceed to recall the later items in the list, thus resulting in greater recency and reduced primacy effects.

As previously outlined, the tendency to initiate recall with the first item on the list in the verbal domain may be augmented by a verbal recoding mechanism such as the Phonological loop (Spurgeon *et al*., 2014a) or some kind of verbal STS (Spurgeon *et al*., 2014b) but does not necessitate either. Finding this tendency to start at the start in the non-verbal visuo-spatial domain across all seven experiments further supports these claims that these output order effects are not underpinned by a language-specific mechanism. This was further supported in Experiments 1 to 3, where articulatory suppression in the visuo-spatial domain had no effect on recall patterns. Consequently, this converging evidence implies that this tendency to start at the start and recall in a forward ordered manner is not a result of an order-sensitive language-specific mechanism but may reflect a more general property of memory that holds across a range of materials and timescales.

WHY START AT THE START?

The question of why this forward-ordered tendency is found across a range of stimulus domains is undoubtedly an interesting one. One line of argument is that the ability to perform things in forward serial order is necessary in day-to-day activities, from the learning of sequences of phonemes and graphemes to enable vocabulary acquisition, to the retention of sequences of motor actions and social behaviours that are necessary to perform complex tasks and function effectively within society (Lashley, 1951). Since this forward order is necessary to perform higher-level cognitive functions, it may be "hard-wired" into our memory processes

(Hurlstone *et al*. 2014). Indeed, there is evidence suggesting that we may naturally segment our day-to-day experiences into separate events at different temporal contexts, and that recall of these events is highly dependent on perceptual event boundaries (Kurby & Zacks, 2008; Swallow *et al*., 2009). Similarly, Farrell (2012) argues that when encoding lists of words in verbal immediate memory tasks, similar temporal clustering also occurs and therefore assumes that verbal IFR utilises the same forward-ordered mechanism used to recall words in the same order as presented in ISR tasks.

A second line of argument could be that recalling short lists of words in forwards order maximises recall accuracy. Kahana and Caplan (2002) presented participants with lists of words for serial learning and then used a probed recall task, where participants were required to recall an item after being cued using preceding or consecutive items. They found that a recall for a particular item is better when cued with the item preceding it, rather than the one following it, thus showing a clear advantage for forward serial order. Additionally, Lohnas and Kahana (2014) showed that in IFR, recalling two items from successive serial positions, resulted in stronger temporal contiguity effects and heightened recall advantage for the third recalled item; a phenomenon that they termed compound cueing. Finally, in a list learning experiment, Klein, Addis, and Kahana (2005) showed that whereas the recall accuracy is higher for IFR compared to ISR on the first recall, the overall list is learnt quicker in ISR than IFR. When considering the above discussed evidence, it is possible that participants choose to start with the first presented item to benefit from these forward-ordered contiguity effects.

WHY DO PARTICIPANTS START RECALL WITH A WORD IN DUAL-MODALITY IFR?

Experiments 4 to 7 compared verbal and visuo-spatial IFR in single- and dual-modality tasks. The use of mixed-modality lists allowed for the analysis of which modality is outputted first as well as the output order within- and across-modality. Regardless of whether the mixed-modality lists were made up of concurrently or sequentially presented auditory-words and visuo-spatial locations, participants started their recall with a word more often than a visuo-spatial locations, despite the fact that in sequential mixed-modality lists, only half of the trials were initiated with an auditory-word.

There are three possible lines of arguments that can explain this preference to start recall with a word. One line of argument is that auditory traces are more accessible after a short delay than visual ones, and so are more available at test. In accordance with this, whereas auditory traces have been found to last for approximately three seconds (Darwin *et al.*, 1972), visual traces last about one second (Averbach & Coriell, 1960). Additionally, since verbal words vary along multiple dimensions and have more distinct characteristics (e.g. semantic, phonology) than visuo-spatial dots or rectangles, they may, according to some models have more features and so are more discriminable (Nairne, 1988). Perhaps participants are aware that their retention for visuo-spatial locations is much less durable than auditory-words, and therefore choose to start with the modality of which they are most certain.

A second line of argument is related to the fact that the tendency to start with the first presented item (although not necessitating a language-specific mechanism), is nevertheless augmented by some degree of verbal recoding. Rehearsal may make the output order effects somewhat stronger in the verbal domain, when compared to the visuo-spatial modality, and so, when both items can be outputted in a dual-modality IFR task, participants may output the word first since this allows for a better chance of recalling in forwards order, which may result in better accuracy.

The third line of argument offers a more practical reason. Words can be simply output as soon as the test phase starts, whereas to output visuo-spatial locations, participants need to move the cursor from the fixed locked position and adjust it to the position of the visuo-spatial item they are trying to output. As discussed in Chapter 4, the tendency to alternate between words and visuo-spatial locations, even when participants are presented with randomly presented auditory-words and visuo-spatial locations, is likely to be at least partially, a strategy of reducing the time taken to output responses, and therefore it is conceivable that the preference to output a word first may also be a similar strategy.

IMPLICATIONS FOR MODELS OF IMMEDIATE MEMORY

In this section, I will first broadly discuss the implications of my findings for theories of IFR and ISR for both the verbal and visuo-spatial domains. I will then discuss in-depth how various domain-general (Working Memory model) and domain-specific (Embedded-Processes model, O-OER, Perceptual-Gestural account) models of memory can account for my findings, in particular the IFR performance of dual-modality tasks.

IMPLICATIONS FOR IFR MODELS

As discussed in Chapter 1, many models and theories of immediate memory were concerned solely with verbal material and therefore these models have never been directly applied to non-verbal recall. This is particularly due to the fact that it has only been in the last twenty years, that extensive similarities between stimulus domains have been expounded on (e.g. Jones *et al*., 1995; Parmentier, 2014; Ward *et al.*, 2005). However, given the similarities in the list length and output order effects in the verbal and visuo-spatial domain, I will discuss how such models can account for the data in both modalities.

Unitary IFR models that assume that there are common mechanisms for encoding, storage and retrieval of all list items (e.g. Brown *et al*., 2007; Glenberg *et al.*, 1980; Howard & Kahana, 2002; Polyn *et al.*, 2009; Sederberg *et al*., 2008; Tan & Ward, 2000), are able to account for both recency and contiguity effects found across stimulus domains. Such temporal distinctiveness models, assume that recency is the result of the last few list items being learned against a temporal context that has not drifted much by the recall test (Glenberg *et al*., 1980; Howard & Kahana, 2002), or that the last few items are the last items being rehearsed and thus can be easily retrieved (Tan & Ward, 2000). Since neighbouring items have a shared context, they are recalled closely together (hence, the temporal contiguity effects) and therefore an effective context enables the recall of all items associated or learned against the particular retrieved context. Although such models can account for primacy by assuming that the first temporal context has the advantage of being highly distinctive due to the reduced number of neighbours or the increased opportunities for rehearsal, they do not account for the fact that the primacy at short lists is considerably stronger than the recall of the last few presented items (i.e. the flat serial position curves).

The tendency to recall a list of words or visuo-spatial locations in an "ISR-like" manner, is also problematic for IFR dual-store models that are concerned with explaining the recency found at long lists and that are therefore unable to account for the heightened accessibility of the first presented item (e.g. Davelaar *et al*., 2005; Farrell, 2010; Lehman & Malmberg, 2013; Raaijmakers & Shiffrin, 1981; Unsworth & Engle, 2007).

However, this tendency to output lists in an IFR tasks in "ISR-like" manner could be explained through a temporal grouping account, such as the clustering account (Farrell, 2012). The clustering account assumes that lists are grouped into separate clusters and explains forward ordered recall through the use of within-group markers that make use of a primacy gradient at recall - this is consistent regardless of whether the task at hand is IFR or ISR. A more detailed discussion of how such an account can apply to the present data will be put forth later on in this chapter.

Figure 1.1 (see Chapter 1, page 4) depicted the different relationships that can be explored through the comparison of verbal and visuo-spatial IFR. Since IFR models were particularly tailored to explaining the recall of long lists of words, it is of interest to examine how such models can encapsulate the visuo-spatial IFR data. Overall, given the similar list length and output order effects in both domains, it seems that the findings from visuo-spatial IFR can be explained in similar ways to those of verbal IFR and thus it is possible to conclude that they work in quasi-identical ways (see (2) on Figure 1.1). Finally, since the sequential mixed-modality lists showed similar output order effects when using both within-modality and overall cross-modality serial positions, the same arguments made for how the IFR models account for the data also applies to those experiments using dual-modality tasks.

IMPLICATIONS FOR ISR MODELS

Although all the experiments within the present thesis made use of IFR tasks, it is important to note that a discussion of the implications of the present data for ISR models is necessary. This is mainly due to two reasons: (1) there have been numerous studies showing that IFR and ISR are underpinned by similar mechanisms and are affected similarly by different variables (Beaman, 2006; Bhatarah *et al.*, 2008; Bhatarah *et al.*, 2009; Brown *et al.*, 2007; Farrell, 2012; Grenfell-Essam *et al.*, 2013, Spurgeon *et al.*, 2014a, 2014b; Ward *et al.*, 2010) and (2) that investigations of visuo-spatial immediate memory have predominantly made use of ISR rather IFR tasks (see Chapter 1). Therefore, given that there are a number of similarities between IFR and ISR tasks in the verbal domain, visuo-spatial IFR can in turn also be informative for ISR models.

Similar to IFR models, the majority of models that have attempted to explain the primacy effects and forward serial order that are typically found in ISR tasks have done so within the verbal domain (Botvinick & Plaut, 2006; Brown *et al.*, 2000; Burgess & Hitch, 1999, 2006; Farrell & Lewandowsky, 2002; Henson, 1998; Lewandowsky & Farrell, 2008; Lewandowsky & Murdock, 1989; Nairne, 1988, 1990; Neath, 2000; Page & Norris, 1998, 2003), with very few attempting to do this in both the verbal and non-verbal domain (Baddeley, 1986, 2007, 2012; Hughes *et al*., 2009; Jones, 1993; Jones *et al*., 1996, 2006, 2007) and in some cases the models' exhaustiveness comes at the expense of "the model being vague in places" (Cowan, 2005, p. 40). These theories and models are not usually used to explain IFR data, and cannot account why at longer lists, one of the last few presented items have heightened accessibility over the first list item in both the verbal and the visuo-spatial domains.

Spurgeon *et al*. (2014a) examined whether the Working Memory model (Baddeley, 1986, 2007, 2012) could encompass the tendency to start with the first item in short lists and the tendency to start with one of the last few items in longer lists. They posit that perhaps the "ISR-like" output is a result of the phonological loop, whereas the recency in the IFR of longer lists could be the result of the episodic buffer, which has the back-up role of supporting ISR (Baddeley, 2000). However, they found limited evidence that recall from the phonological loop (visual recall without articulatory suppression), was qualitatively different from recall from the episodic buffer (visual recall with articulatory suppression), and therefore concluded that the Working Memory model cannot fully account for these output order effects. As previously discussed, finding output order effects in the visuo-spatial domain further implies that the this tendency is not the merely a characteristic of the phonological loop. Although it is possible for the visuo-spatial sketchpad to operate in a quasi-identical manner to the phonological loop, I will later discuss why the findings from dual-modality tasks may not be entirely compatible with this approach.

The tendency to start with the first presented item, presents a second potential problem for ISR models that predict graded primacy. Models that assume that the first item is retrieved due to its association with a special context (Brown *et al.*, 2000; Burgess & Hitch, 1999, 2006; Henson, 1998) or heightened activation (Lewandowsky & Farrell, 2008; Page & Norris, 1998) and therefore if it is not retrieved, the second presented item is more likely to be recalled, followed by the consequent list items. In my data, the recall from both the verbal and visuo-spatial IFR tasks showed that the tendency to start with either the first item or one of the last four items heavily outweighed the proportion of trials where recall was initiated with the one of the middle list items (denoted by 'Other' in PFR plots).

As discussed in the preceding paragraphs, although ISR models cannot fully account for the output order effects found in the verbal and visuo-spatial domain, especially because they were modelled mostly with verbal data, they may still prove to be useful to an extent, to explain non-verbal findings (Vandierendonck & Szmalec, 2011). This has been discussed in a recent review by Hurlstone *et al*. (2014), who delineated the main computational memory mechanisms utilised in ISR models (i.e. competitive queuing, position marking, primacy gradient, response suppression, cumulative matching and output interference) in order to examine whether verbal, visual and spatial memory are underpinned by similar serial order mechanisms.

Hurlstone *et al*. (2014) argue for separate verbal, visual and spatial short-term memory systems but state that the similarities found across stimulus domains is driven by competitive queuing. In competitive queuing, all presented list items are simultaneously considered for output and the item with the strongest activation is outputted and immediately suppressed, to enable the output of other list items. Moreover, they suggest that whereas there is evidence that serial order is also represented by a primacy gradient, position marking, response suppression and cumulative matching in the verbal domain, and that recall is effected by item similarity and output interference, there is limited evidence of this in the non-verbal domain which is mainly due to sparse research within the field. Finally, Hurlstone *et al*. argue that the Burgess and Hitch (1999, 2006) revised network model is potentially the strongest ISR model that is able to account for large number of data sets, including the Hebb repetition effect.

The present data partially support the arguments for an integrated approach to serial order across domains made by Hurlstone *et al*. by showing similar list length and output order effects in both the verbal and visuo-spatial modalities. However, as described above, there is not much evidence for primacy grading in the visuo-spatial domain, since participants were more likely to either start at the start or with one of the last few list items relative to the second item or other middle items. Finally, the constrained within- and cross-modality output order found in the dual-modality tasks suggest that the retrieval mechanisms for the verbal and visuo-spatial may not be entirely independent.

A contrasting approach to serial order across domains was put forth by Abrahamse *et al*. (2014) who state that serial order has its roots in the spatial attention system, whereby each item is marked by a position marker akin to a spatial coordinate that is then used to reconstruct order, where effective retrieval requires the particular spatial coordinates to be selected by spatial attention. Abrahamse *et al*. (2014) explain the Gmeindl *et al*.'s (2011) findings that visuo-spatial items were less likely to be bound to serial order when compared to words, by stating that the internal spatial attention required to recall serial order interferes with the maintenance of external visuo-spatial locations. Using this line of argument, it is possible that the tendency to start with either the first or last few list items is reduced relative to the verbal domain due to the interference between spatial attention required for serial order and the maintenance of a visuo-spatial list.

As can be gleaned from the above approaches to serial order, there is an on-going debate as to whether there are domain-general or domain-specific retrieval mechanisms. As a consequence, I will now describe the implications of the dual-task findings on domain-general and domain-specific frameworks of immediate memory.

DOMAIN-GENERAL VS DOMAIN-SPECIFIC MODELS OF MEMORY

The similar list length and output order effects found in the present thesis, more specifically, the tendency to start with the first list item in single-modality verbal and visuo-spatial lists could be reflective of three possibilities. The first possibility is that there are separate domain-specific verbal and visuo-spatial memory stores that each maintains the serial order of items in quasi-identical ways (e.g. the phonological loop and the visuo-spatial sketch pad which maintain serial order in the same way in the Working Memory model; Logie, 1995).

The second possibility is that memory is domain-specific and retains the serial order of all stimuli but selective interference, through for example, articulatory suppression in the verbal domain, results from the primary and secondary tasks relying on somewhat similar perceptual organization and gestural execution in order to output responses (Jones *et al*., 2006, 2004). A somewhat related third possibility is that memory is a non-modular mechanism that retains the serial order of all stimuli, but that selective interference occurs when the primary and secondary tasks contain similar items having common features (e.g. items from a specific modality), and therefore items having similar features interfere more with each other than items that do not share common features (Cowan, 2005).

The findings from the dual-modality tasks utilising mixed-modality lists, in particular capacity and output order effects, help distinguish between the three possibilities. I will therefore discuss and compare how each of the three memory frameworks can account for these effects across the various dual-modality tasks and conclude with my preferred interpretation of the results.

ACCOUNTING FOR CAPACITY

In Chapters 3 and 4, I used the analogy of the recording devices to help visualise the implications of dual-modality tasks on domain-general and domain-specific memory frameworks. The Working Memory Model (Baddeley, 1986, 2007, 2012) is a multi-component model comprising of domain-specific stores: the phonological loop for verbal information and the visuo-spatial sketchpad for visuo-spatial material. In the recording devices analogy the phonological loop can be likened to a recording tape, whereas the visuo-spatial sketchpad can be thought of as a silent camera. Consequently, these domain-specific stores are able to store, maintain, rehearse and retrieve information independently of each other and therefore can also have different capacities.

Conversely, a domain-general mechanism such as the O-OER (Jones, 1993; Jones *et al*., 1996), Perceptual-Gestural account (Hughes *et al*., 2009; Jones *et al*., 2006, 2007) and the Embedded-Processes model (Cowan, 1988, 1995, 1999, 2005) can be likened to a multimedia video camera that can capture both sounds and sight and therefore does not posit a functional distinction between verbal and non-verbal modalities. Such frameworks have a central amodal capacity and therefore if the summed capacities in single-modality task exceed this central capacity then one should expect an overall capacity decrease in dual-modality tasks relative to their single-modality counterpart.

When participants were required to recall concurrently presented auditory-words and visuo-spatial dots, there was no trade-off between the verbal and visuo-spatial performance and especially at mid-length lists, there were summed capacities of both domain in the dual-modality task. This would be predicted in a domain-specific approach, since both stores can hold information independently. However, the findings can be somewhat problematic for a domain-general approach with a central limit capacity, unless one were to assume that mid-length lists were within the central limit capacity. Cowan (2001, 2005) argues that concurrent presentation encourages a closer association or grouping between items than sequential presentation, and this may increase the number of items that can be maintained in the central limit capacity. This would be somewhat consistent with the asymmetry found between the verbal and visuo-spatial domain in sequentially presented mixed-modality lists, where cross-modality items were less likely to be grouped together.

When cross-domain stimuli were presented in alternation or in a randomised serial order, the visuo-spatial performance decreased in the dual-modality task, compared to the single-modality task, whereas the verbal performance remained relatively consistent. This asymmetry cannot be fully explained by a domain-specific framework, because if the stores are independent, then the maintenance of one domain should not hinder that of another. The episodic buffer, which has the role of supporting and integrating information from the two domain-specific stores also could not account for this asymmetry unless there is evidence that the visuo-spatial sketch pad is less supported by the episodic buffer relative to the phonological loop (Morey & Mall, 2012).

A domain-general view is perhaps better placed in explaining these results since once the central limit capacity is reached due to the doubling of information in the dual-modality tasks, one would expect an overall adverse effect on recall. However, it is unclear why the decrease in performance only affects the visuo-spatial domain. This asymmetry is quite hard to explain in O-OER model (Jones, 1993; Jones *et al*., 1996). One could assume that when the stimuli were presented concurrently, an auditory-word and a visuo-spatial location were detected as being a singular object, whereas in sequential presentation, the consistent change in energy due to the different modality objects, resulted in effectively twice as many objects to be recalled. This would result in an overall decrease but its less clear why verbal recall remains unaffected.

A perceptual-gestural account (Hughes *et al*., 2009; Jones *et al*., 2006, 2007) can potentially account for this asymmetry if one were to assume that because auditory-verbal material is encountered more often than visuo-spatial locations on a limited visual field, the speech-based motor processes required to recall verbal material are more readily accessible and refined than visuo-spatial motor plans (Morey & Mall, 2012). However, if this is the case, then it is unclear why the asymmetry is not found in concurrently presented stimuli, unless one were to assume that somehow the concurrently presented auditory-words and visuo-spatial stimuli were assigned to the same stream. This is unlikely to be the case since the model centres around list items being organised into different streams even within an auditory stream, whereby even a difference in the tone or pitch can lead to organisation in different streams (Hughes *et al*., 2009).

In the Embedded-Processes model (Cowan 1995, 2005), the asymmetry can only be explained if one were to assume that the auditory-verbal information has stronger activations than visuo-spatial information. This may be due to the fact that auditory traces are more resistant to temporal decay than visual ones (Kahana, 2012) and therefore the auditory-words remain longer in the focus of attention. Additionally, Cowan (2005) states that whereas the stimuli's sensory characteristics result in automatic activation, semantic features require attention to enable activation. It is conceivable that because verbal material requires the activation of both sensory and semantic features, participants may expend more attention on the verbal material at the expense of the visuo-spatial locations. Moreover, because verbal material has more varying and distinguishing features both within itself and when compared to visuo-spatial information, this may lead to heightened activation for the verbal material which is therefore more likely to remain in the focus of attention than its visuo-spatial counterpart.

The decrease in the verbal and visuo-spatial capacities (although more marked in the visuo-spatial domain) in the dual-modality postcued condition can also help inform whether there are domain-general or domain-specific mechanisms. In a domain-specific approach, such as the Working Memory model, each list item in a mixed-modality list is stored and maintained in its respective store. Since the stores are independent, having to then output an individual store, depending on which modality is required, should not result in a decrease in recall performance. Therefore, the Working Memory model is not well placed to account for these post-cued dual-modality task findings.

Within the O-OER, the decrease in performance in both domains can be explained due to twice as many pointers at encoding, thus leading to less rehearsal of list items, increased temporal decay and consequently decreased capacities. Within the perceptual-gestural account, at encoding, a time-critical mixed-modality motor plan is constructed, but at recall, this motor plan is not entirely useful since to recall one modality, participants need to go through the motor plan and inhibit those items that need not be recalled. This may have a disruptive effect on the motor plan and consequently the required recall. In the embedded-processes model, mixed-modality list items are chunked into new events through episodic links. Since events can very rarely be retrieved and recalled in their entirety (because only one modality is required at test), the requirement to inhibit the items that are not required may result in an overall decrease in performance.

ACCOUNTING FOR OUTPUT ORDER

By reusing the analogy of the recording devices, domain-specific frameworks postulating functionally distinct verbal and visuo-spatial domains have independent output orders, such that it is possible for one store to output domain-specific items from the start of the list, while the other one outputs item from the end of the list (since the serial order of items in the recording tape are independent of those in the silent camera). Additionally, it is potentially more efficient to output one store/device followed by the other, rather than consistently switching between stores and therefore this should result in channel-by-channel recall. All the dual-modality task data showed that participants do not output by modality, but rather in a forward-ordered manner, whereby neighbouring verbal and visuo-spatial stimuli were recalled in close proximity of each other resulting in temporal contiguity effects. In fact, there was very limited evidence that participants recall the two domains from different ends of the list.

In the case of a domain-general retrieval mechanism akin to a multimedia video camera, it is intuitive to assume that at test participants are able to "rewind" back to the start of the list and recall in forwards order regardless of modality. This would lead to constrained output orders and temporal contiguity effects. In parallel presentation, outputs were tightly yoked, such that a word of serial position *x* was almost always followed by the visuo-spatial location of a matching serial position; presenting cross-domain stimuli in alternation between domains also yielded very similar results. Randomising presentation was done to ensure that the cross-domain stimuli were not being associated on a one-to-one basis and even in this manipulation, outputs were still constrained and there were temporal contiguity effects.

The O-OER model states that serial order is maintained via links or pointers that act as associative cues to objects (Jones *et al*., 1993). These pointers decay over time and therefore require rehearsal. Since this model allows for both serial and non-serial recall procedures, this model can account for the output order found in the dual-modality tasks, since the data shows a great deal of forward serial order recall in IFR tasks.

In the perceptual-gestural account, order information is best encoded in sequence boundaries and items within one stream are easier to recall in order. This encapsulates some of the dual-modality task data, particularly in the alternating condition, whereby this meant that each item had its own boundaries due to a consistent change in modality and this would therefore explain the constrained output. However, if items within one stream are easier to recall, then consecutive same-modality items should be better recalled than cross-modality items. Although outputting consecutive words results in a similar overall number of correct outputs as when participants alternate, this does not hold in the visuo-spatial domain (i.e. when participants recall three consecutive visuo-spatial locations).

The embedded-processes model does not have an explicit mechanism that explains how serial order is processed (Acheson & MacDonald, 2009). However, Cowan (1995, 2005) states that working memory is not merely heightened activated items within long-term memory, but also plays an active part in creating new episodic links that are then structured into events. Since during list presentation items are activated and are within the scope of attention, the episodic links formed by working memory are inevitably constructed in the forward serial order that the items are presented in. It is possible to speculate that in such a framework, recall is done through reinstating the newly formed episodic links within the focus of attention and therefore this would result in a forward order recall and temporal contiguity effects.

From the above discussion of how domain-specific and domain-general retrieval mechanisms can account for the present findings, it is clear that my data do not subscribe to any one type of framework. Accordingly, I will tentatively put forth a potential framework that I think best fits the novel findings of the thesis.

INTEGRATING ISR AND IFR ACROSS DOMAINS

Although earlier research with the IFR and ISR of words expounded on the differences between the two tasks, there is now a number of studies that show support for the theoretical integration of the two tasks, as they have been found to be underpinned by similar processes and are affected by a number of common variables (Beaman, 2006; Bhatarah *et al.*, 2008; Bhatarah *et al.*, 2009; Brown *et al.*, 2007; Farrell, 2012; Grenfell-Essam *et al.*, 2013, Spurgeon *et al.*, 2014a, 2014b; Ward *et al.*, 2010). The tendency to recall a short list of words in an IFR task in an "ISR-like" manner is a well-replicated finding (Spurgeon *et al.*, 2014a, 2014b; Ward *et al.*, 2010).

The present thesis replicated this finding in the IFR of words as well as extended it to the non-verbal domain, by finding similar list length and output order effects in the IFR of visuo-spatial rectangles or dots. Since there are only two previous studies that utilised a visuo-spatial IFR task, my present thesis is the first comprehensive study of the output order and list length effects found in visuo-spatial IFR and consequently has delineated novel gross similarities between verbal and visuo-spatial IFR. Given that there are a number of similar findings found in both the ISR of verbal and non-verbal material, such as similar serial position curves (Avons, 1998; Avons & Mason, 1999; Smyth *et al.*, 2005), list length effects (Ward *et al.*, 2005; Agam *et al.*, 2005), error patterns and generalization gradients (Guérard and Tremblay, 2008) and temporal grouping effects (Parmentier *et al*., 2004, 2006) amongst others (refer to Chapter 1), it is possible that equating visuo-spatial IFR and ISR will also lead to similar findings in both types of task.

Referring back to Figure 1.1, my present thesis has firstly supported the evidence that verbal IFR and ISR are underpinned by similar mechanisms due to the "ISR-like" recall in IFR. Second, it has shown that there are a number of similarities between verbal and visuo-spatial IFR. Third, as summarised in Chapter 1, there are also a number of similarities between verbal and visuo-spatial ISR. Fourth, the present thesis showed that visuo-spatial IFR yields bowed serial position curves and list length effects similar to those found in visuo-spatial ISR (Avons, 1998; Ward *et al*., 2005) and this could imply that there are similar mechanisms for these two tasks as well.

MY PREFERRED INTERPRETATION OF THE FINDINGS

In their study of concurrently and sequentially presented verbal and visuo-spatial items, Morey and Mall (2012) examine a number of domain-general (Working Memory model) and domain-specific models of memory (Perceptual-Gestural account; Embedded-Processes model) and they propose that none of these current models summarised in their paper (and subsequently in my thesis) could fully account for the asymmetry found between the verbal and visuo-spatial capacities. My data also cannot be fully encapsulated within either type of framework and I will therefore propose a hybrid model that is more domain-general than domain-specific in nature, that can potentially account for the ISR and IFR findings across domains.

Given the number of similarities found between the ISR and IFR across the verbal and visuo-spatial domain, I argue that a domain-general framework such as the Embedded-Processes model (Cowan, 1988, 1995, 2005) with a serial order mechanism that can account for both IFR and ISR findings is well placed to account for my data. Regrettably, Cowan's model has never delineated an explicit mechanism for how serial order is maintained (Acheson & MacDonald, 2009). Instead, at encoding list items are associated to each other and to their serial position, through episodic links that create new episodic records in long-term memory.

Cowan's (1988, 1995, 1999, 2005) model proposes a unitary memory system akin to long-term memory, where some items that are especially accessible for a limited time are termed activated memory. Activated memory is amodal and therefore it includes all types of processing: verbal, visual, spatial, olfactory, tactile etc. A smaller portion of activated memory is within the focus of attention and this leads to efficient recall. When participants are presented with an immediate recall task, some stimuli's features activate portions of long-term memory, whereas other features are harder to activate unless they are brought within the focus of attention. Additionally, whereas sensory features are automatic so that they can enable quick detection in the environment, other features such as semantic and phonological features are activated through the use of attention (Conway, Cowan, & Bunting, 2001). The focus of attention is very limited and in adulthood it can hold between three to five chunks, however, activated memory does not have capacity limits, but is constrained because of time and interference, where similar items interfere more with one another than dissimilar ones; this explains selective interference (e.g. effect of articulatory suppression).

As previously discussed, the model can account for the summed capacities in concurrently presented cross-domain stimuli, since they are more easily grouped together and this results in an increase in the amount of data in a chunk. The asymmetry between the domains' capacity when cross-domain stimuli are presented sequentially can be explained by two assumptions. First, activated memory is constrained by temporal decay, and since auditory traces last longer than visual ones (Kahana, 2012), auditory-words are more likely to be strongly activated than visuo-spatial locations. Second, auditory-words have a larger number of features (e.g. phonology, semantics) compared to visuo-spatial locations. This has two implications: (1)

auditory-words are more likely to activate portions of long-term memory (2) they are also more likely to attract heightened attention due to their added features.

Although a domain-general framework like Cowan's is relatively good to account for the capacity findings in the dual-modality task, it is less well suited to account for the output order effects, and this is due to the lack of an explicit serial order mechanism. In this framework, when a list of items is presented each item is associated with another as well as its serial position, thus creating a novel episodic record within long-term memory. At recall, this episodic record is assumed to be highly activated, resulting in it moving within the focus of attention and consequent recall. The episodic links between items should be forward-ordered since they are formed as the list is presented, and therefore at retrieval, output should be forward-ordered and neighbouring items should be recalled together. To a certain extent, this can explain the "ISR-like" recall in IFR and the tendency to start with the first item in short lists. However, it cannot really account for bowed serial position curves, as well as the tendency to start with one of the last four items in longer lists, unless one were to assume that the last few items are chunked into one event that is the most highly activated and thus most likely to be recalled. However, this is never explicitly described within the model and therefore I propose that such a model requires a serial order mechanism based on temporal grouping such as the clustering account by Farrell (2012).

I will now describe how such a mechanism can be incorporated within the embedded-processes model. The clustering account suggests that IFR and ISR are underpinned by a similar encoding mechanism, where items within a list are grouped into different clusters - this is similar to the concept of chunks within the embedded-processes model, where items are bound to each other and to a temporal context. The number and size of groups is dependent on a number of factors such as age of the individual and type of material - this is also relatively similar to the concept of chunking in Cowan's model. Each group consists of a number of markers that follow a primacy gradient, where items at group boundaries are better recalled due to their special status.

At test, recall is hierarchical, in that a group first needs to be retrieved, then the group marker is outputted first, followed by the retrieval of the other items within the group, thus resulting in forward-ordered recall and temporal contiguity effects. At retrieval, the group that was last encoded is more likely to be recalled apart from the first group that has the greatest temporal distinctiveness due to its novel status. Whereas in ISR, groups need to be recalled in the order they were presented, there is also flexibility that allows for IFR, and in this case participants tend to first output those groups that are easiest to retrieve. This model also accounts for the lack of primacy gradient in the single-modality data since, for example the second and third items can never be group markers and therefore if their groups are not retrieved, they are unlikely to be recalled.

Finally, although such a serial order mechanism can account for most of my data in that it can account for the forward serial order and temporal contiguity effects found in both the single- and dual-modality tasks, it is unable to explain why participants in the dual-modality tasks tend to start output with a word. Perhaps, the model could benefit from elaborating how different stimulus domains can have heightened group status due to their inherent features and characteristics, or how different stimulus domains can have an impact on group size.

Overall, I have described how a hybrid of Cowan's (1988, 1995, 2005) domain-specific model with Farrell's (2012) temporal clustering account as a serial order mechanism can help achieve a more parsimonious account that is able to integrate a large number of datasets of ISR and IFR tasks across domains. I will now describe further research that can help inform this hybrid model further.

DIRECTIONS FOR FUTURE RESEARCH

DEALING WITH THE LOW PERFORMANCE IN THE VISUO-SPATIAL DOMAIN

My thesis has shown that when properly equating verbal and visuo-spatial tasks, by utilising the dots task, performance was relatively poor in the visuo-spatial domain compared to the verbal task. The visuo-spatial rectangles IFR task yields a more comparable recall performance to verbal IFR, but there is an undeniable recognition element in this task. Consequently, the dots task is a truer IFR test than the rectangles task, albeit a much more challenging one. In my experiments, for a response to be considered correct, participants had to click within the area covered by the visuo-spatial dot. Widening the target response area could potentially be beneficial for overall recall performance as it would reduce the number of near-misses (i.e. clicks just outside the border of the dot).

DIRECT COMPARISON OF VISUO-SPATIAL ISR AND IFR

Whereas there have been a number of studies comparing IFR and ISR tasks in the verbal domain, to my knowledge, there are no such comparisons within the visuo-spatial field. The fact that I have found list length effects, bowed serial position curves and forward ordered recall in visuo-spatial IFR, encourages the assumption that when IFR and ISR are equated in the visuo-spatial domain, further similarities can be expounded on. A number of variables that have been explored in the comparison of verbal ISR and IFR can be examined in the visuo-spatial domain such as the effects of visual complexity (analogous to word length effect; Bhatarah *et al*., 2009), presentation rate (Bhatarah *et al*., 2009), spatial tapping (analogous to articulatory suppression; Bhatarah *et al*., 2006, 2009) delayed and continuous distracter free recall (Spurgeon *et al*., 2014a, 2014b) and temporal grouping (Spurgeon, Ward, Matthews, & Farrell, 2015). Some of these effects have been found in visuo-spatial ISR and RoO tasks, such as active interference (Barton *et al*., 1995; Farmer *et al*., 1986; Smyth & Scholey, 1994), visual complexity effects (Bruyer & Scailquin, 1998; Parmentier *et al*., 2005) and temporal grouping effects (Parmentier *et al*., 2004, 2006). However it would be more useful to have a direct comparison of these effects in IFR and ISR to help delineate the similarities of these tasks across domains.

My current thesis also used inter-response times as a measure in both verbal and visuo-spatial domains. Although a number of studies have recorded such data for verbal immediate recall tasks (e.g. Sederberg, Miller, Howard & Kahana, 2010; Miller, Kahana & Wiedermann, 2012; Murdock & Okada, 1970) very little is known about visuo-spatial response times. In the present thesis inter-response times were very consistent across outputs. It would be of interest to test whether visuo-spatial ISR will have similar reaction times to those found in IFR. It is possible that because IFR does not require the reassembling of serial order, outputs are faster than those situations were items do not only need to be retrieved but also need to be outputted in the order they were presented in.

Another alternative measure for visuo-spatial performance is the analysis of incorrect items and omissions. Guérard and Tremblay (2008), analysed errors in visuo-spatial ISR and found similar patterns and generalization gradients to those found with verbal ISR. More specifically, that transposition errors are more common than item errors and that intrusion and omission errors increased with increasing serial position. It would therefore be of interest to see whether visuo-spatial IFR yields similar error patterns to its ISR counterpart, as it could be further evidence of similar mechanisms underpinning both tasks.

FINDING ADDITIONAL PHENOMENA ACROSS DOMAINS

In their recent review of serial order phenomena across the verbal, visual and spatial domain, Hurlstone *et al*. (2014) identify a number of findings that have been found in the verbal domain but have yet to be investigated in the visual and/or spatial domain. These include analysis of latency in forwards and backwards serial position curves, analysis of transposition latencies, protrusions and repetitions in error patterns, item similarity effects and the Ranschburg effect amongst other. Given that these findings would shed light on whether serial order is maintained in similar ways across domains, data sets expounding on such recall patterns could be invaluable for the research field.

FURTHERING THE DUAL-MODALITY TASK

The present thesis made use of mixed-modality lists that aid the understanding of whether there are domain-general or domain-specific mechanisms. Utilising such lists within a FR setting is extremely informative because it demonstrates how participants naturally retrieve items of different modalities within a list. Given the temporal contiguity effects and the forward serial order in the IFR task, it is conceivable that similar recall patterns could be also be found in the ISR of such lists.

Moreover, although the dual-modality tasks showed temporal contiguity effects, participants clearly prefer to output by alternating modalities, since this is the most time-efficient way of outputting cross-modality items (i.e. saying a word while simultaneously moving the cursor to a visuo-spatial location). It would be of interest to see how capacities are affected when this tendency is restricted by list structure. Additionally, manipulating list structure in ISR would be helpful to determine the boundaries of participants' output order capabilities. For example, participants very rarely choose to output by modality, and therefore it would be of interest to see how recall performance is affected when participants are required to do so due to the presented list structure.

SELECTIVE INTERFERENCE WITHIN THE DUAL-MODALITY TASK

In single-modality tasks, secondary tasks such as spatial tapping or articulatory suppression result in selective interference, i.e. a verbal secondary task interferes more with a verbal task than with a visuo-spatial one and vice versa (e.g. Farmer *et al*., 1986). It would be of interest to test whether this selective interference would still be found in mixed-modality lists. This is of particular interest in situations where auditory-words are more likely to be associated to a visuo-spatial location, such as in the parallel presentation condition. If these cross-modality items are bound together, it is possible that a secondary task might interfere with the recall of both items. However, in a randomised mixed-modality list, where items are perceived individually and are thus not grouped or bound together, a secondary task should only affect the items of the same domain.

THE ROLE OF STIMULI CHARACTERISTICS IN DOMAIN ASYMMETRY

One line of argument used throughout my thesis, that attempts to explain the asymmetry between verbal and visuo-spatial recall, is that verbal information varies along more dimensions than monochrome visuo-spatial dots or rectangles. To test such a hypothesis, it is possible to add more characteristics to the visuo-spatial stimuli without making them amenable to verbal recoding, by utilising unnameable stimuli such as random polygons (Chen, Eng, & Jiang, 2006), snowflakes (Neath, 1993) or Chinese characters (Eadie & Shum, 1995). Alternatively, verbal material can be stripped off its semantic meanings and links to long-term memory by utilising non-words. However, given that verbal stimuli in dual-modality tasks are presented in auditory format and responses are spoken so as to enable the recording of reaction times that is then used to determine the overall output order, spoken non-words can be problematic to score definitively.

Perhaps, a RoO task would be better suited to determine whether the asymmetry found in the recall of mixed-modality lists is due to the stimulus features.

SUMMARY AND CONCLUSIONS

In summary, I have provided a number of novel findings regarding list length, capacities and output order effects by comparing the IFR of verbal and visuo-spatial stimuli in single- and dual-modality tasks. I have shown that the tendency to start with the first item in the verbal domain does not necessitate a language-mechanism since this tendency can also be found in visuo-spatial IFR. In dual-modality tasks using mixed-modality lists, I found forward serial order recall and temporal contiguity effects that are enhanced if auditory-words and visuo-spatial locations are presented concurrently or in alternation relative to a randomised order. Additionally, whereas parallel presentation of two stimulus domains leads to summed capacities, sequential presentation results in a disadvantage for the visuo-spatial domain. In light of these findings I argue that the capacity and output order effects are better accounted within a domain-general framework of memory rather than a domain-specific one and argue that this requires a detailed serial mechanism across domains that can account for both IFR and ISR findings.

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APPENDICES

Appendix 2.1

Experiment 1: Analyses of the IFR serial position curves from Experiment 1, shown in Figure 2.3, using all the data with FR scoring for the No AS and AS groups respectively. At each list length, the IFR data were subjected to a 2 (AS and No AS group) x *n* (serial position: SP, 1, …, *n*) mixed ANOVA, where *n* refers here, and throughout the Appendices, to the list length.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
2	F (1,38) = 1.04, MSE=.005, η^2_p= .027, p = .313	F (1,38) = .322, MSE=.005, η^2_p= .008, p = .574	F (1,38) = .322, MSE=.005, η^2_p= .008, p = .574
3	F (1,38) = .581, MSE=.016, η^2_p= .015, p = .451	F (2,76) = .687, MSE=.010, η^2_p= .018, p = .506	F (2,76) = .873, MSE=.010, η^2_p= .022, p = .422
4	F (1,38) = .114, MSE=.016, η^2_p= .003, p = .737	F (3,114) = .606, MSE=.020, η^2_p= .016, p = .612	F (3,114) = 1.28, MSE=.020, η^2_p= .033, p = .284
5	F (1,38) = 2.21, MSE=.051, η^2_p= .055, p = .145	**F (4,152) = 2.65, MSE=.022, η^2_p= .065, p = .035**	F (4,152) = .929, MSE=.022, η^2_p= .024, p = .449
6	F (1,38) = 3.81, MSE=.042, η^2_p= .091, p = .059	**F (5,190) = 4.71, MSE=.031, η^2_p= .110, p < .001**	F (5,190) = 1.03, MSE=.031, η^2_p= .026, p =. 400
7	F (1,38) = 3.39, MSE=.063, η^2_p= .082, p = .073	**F (6,228) = 5.97, MSE=.030, η^2_p= .136, p < .001**	F (6,228) = .858, MSE=.030, η^2_p= .022, p = .527
8	**F (1,38) = 4.64, MSE=.061, η^2_p= .109, p = .038**	**F (7,266) = 9.40, MSE=.033, η^2_p= .198, p < .001**	F (7,266) = .990, MSE=.033, η^2_p= .025,p = .439
10	F (1,38) = .249, MSE=.054, η^2_p= .007, p = .621	**F (9,342) = 7.01, MSE=.034, η^2_p= .156, p < .001**	F (9,342) = .970, MSE=.034, η^2_p= .025p = .464
12	F (1,38) = .214, MSE=.053, η^2_p= .006, p = .646	**F (11,418) = 10.1, MSE=.034, η^2_p=.210, p < .001**	F (11,418) = 1.19, MSE=.034, η^2_p=.030, p =.290
15	F (1,38) = 1.96, MSE=.039, η^2_p= .049, p = .170	**F (14,532) = 6.28, MSE=.030, η^2_p= .142, p < .001**	**F (14,532) = 1.74, MSE=.030, η^2_p= .044, p=.044**

Note: significant main effects and interactions are presented in bold

Appendix 2.2

Experiment 1: Analyses of the IFR serial position curves from Experiment 1, shown in Figure 2.5 (panels A and B), using only data from trials starting with SP1 with FR scoring. At each list length, the free recall data were subjected to a 2 (group: AS and No AS) x $n - 1$ (serial position: SP, 2, …,n) mixed ANOVA. Note that there were relatively few participants included in the analysis at longer list lengths.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
3 AS = 20; S = 19	F (1,37)=.037, MSE= .017, η^2_p= .001, p = .849	F (1,37) = 3.88, MSE= .021, η^2_p= .095, p = .056	F (1,37) = .312, MSE= .021, η^2_p= .008, p = .580
4 AS = 20; S = 20	F (1,38) =1.72, MSE= .052, η^2_p= .043, p = .197	F (2,76) = .413, MSE= .037, η^2_p= .011, p = .663	F (2,76) = .402, MSE= .037, η^2_p= .010, p = .671
5 AS = 18; S = 19	F (1,35) = .627, MSE= .080, η^2_p= .018, p = .434	F (3,105) = .725, MSE= .040, η^2_p= .020, p = .539	F (3,105) = .245, MSE= .040, η^2_p= .007, p = .865
6 AS = 17; S = 20	F (1,35) = 3.88, MSE= .070, η^2_p= .100, p = .057	**F (4,140) = 3.75, MSE= .081, η^2_p= .097, p = .006**	F (4,140) = 1.19, MSE= .081 , η^2_p= .033, p = .319
7 AS = 17; S = 18	F (1,33) = 3.92, MSE= .127, η^2_p= .106, p = .056	F (5,165) = 1.81, MSE= .102, η^2_p= .052, p = .114	F (5,165) = 1.74, MSE= .102, η^2_p= .050, p = .127
8 AS = 19; S = 16	F (1,33) = .124, MSE= .234, η^2_p= .004, p = .727	**F (6,198) = 2.46, MSE= .096, η^2_p= .069, p = .026**	F (6,198) = 1.65, MSE= .096, η^2_p= .048, p = .135
10 AS = 15; S = 15	F (1,28) = .006, MSE= .134, η^2_p< .001, p = .938	**F (8,224) = 2.04, MSE= .153, η^2_p= .068, p = .043**	F (8,224) = .975, MSE= .153, η^2_p= .034, p = .456
12 AS = 13; S = 13	F (1,24) = .017, MSE= .175, η^2_p= .001, p = .898	F (10,240) = 1.77, MSE= .147, η^2_p=.069, p = .068	F (10,240) = .324, MSE= .147 , η^2_p= .013, p = .974
15 AS = 10; S = 12	F (1,20) = 2.98, MSE= .101, η^2_p= .130, p = .100	**F (13,260) = 2.14, MSE= .171, η^2_p= .097, p = .012**	F (13,260) = .760, MSE= .171 , η^2_p= .037, p = .702

Note: significant main effects and interactions are presented in bold. ‘AS’ and ‘S’ stand for the number of participants contributing to the ANOVA from the AS and No AS groups respectively.

Appendix 2.3

Experiment 1: Analyses of the IFR serial position curves from Experiment 1, shown in Figure 2.5 (panels C and D), using only data from trials starting with SP1 with SR scoring. At each list length, the free recall data were subjected to a 2 (group: AS and No AS) x $n - 1$ (serial position: SP, 2, …,n) mixed ANOVA. Note that there were relatively few participants included in the analysis at longer list lengths.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
3 AS = 20; S = 19	F (1,37)=.830, p = .368, η^2_p= .022, MSE= .119	**F (1,37) = 5.24, p = .028, η^2_p= .124, MSE= .009**	F (1,37) = .591, p = .447, η^2_p= .016, MSE= .009
4 AS = 20; S = 20	F (1,38) =.237, p = .629, η^2_p= .006, MSE= .199	F (2,76) = 1.10, p = .337, η^2_p= .028, MSE= .052	F (2,76) = .057, p = .944, η^2_p= .002, MSE= .052
5 AS = 18; S = 19	F (1,35) = 3.83, p = .058, η^2_p= .099, MSE= .126	**F (3,105) = 4.54, p = .005, η^2_p= .115, MSE= .054**	F (3,105) = .519, p = .670, η^2_p= .015, MSE= .054
6 AS = 17; S = 20	F (1,35) = 1.60, p = .214, η^2_p= .044, MSE= .110	**F (4,140) = 9.38, p < .001, η^2_p= .211, MSE= .063**	F (4,140) = .437, p = .782, η^2_p= .012, MSE= .063
7 AS = 17; S = 18	F (1,33) = .449, p = .507, η^2_p= .013, MSE= .106	**F (5,165) = 5.14, p < .001, η^2_p= .135, MSE= .067**	F (5,165) = 1.80, p = .117, η^2_p= .052, MSE= .067
8 AS = 19; S = 16	F (1,33) = .238, p = .629, η^2_p= .007, MSE= .067	**F (6,198) = 9.04, p < .001, η^2_p= .215, MSE= .041**	F (6,198) = .562, p = .760, η^2_p= .017, MSE= .041
10 AS = 15; S = 15	F (1,28) = .635, p = .432, η^2_p=.022, MSE= .119	**F (8,224) = 4.45, p < .001, η^2_p= .137, MSE= .045**	F (8,224) = 1.13, p = .344, η^2_p= .039, MSE= .045
12 AS = 13; S = 13	F (1,24) = .087, p = .721, η^2_p= .004, MSE= .047	F (10,240) = 1.80, p = .061, η^2_p=.070, MSE= .041	F (10,240) = .915, p = .520, η^2_p= .037, MSE= .041
15 AS = 10; S = 12	F (1,20) = .239, p = .239, η^2_p= .068, MSE= .044	**F (13,260) = 4.38, p < .001, η^2_p= .180, MSE= .131**	F (13,260) = .569, p = .878, η^2_p= .028, MSE= .031

Note: significant main effects and interactions are presented in bold. 'AS' and 'S' stand for the number of participants contributing to the ANOVA from the AS and No AS groups respectively.

Appendix 2.4

Experiment 1: Analyses of the IFR serial position curves from Experiment 1, shown in Figure 2.5 (panels E and F), using only data from trials starting with one of the last 4 serial positions with FR scoring. At each list length, the free recall data were subjected to a 2 (group: AS and No AS) x *n* (serial position) mixed ANOVA.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
3 AS = 18; S = 17	*F* (1,33) = .658, *MSE* = .045, η^2_p = .020, *p* = .423	***F* (2,66) = 5.42, *MSE* = .041, η^2_p= .134, *p* = .007**	*F* (2,66) = 1.13, *MSE* = .041, η^2_p= .033, *p* = .330
4 AS = 17; S = 17	*F* (1,32) = 1.66, *MSE* = .040, η^2_p= .049, *p* = .207	*F* (3,96) = 1.58, *MSE* = .034, η^2_p= .040, *p* = .200	*F* (3,96) = .221, *MSE* = .034 , η^2_p= .007, *p* = .882
5 AS = 18; S = 17	*F* (1,33) = .316, *MSE* = .109, η^2_p= .009, *p* = .578	***F* (4,132) = 4.59, *MSE* = .058, η^2_p= .109, *p* = .002**	*F* (4,132) = 1.66, *MSE* = .058, η^2_p= .048, *p* = .163
6 AS = 17; S = 18	*F* (1,33) = 2.39, *MSE* = .150, η^2_p= .067, *p* = .132	***F* (5,165) = 6.21, *MSE* = .069, η^2_p= .163, *p* < .001**	*F* (5,165) = .428, *MSE* = .069, η^2_p= .013, *p* = .828
7 AS = 17; S = 18	*F* (1,33) = .552, *MSE* = .124, η^2_p= .016, *p* = .463	***F* (6,198) = 9.54, *MSE* = .066, η^2_p= .211, *p* < .001**	*F* (6,198) = .626, *MSE* = .066, η^2_p= .019, *p* = .709
8 AS = 17; S = 18	***F* (1,33) = 4.57, *MSE* = .098, η^2_p= .122, *p* = .040**	***F* (7,231) = 12.7, *MSE* = .064, η^2_p= .278, *p* < .001**	*F* (7,231) = .674, *MSE* = .064, η^2_p= .020, *p* = .694
10 AS = 17; S = 19	*F* (1,34) = 1.40, *MSE* = .069, η^2_p = .040, *p* = .245	***F* (9,306) = 7.68, *MSE* = .073, η^2_p= .184, *p* < .001**	*F* (9,306) = .354, *MSE* = .073, η^2_p= .010, *p* =.956
12 AS = 18; S = 20	*F* (1,36) = .198, *MSE* = .073, η^2_p= .005, *p* = .659	***F* (11,396) = 7.93, *MSE* = .084, η^2_p=.180, *p* < .001**	*F* (11,396) = 1.78, *MSE* = .084, η^2_p=.047, *p* = .056
15 AS = 19; S = 19	*F* (1,36) = 1.53, *MSE* = .091, η^2_p= .041, *p* = .224	***F* (14,504) = 6.31, *MSE* = .078, η^2_p= .141, *p* < .001**	*F* (14,504) = 1.66, *MSE* = .078 , η^2_p= .044, *p* = .060

Note: significant main effects and interactions are presented in bold. ‘AS’ and ‘S’ stand for the number of participants contributing to the ANOVA from the AS and No AS groups respectively.

Appendix 2.5

Experiment 2: Analyses of the IFR serial position curves from Experiment 2, shown in Figure 2.7, using all the data with FR scoring for the verbal and visuo-spatial group respectively. At each list length, the IFR data were subjected to a 2 (AS and No AS group) x n (serial position: SP, 1, …, n) mixed ANOVA, where n refers here, and throughout the Appendices, to the list length.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
Verbal Data			
2	**F (1,19) = 4.44, MSE=.016, η^2_p= .189, p = .049**	F (1,19) = .884, MSE=.009, η^2_p = .044, p = .359	F (1,19) = .002, MSE=.007, η^2_p= .014, p = .606
3	**F (1,19) = 15.8, MSE=.064, η^2_p= .454, p = .001**	F (2,38) = 2.03, MSE=.039, η^2_p= .096, p = .146	F (2,38) = 1.22, MSE=.035, η^2_p= .060, p = .306
4	**F (1,19) = 88.4, MSE=.029, η^2_p= .823, p < .001**	**F (3,57) = 4.62, MSE=.053, η^2_p= .196, p = .006**	**F (3,57) = 5.70, MSE=.047, η^2_p= .231, p = .002**
5	**F (1,19) = 57.8, MSE=.033, η^2_p= .753, p < .001**	**F (4,76) = 3.87, MSE=.046, η^2_p= .169, p = .007**	**F (4,76) = 14.3, MSE=.049, η^2_p= .429, p < .001**
6	**F (1,19) = 37.1, MSE=.045, η^2_p= .661, p < .001**	**F (5,95) = 11.2, MSE=.058, η^2_p= .370, p < .001**	**F (5,95) = 9.32, MSE=.046, η^2_p= .329, p < .001**
7	**F (1,19) = 20.6, MSE=.064, η^2_p= .520, p < .001**	**F (6,114) = 11.1, MSE=.056, η^2_p= .370, p < .001**	**F (6,114) = 7.75, MSE=.042, η^2_p= .290, p < .001**
8	**F (1,19) = 44.0, MSE=.022, η^2_p= .699, p < .001**	**F (7,133) = 16.8, MSE=.052, η^2_p= .469, p < .001**	**F (7,133) = 3.19, MSE=.042, η^2_p= .144, p = .004**
10	**F (1,19) = 39.1, MSE=.024, η^2_p= .673, p < .001**	**F (9,171) = 14.8, MSE=.073, η^2_p= .437, p < .001**	**F (9,171) = 3.10, MSE=.048, η^2_p= .140, p = .002**
12	**F (1,19) = 47.2, MSE=.020, η^2_p= .713, p < .001**	**F (11,209) = 24.1, MSE=.041, η^2_p=.559, p < .001**	**F (11,209) = 2.63, MSE=.033, η^2_p=.121, p = .004**
Visuo-Spatial Data			
2	F (1,19) = .664, MSE=.019, η^2_p= .034, p = .425	F (1,19) = 1.21, MSE=.020, η^2_p = .060, p = .286	F (1,19) = .026, MSE=.019, η^2_p = .001, p = .874
3	**F (1,19) = 6.26, MSE=.023, η^2_p= .248, p = .022**	F (2,38) = 1.00, MSE=.013, η^2_p= .050, p = .377	F (2,38) = .649, MSE=.020, η^2_p= .033, p = .528
4	**F (1,19) = 10.0, MSE=.062, η^2_p= .345, p = .005**	F (3,57) = 1.25, MSE=.086, η^2_p= .062, p = .300	F (3,57) = .789, MSE=.031, η^2_p= .040, p = .505
5	F (1,19) = .964, MSE=.035, η^2_p= .048, p = .339	F (4,76) = 1.14, MSE=.046, η^2_p= .057, p = .344	F (4,76) = .346, MSE=.041, η^2_p= .018, p = .846
6	F (1,19) = .437, MSE=.046, η^2_p= .022, p = .516	**F (5,95) = 3.70, MSE=.069, η^2_p= .163, p = .004**	F (5,95) = .620, MSE=.046, η^2_p= .032, p = .685

7	$F\,(1,19) = .260$, MSE=.067, η^2_p= .013, $p = .616$	**$F\,(6,114) = 6.68$, MSE=.079, η^2_p= .260, $p < .001$**	$F\,(6,114) = .812$, MSE=.044, η^2_p= .041, $p = .563$
8	$F\,(1,19) = .011$, MSE=.104, η^2_p= .001, $p = .918$	**$F\,(7,133) = 3.30$, MSE=.080, η^2_p= .148, $p = .003$**	$F\,(7,133) = .940$, MSE=.045, η^2_p= .047, $p = .478$
10	$F\,(1,19) = 1.53$, MSE=.024, η^2_p= .074, $p = .232$	**$F\,(9,171) = 6.93$, MSE=.074, η^2_p= .267, $p < .001$**	$F\,(9,171) = .829$, MSE=.044, η^2_p= .042, $p = .591$
12	$F\,(1,19) = 2.33$, MSE=.108, η^2_p= .109, $p = .143$	**$F\,(11,209) = 7.80$, MSE=.055, η^2_p=.291, $p < .001$**	$F\,(11,209) = .673$, MSE=.050, η^2_p=.034, $p = .763$

Note: significant main effects and interactions are presented in bold

Appendix 2.6

Experiment 2: Analyses of the IFR serial position curves from Experiment 2, shown in Figure 2.9 and Figure 2.10 (panels A and B), using only data from trials starting with SP1 with FR scoring. At each list length, the free recall data were subjected to a 2 (group: AS and No AS) x $n - 1$ (serial position: SP, 2, …,n) mixed ANOVA. Note that there were relatively few participants included in the analysis at longer list lengths.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
Verbal Data			
3 N = 19	**F (1,18) = 7.55, MSE= .079, η^2_p= .296, p = .013**	F (1,18) = .749, MSE= .079, η^2_p= .040, p = .398	F (1,18) = .406, MSE= .048, η^2_p= .022, p = .532
4 N = 16	**F (1,15) = 19.0, MSE= .075, η^2_p= .558, p = .001**	F (2,30) = .458, MSE= .084, η^2_p= .030, p = .637	F (2,30) = 1.48, MSE= .067, η^2_p= .090, p = .244
5 N = 11	**F (1,10) = 33.0, MSE= .026, η^2_p= .767, p < .001**	F (3,30) = .904, MSE= .081, η^2_p= .083, p = .451	**F (3,30) = 7.15, MSE= .088, η^2_p= .417, p = .001**
6 N = 13	**F (1,12) = 13.1, MSE= .104, η^2_p= .521, p = .004**	F (4,48) = 1.49, MSE= .124, η^2_p= .110, p = .221	**F (4,48) = 3.84, MSE= .128 , η^2_p= .243, p = .009**
7 N = 10	**F (1,9) = 30.6, MSE= .051, η^2_p= .772, p < .001**	F (5,45) = .150, MSE= .188, η^2_p= .016, p = .979	F (5,45) = 1.50, MSE= .181, η^2_p= .143, p = .208
8 N = 6	F (1,5) = 2.77, MSE= .057, η^2_p= .356, p = .157	**F (6,30) = 3.47, MSE= .122, η^2_p= .410, p = .010**	F (6,30) = 1.50, MSE= .142, η^2_p= .231, p = .212
10 N = 5	**F (1,4) = 10.1, MSE= .031, η^2_p= .716, p = .036**	F (8,32) = 2.10, MSE= .146, η^2_p= .344, p = .065	F (8,32) = .458, MSE= .171, η^2_p= .103, p = .876
12 N = 5	**F (1,4) = 52.1, MSE= .008, η^2_p= .929, p = .002**	F (10,40) = .667, MSE= .097, η^2_p=.143, p = .747	F (10,40) = 1.29, MSE= .109 , η^2_p= .243, p = .271
Visuo-Spatial Data			
3 N = 20	F (1,19)= 4.19, MSE= .056, η^2_p= .181, p = .055	F (1,19) = .656, MSE= .058, η^2_p= .033, p = .428	F (1,19) = .359, MSE= .060, η^2_p= .019, p = .556
4	F (1,18) = 2.50, MSE= .070, η^2_p= .122, p = .131	F (2,36) = .023, MSE= .097, η^2_p= .001, p = .977	F (2,36) = .059, MSE= .074, η^2_p= .003, p = .943

$N = 19$			
5 $N = 16$	F (1,15) = .140, MSE= .072, η^2_p= .009, p = .714	F (3,45) = 2.67, MSE= .053, η^2_p= .151, p = .059	F (3,45) = .817, MSE= .076, η^2_p= .052, p = .492
6 $N = 18$	F (1,17) = .262, MSE= .083, η^2_p= .015, p = .615	F (4,68) = 2.22, MSE= .116, η^2_p= .115, p = .076	F (4,68) = .808, MSE= .117, η^2_p= .045, p = .525
7 $N = 16$	F (1,15) = .638, MSE= .104, η^2_p= .041, p = .437	**F (5,75) = 5.10, MSE= .133, η^2_p= .254, $p < .001$**	**F (5,75) = 2.43, MSE= .084, η^2_p= .140, p = .042**
8 $N = 14$	F (1,13) = .430, MSE= .088, η^2_p= .032, p = .524	**F (6,78) = 4.75, MSE= .133, η^2_p= .267, $p < .001$**	F (6,78) = 1.06, MSE= .099, η^2_p= .075, p = .396
10 $N = 17$	F (1,16) = .073, MSE= .046, η^2_p= .005, p = .790	**F (8,128) = 3.30, MSE= .105, η^2_p=.171, p = .002**	F (8,128) = .776, MSE= .126, η^2_p=.046, p = .624
12 $N = 13$	F (1,12) = 2.30, MSE= .070, η^2_p= .161, p = .155	**F (10,120) = 2.73, MSE= .132, η^2_p= .185, p = .005**	F (10,120) = .286, MSE= .142, η^2_p= .023, p = .983

Note: significant main effects and interactions are presented in bold. *N* stands for the number of participants contributing to the ANOVA.

Appendix 2.7

Experiment 2: Analyses of the IFR serial position curves from Experiment 2, shown in Figure 2.9 and Figure 2.10 (panels C and D), using only data from trials starting with SP1 with SR scoring. At each list length, the free recall data were subjected to a 2 (group: AS and No AS) x $n - 1$ (serial position: SP, 2, …,n) mixed ANOVA. Note that there were relatively few participants included in the analysis at longer list lengths.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
Verbal Data			
3 N = 19	**F (1,18) = 16.5, MSE= .112, η^2_p= .477, p = .001**	**F (1,18) = 6.75, MSE= .023, η^2_p= .273, p = .018**	F (1,18) = 2.32, MSE= .020, η^2_p= .114, p = .145
4 N = 16	**F (1,15) = 71.2, MSE= .082, η^2_p= .826, $p < .001$**	**F (2,30) = 5.62, MSE= .045, η^2_p= .272, p = .008**	F (2,30) = 1.28, MSE= .031, η^2_p= .079, p = .239
5 N = 11	**F (1,10) = 26.8, MSE= .138, η^2_p= .728, $p < .001$**	**F (3,30) = 21.5, MSE= .027, η^2_p= .682, $p < .001$**	**F (3,30) = 5.95, MSE= .031, η^2_p= .373, p = .003**
6 N = 13	**F (1,12) = 9.78, MSE= .133, η^2_p= .449, p = .009**	**F (4,48) = 18.7, MSE= .048, η^2_p= .609, $p < .001$**	**F (4,48) = 5.74, MSE= .035 , η^2_p= .324, p = .001**
7 N = 10	**F (1,9) = 10.7, MSE= .100, η^2_p= .542, p = .010**	**F (5,45) = 9.58, MSE= .035, η^2_p= .516, $p < .001$**	**F (5,45) = 3.16, MSE= .044, η^2_p= .260, p = .016**
8 N = 6	F (1,5) = 2.47, MSE= .149, η^2_p= .330, p = .177	**F (6,30) = 10.3, MSE= .046, η^2_p= .672, $p < .001$**	F (6,30) = .895, MSE= .057, η^2_p= .152, p = .511
10 N = 5	F (1,4) = 4.57, MSE= .010, η^2_p= .533, p = .099	**F (8,32) = 6.89, MSE= .019, η^2_p= .633, $p < .001$**	F (8,32) = 1.16, MSE= .022, η^2_p= .224, p = .355
12 N = 5	F (1,4) = 4.75, MSE= .043, η^2_p= .543, p = .095	F (10,40) = 1.68, MSE= .027, η^2_p=.295, p = .121	F (10,40) = 1.68, MSE= .027 , η^2_p= .295, p = .121
Visuo-Spatial Data			
3 N = 20	**F (1,19)= 4.43, MSE= .148, η^2_p= .189, p = .049**	F (1,19) = 2.60, MSE= .032, η^2_p= .120, p = .123	F (1,19) = 1.81, MSE= .032, η^2_p= .087, p = .194
4	F (1,18) = .247, MSE= .185, η^2_p= .014, p = .625	F (2,36) = 3.04, MSE= .041, η^2_p= .144, p = .060	F (2,36) = .584, MSE= .052, η^2_p= .031, p = .563

N = 19			
5 *N* = 16	***F* (1,15) = 6.74, *MSE*= .118, η^2_p= .310, *p* = .020**	***F* (3,45) = 5.87, *MSE*= .057, η^2_p= .281, *p* = .002**	*F* (3,45) = .505, *MSE*= .083, η^2_p= .033, *p* = .680
6 *N* = 18	*F* (1,17) = .016, *MSE*= .168, η^2_p= .001, *p* = .900	***F* (4,68) = 9.87, *MSE*= .086, η^2_p= .367, *p* < .001**	*F* (4,68) = 1.57, *MSE*= .066, η^2_p= .085, *p* = .192
7 *N* = 16	***F* (1,15) = 5.05, *MSE*= .071, η^2_p= .252, *p* = .040**	***F* (5,75) = 11.5, *MSE*= .075, η^2_p= .434, *p* < .001**	***F* (5,75) = 1.59, *MSE*= .074, η^2_p= .096, *p* = .173**
8 *N* = 14	*F* (1,13) = .109, *MSE*= .058, η^2_p= .008, *p* = .747	***F* (6,78) = 10.1, *MSE*= .087, η^2_p= .438, *p* < .001**	*F* (6,78) = 1.38, *MSE*= .051, η^2_p= .096, *p* = .232
10 *N* = 17	*F* (1,16) = .129, *MSE*= .060, η^2_p= .008, *p* = .724	***F* (8,128) = 15.6, *MSE*= .046, η^2_p=.493, *p* < .001**	*F* (8,128) = .303, *MSE*= .048, η^2_p=.019, *p* = .964
12 *N* = 13	*F* (1,12) = 2.59, *MSE*= .033, η^2_p= .177, *p* = .134	***F* (10,120) = 11.8, *MSE*= .044, η^2_p= .496, *p* < .001**	*F* (10,120) = .341, *MSE*= .027, η^2_p= .028, *p* = .968

Note: significant main effects and interactions are presented in bold. *N* stands for the number of participants contributing to the ANOVA.

Appendix 2.8

Experiment 2: Analyses of the IFR serial position curves from Experiment 2, shown in Figure 2.9 and Figure 2.10 (panels E and F), using only data from trials starting with one of the last 4 presented items with FR scoring. At each list length, the free recall data were subjected to a 2 (group: AS and No AS) x *n* (serial position) mixed ANOVA. Note that the number of participants included in the analysis increases with increasing list length, especially in the verbal group.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
Verbal Data			
3 $N = 5$	F (1,4) = 3.47, MSE= .167, η^2_p= .465, p = .136	F (2,8) = 3.90, MSE= .075, η^2_p= .494, p = .066	F (2,8) = .762, MSE= .136, η^2_p= .160, p = .498
4 $N = 4$	F (1,3) = .158, MSE= .111, η^2_p= .050, p = .718	F (3,9) = 2.08, MSE= .106, η^2_p= .409, p = .173	F (3,9) = 1.52, MSE= .073, η^2_p= .337, p = .274
5 $N = 14$	**F (1,13) = 4.70, MSE= .094, η^2_p= .265, p = .049**	**F (4,52) = 9.25, MSE= .098, η^2_p= .416, p < .001**	F (4,52) = .927, MSE= .135, η^2_p= .067, p = .455
6 $N = 14$	**F (1,13) = 10.9, MSE= .053, η^2_p= .457, p = .006**	**F (5,65) = 8.28, MSE= .116, η^2_p= .389, p < .001**	F (5,65) = 1.23, MSE= .110, η^2_p= .087, p = .303
7 $N = 17$	**F (1,16) = 9.15, MSE= .055, η^2_p= .364, p = .008**	**F (6,96) = 15.8, MSE= .104, η^2_p= .496, p < .001**	**F (6,96) = 2.67, MSE= .080, η^2_p= .143, p = .019**
8 $N = 17$	**F (1,16) = 20.0, MSE= .047, η^2_p= .556, p < .001**	**F (7,112) = 11.8, MSE= .096, η^2_p= .425, p < .001**	**F (7,112) = 2.28, MSE= .068, η^2_p= .125, p = .033**
10 $N = 17$	**F (1,16) = 24.3, MSE= .036, η^2_p= .603, p < .001**	**F (9,144) = 6.89, MSE= .019, η^2_p= .633, p < .001**	F (9,144) = 1.02, MSE= .070, η^2_p= .060, p = .424
12 $N = 20$	**F (1,19) = 22.9, MSE= .033, η^2_p= .547, p < .001**	**F (11,209) = 26.8, MSE= .069, η^2_p=.585, p < .001**	F (11,209)= 1.78, MSE= .067, η^2_p=.086, p = .058
Visuo-Spatial Data			
3 $N = 20$	F (1,8) = 1.43, MSE= .073, η^2_p= .018, p = .715	F (2,16) = 7.39, MSE= .036, η^2_p= .480, p = .005	F (2,16) = .280, MSE= .087, η^2_p= .034, p = .759

4 $N = 19$	F (1,5) = 2.29, MSE= .091, η^2_p= .314, p = .191	F (3,15) = 2.23, MSE= .064, η^2_p= .308, p = .127	F (3,15) = .409, MSE= .134, η^2_p= .076, p = .749
5 $N = 16$	F (1,9) = .028, MSE= .102, η^2_p= .003, p = .871	F (4,36) = .797, MSE= .079, η^2_p= .081, p = .535	F (4,36) = .836, MSE= .086, η^2_p= .085, p = .512
6 $N = 18$	F (1,8) < .001, MSE= .126, η^2_p< .001, p = 1.00	**F (5,40) = 5.40, MSE= .105, η^2_p= .403, p = .001**	F (5,40) = .801, MSE= .172, η^2_p= .091, p = .556
7 $N = 16$	F (1,9) = .002, MSE= .088, η^2_p< .001, p = .963	**F (6,54) = 2.95, MSE= .153, η^2_p= .247, p = .015**	F (6,54) = .680, MSE= .126, η^2_p= .070, p = .666
8 $N = 14$	F (1,8) = .120, MSE= .095, η^2_p= .015, p = .738	**F (7,56) = 10.5, MSE= .093, η^2_p= .508, p < .001**	F (7,56) = .577, MSE= .159, η^2_p= .067, p = .771
10 $N = 17$	F (1,9) = .225, MSE= .128, η^2_p= .024, p = .647	**F (9,81) = 8.43, MSE= .123, η^2_p=.484, p < .001**	**F (9,81) = 2.33, MSE= .096, η^2_p=.206, p = .022**
12 $N = 13$	F (1,10) = 1.54, MSE= .144, η^2_p= .133, p = .243	**F (11,110) = 11.7, MSE= .091, η^2_p= .540, p < .001**	F (11,110) = 1.10, MSE= .118, η^2_p= .099, p = .371

Note: significant main effects and interactions are presented in bold. *N* stands for the number of participants contributing to the ANOVA.

Appendix 2.9

Experiment 3: Analyses of the IFR serial position curves from Experiment 3, shown in Figures 2.13, using all the data with FR scoring for the verbal and visuo-spatial groups respectively. At each list length, the IFR data were subjected to a 2 (AS and No AS group) x *n* (serial position: SP, 1, …, n) mixed ANOVA.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
Verbal Data			
2	**F(1,19) = 12.0, MSE=.009, η^2_p= .388, p = .003**	F(1,19) = .038, MSE=.013, η^2_p= .002, p = .847	F(1,19) = .023, MSE=.022, η^2_p= .001, p = .881
3	**F(1,19) = 36.2, MSE=.015, η^2_p= .656, p < .001**	**F(2,38) = 6.39, MSE=.024, η^2_p= .252, p = .004**	**F(2,38) = 5.68, MSE=.014, η^2_p= .230, p = .007**
4	**F(1,19) = 59.4, MSE=.043, η^2_p= .758, p < .001**	**F(3,57) = 6.16, MSE=.049,η^2_p= .245, p = .001**	**F(3,57) = 10.2, MSE=.041, η^2_p= .349, p < .001**
5	**F(1,19) = 39.1, MSE=.064, η^2_p= .673, p < .001**	**F(4,76) = 2.70, MSE=.047, η^2_p= .124, p = .037**	**F(4,76) = 7.77, MSE=.053, η^2_p= .290, p < .001**
6	**F(1,19)= 48.6, MSE=.045, η^2_p= .719, p < .001**	**F(5,95) = 7.84, MSE=.079, η^2_p= .292, p < .001**	**F(5,95) = 10.8, MSE=.046, η^2_p= .362, p < .001**
7	**F(1,19)= 49.3, MSE=.026, η^2_p= .722, p < .001**	**F(6,114) = 6.14, MSE=.076, η^2_p= .244, p < .001**	**F(6,114) = 8.30, MSE=.067, η^2_p= .304, p < .001**
8	**F(1,19)= 86.7, MSE=.018, η^2_p= .820, p < .001**	**F(7,133) = 9.37, MSE=.083, η^2_p= .330, p < .001**	**F(7,133) = 4.28, MSE=.069, η^2_p= .184, p < .001**
10	**F(1,19)= 40.2, MSE=.023, η^2_p= .679, p = .023**	**F(9,171) = 13.8, MSE=.073, η^2_p= .421, p < .001**	**F(9,171) = 5.19, MSE=.049, η^2_p= .215, p < .001**
12	**F(1,19)= 32.6, MSE=.049, η^2_p= .631, p < .001**	**F(11,209) = 11.3, MSE=.071, η^2_p= .373, p < .001**	**F(11,209) = 4.66, MSE=.042, η^2_p= .197, p< .001**
15	**F(1,19)= 19.0, MSE=.067, η^2_p= .500, p < .001**	**F(14,266) = 16.9, MSE=.056, η^2_p= .470, p < .001**	**F(14,266) = 2.30, MSE=.040, η^2_p= .108, p = .005**
Visuo-spatial Data			
2	F(1,19) = .134, MSE=.060, η^2_p= .007, p = .718	F(1,19) = 3.07, MSE=.079, η^2_p= .139,p = .096	F(1,19) = 1.03, MSE=.031, η^2_p= .052, p = .322
3	F(1,19) = 3.53, MSE=.032, η^2_p= .150, p = .083	F(2,38) = .471, MSE=.083, η^2_p= .024, p = .628	F(2,38) = .962, MSE=.028, η^2_p= .048, p = .391
4	F(1,19) = .005, MSE=.051, η^2_p< .001, p = .945	F(3,57) = 2.36, MSE=.038, η^2_p= .111, p = .081	F(3,57) = .151, MSE=.050, η^2_p= .008, p = .929
5	F(1,19) = .584, MSE=.041, η^2_p= .030, p = .454	F(4,76) = 1.13, MSE=.061, η^2_p= .056, p = .350	F(4,76) = .830, MSE=.052, η^2_p= .042, p = .510
6	F(1,19)= 3.72, MSE=.026, η^2_p= .164, p = .069	**F(5,95) = 3.52, MSE=.055, η^2_p= .156, p = .006**	F(5,95) = 1.18, MSE=.048, η^2_p= .059, p = .324
7	F(1,19)= .044, MSE=.029, η^2_p= .002, p = .836	**F(6,114) = 2.91, MSE=.038, η^2_p= .133, p = .011**	F(6,114) = .654, MSE=.050, η^2_p= .033, p = .687
8	F(1,19)= .038, MSE=.029, η^2_p= .002, p = .847	**F(7,133) = 4.67, MSE=.053, η^2_p= .197, p < .001**	F(7,133) = .513, MSE=.036, η^2_p= .026, p = .824

10	**F(1,19)= 6.10, MSE=.014, η^2_p= .243, p = .023**	**F(9,171) = 7.97, MSE=.036, η^2_p= .296, p < .001**	F(9,171) = 1.49, MSE=.030, η^2_p= .073, p = .154
12	F(1,19)= .477, MSE=.017, η^2_p= .025, p = .498	**F(11,209) = 7.18, MSE=.051, η^2_p= .274, p < .001**	F(11,209) = 1.52, MSE=.028, η^2_p= .074, p = .125
15	F(1,19)= 2.82, MSE=.026, η^2_p= .129, p = .109	**F(14,266) = 7.61, MSE=.036, η^2_p= .286, p < .001**	F(14,266) = 1.24, MSE=.031, η^2_p= .061, p = .243

Note: significant main effects and interactions are presented in bold

Appendix 2.10

Experiment 3: Analyses of the IFR serial position curves from Experiment 3, shown in Figures 2.15 and Figure 2.16 (Panels A and B, for the No AS and AS trials respectively), using only data from trials starting with SP1 with FR scoring. At each list length, the free recall data were subjected to a 2 (group: AS and No AS) x $n - 1$ (serial position: SP, 2, …,n) mixed ANOVA. This was done separately for both the verbal and visuo-spatial group. Note that there were relatively few participants included in the analysis at longer list lengths.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
Verbal Data			
3 $N = 20$	**$F(1,19) = 27.3$, $MSE=.017$, $\eta^2_p= .590$, $p < .001$**	$F(1,19) = .024$, $MSE=.021$, $\eta^2_p= .001$, $p = .878$	$F(1,19) = .253$, $MSE=.018$, $\eta^2_p= .013$, $p = .621$
4 $N = 20$	**$F(1,19) = 35.2$, $MSE=.075$, $\eta^2_p= .649$, $p < .001$**	$F(2,38) = 1.66$, $MSE=.099$, $\eta^2_p= .080$, $p = .203$	**$F(2,38) = 4.45$, $MSE=.080$, $\eta^2_p= .190$, $p = .018$**
5 $N = 15$	**$F(1,14) = 24.4$, $MSE=.065$, $\eta^2_p= .635$, $p < .001$**	**$F(3,42) = 4.33$, $MSE=.110$, $\eta^2_p= .236$, $p = .009$**	$F(3,42) = 2.13$, $MSE=.144$, $\eta^2_p= .132$, $p = .111$
6 $N = 10$	**$F(1,9) = 15.3$, $MSE=.094$, $\eta^2_p= .630$, $p = .004$**	$F(4,36) = 1.18$, $MSE=.147$, $\eta^2_p= .116$, $p = .337$	$F(4,36) = 1.74$, $MSE=.116$, $\eta^2_p= .162$, $p = .163$
7 $N = 13$	**$F(1,12) = 8.65$, $MSE=.090$, $\eta^2_p= .419$, $p = .012$**	$F(5,60) = 2.08$, $MSE=.137$, $\eta^2_p= .148$, $p = .081$	$F(5,60) = 1.66$, $MSE=.192$, $\eta^2_p= .122$, $p = .158$
8 $N = 7$	**$F(1,6) = 8.41$, $MSE=.047$, $\eta^2_p= .584$, $p = .027$**	$F(6,36) = 1.79$, $MSE=.181$, $\eta^2_p= .230$, $p = .129$	**$F(6,36) = 3.63$, $MSE=.095$, $\eta^2_p= .377$, $p = .006$**
10 $N = 7$	$F(1,6) = 2.07$, $MSE= .056$, $\eta^2_p=.256$, $p = .200$	**$F(8,48) = 3.82$, $MSE= .105$, $\eta^2_p=.389$, $p = .002$**	$F(8,48) = 1.45$, $MSE= .123$, $\eta^2_p=.194$, $p = .202$
12 $N = 5$	$F(1,4) = 3.82$, $MSE=.086$, $\eta^2_p= .489$, $p = .122$	$F(10,40) = 1.90$, $MSE=.129$, $\eta^2_p= .322$, $p = .075$	$F(10,40) = 1.05$, $MSE=.134$, $\eta^2_p= .209$, $p = .419$
15 $N = 3$	$F(1,2) = 3.51$, $MSE=.024$, $\eta^2_p= .637$, $p = .202$	**$F(13,26) = 2.69$, $MSE=.076$, $\eta^2_p= .573$, $p = .015$**	**$F(13,26) = 2.35$, $MSE=.050$, $\eta^2_p= .540$, $p = .031$**
Visuo-spatial Data			

3 $N = 17$	$F(1,16) = 1.17$, $MSE=.060$, $\eta^2_p= .068$, $p = .296$	$F(1,16) = 2.12$, $MSE=.123$, $\eta^2_p= .117$, $p = .165$	**$F(1,16) = 4.51$, $MSE=.037$, $\eta^2_p= .220$, $p = .050$**
4 $N = 15$	$F(1,14) = .418$, $MSE=.213$, $\eta^2_p= .029$, $p = .528$	$F(2,28) = .741$, $MSE=.067$, $\eta^2_p= .050$, $p = .486$	$F(2,28) = .283$, $MSE=.169$, $\eta^2_p= .020$, $p = .756$
5 $N = 12$	$F(1,11) = .439$, $MSE=.103$, $\eta^2_p= .038$, $p = .521$	**$F(3,33) = 3.83$, $MSE=.155$, $\eta^2_p= .258$, $p = .019$**	$F(3,33) = 2.74$, $MSE=.134$, $\eta^2_p= .199$, $p = .059$
6 $N = 9$	$F(1,8) = 1.31$, $MSE=.147$, $\eta^2_p= .141$, $p = .285$	$F(4,32) = .205$, $MSE=.163$, $\eta^2_p= .025$, $p = .934$	$F(4,32) = 1.04$, $MSE=.190$, $\eta^2_p= .115$, $p = .404$
7 $N = 7$	$F(1,6) = .364$, $MSE=.058$, $\eta^2_p= .057$, $p = .569$	**$F(5,30) = 3.06$, $MSE=.128$, $\eta^2_p= .338$, $p = .024$**	$F(5,30) = 1.86$, $MSE=.132$, $\eta^2_p= .236$, $p = .132$
8 $N = 7$	$F(1,6) = .962$, $MSE=.156$, $\eta^2_p= .138$, $p = .365$	$F(6,36) = .196$, $MSE=.172$, $\eta^2_p= .032$, $p = .976$	$F(6,36) = .436$, $MSE=.142$, $\eta^2_p= .068$, $p = .850$
10 $N = 3$	$F(1,2) = 9.14$, $MSE= .032$, $\eta^2_p=.821$, $p = .094$	$F(8,16) = 1.93$, $MSE= .092$, $\eta^2_p=.490$, $p = .126$	$F(8,16) = 2.31$, $MSE= .142$, $\eta^2_p=.536$, $p = .073$
12 $N = 2$	$F(1,1) = 25.0$, $MSE=.023$, $\eta^2_p= .962$, $p = .126$	$F(10,10) = 1.16$, $MSE=.173$, $\eta^2_p= .537$, $p = .411$	$F(10,10) = 1.37$, $MSE=.123$, $\eta^2_p= .578$, $p = .314$
15 $N = 3$	$F(1,2) < .001$, $MSE=.009$, $\eta^2_p< .001$, $p = 1.00$	$F(13,26) = .846$, $MSE=.120$, $\eta^2_p= .297$, $p = .613$	$F(13,26) = .558$, $MSE=.172$, $\eta^2_p= .218$, $p = .865$

Note: significant main effects and interactions are presented in bold. *N* refers to the number of participants contributing to the ANOVA.

Appendix 2.11

Experiment 3: Analyses of the IFR serial position curves from Experiment 4, shown in Figures 2.15 and Figure 2.16 (Panels A and B, for the No AS and AS trials respectively), using only data from trials starting with serial position 1 using SR scoring. At each list length, the data were subjected to a 2 (group: AS and No AS) x $n - 1$ (serial position: SP, 2, …,n) mixed ANOVA. This was done separately for both the verbal and visuo-spatial group. Note that there were relatively few participants included in the analysis at longer list lengths.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
Verbal Data			
3 $N = 20$	**$F(1,19) = 39.5$, $MSE=.059$, $\eta^2_p= .675$, $p < .001$**	**$F(1,19) = 22.7$, $MSE=.006$, $\eta^2_p= .544$, $p < .001$**	**$F(1,19) = 17.9$, $MSE=.0004$, $\eta^2_p= .485$, $p < .001$**
4 $N = 20$	**$F(1,19) = 75.0$, $MSE=.089$, $\eta^2_p= .798$, $p < .001$**	**$F(2,38) = 32.0$, $MSE=.042$, $\eta^2_p= .628$, $p < .001$**	**$F(2,38) = 3.74$, $MSE=.057$, $\eta^2_p= .164$, $p = .033$**
5 $N = 15$	**$F(1,14) = 19.6$, $MSE=.169$, $\eta^2_p= .584$, $p = .001$**	**$F(3,42) = 22.9$, $MSE=.061$, $\eta^2_p= .621$, $p < .001$**	$F(3,42) = 1.45$, $MSE=.052$, $\eta^2_p= .094$, $p = .242$
6 $N = 10$	**$F(1,9) = 6.04$, $MSE=.219$, $\eta^2_p= .401$, $p = .036$**	**$F(4,36) = 15.5$, $MSE=.040$, $\eta^2_p= .632$, $p < .001$**	**$F(4,36) = 4.29$, $MSE=.050$, $\eta^2_p= .323$, $p = .006$**
7 $N = 13$	$F(1,12) = 4.37$, $MSE=.142$, $\eta^2_p= .267$, $p = .059$	**$F(5,60) = 20.6$, $MSE=.044$, $\eta^2_p= .632$, $p < .001$**	$F(5,60) = 2.07$, $MSE=.074$, $\eta^2_p= .147$, $p = .082$
8 $N = 7$	**$F(1,6) = 10.7$, $MSE=.086$, $\eta^2_p= .641$, $p = .017$**	**$F(6,36) = 14.7$, $MSE=.062$, $\eta^2_p= .710$, $p < .001$**	**$F(6,36) = 2.62$, $MSE=.053$, $\eta^2_p= .304$, $p = .033$**
10 $N = 7$	**$F(1,6) = 17.9$, $MSE= .036$, $\eta^2_p=.749$, $p = .006$**	**$F(8,48) = 8.71$, $MSE= .038$, $\eta^2_p=.592$, $p < .001$**	**$F(8,48) = 4.74$, $MSE= .025$, $\eta^2_p=.441$, $p < .001$**
12 $N = 5$	**$F(1,4) = 11.9$, $MSE=.048$, $\eta^2_p= .748$, $p = .026$**	**$F(10,40) = 4.98$, $MSE=.044$, $\eta^2_p= .555$, $p < .001$**	**$F(10,40) = 2.53$, $MSE=.041$, $\eta^2_p= .387$, $p = .018$**
15 $N = 3$	**$F(1,2) = 112$, $MSE=.003$, $\eta^2_p= .983$, $p = .009$**	**$F(13,26) = 8.81$, $MSE=.029$, $\eta^2_p= .815$, $p < .001$**	**$F(13,26) = 12.2$, $MSE=.007$, $\eta^2_p= .859$, $p < .001$**

Visuo-Spatial Data

3 *N* = 17	*F*(1,16) = .618, *MSE*=.067, η^2_p= .037, *p* = .443	*F*(1,16) = 2.60, *MSE*=.117, η^2_p= .140, *p* = .126	***F*(1,16) = 4.94, *MSE*=.038, η^2_p= .236, *p* = .041**
4 *N* = 15	*F*(1,14) = .273, *MSE*=.238, η^2_p= .019, *p* = .610	*F*(2,28) = .141, *MSE*=.041, η^2_p= .010, *p* = .869	*F*(2,28) = .348, *MSE*=.128, η^2_p= .024, *p* = .709
5 *N* = 12	*F*(1,11) = .001, *MSE*=.095, η^2_p< .001, *p* = .978	***F*(3,33) = 3.30, *MSE*=.142, η^2_p= .230, *p* = .032**	*F*(3,33) = 2.11, *MSE*=.101, η^2_p= .161, *p* = .118
6 *N* = 9	*F*(1,8) = 3.45, *MSE*=.181, η^2_p= .301, *p* = .100	*F*(4,32) = .648, *MSE*=.075, η^2_p= .075, *p* = .632	*F*(4,32) = .231, *MSE*=.090, η^2_p= .028, *p* = .919
7 *N* = 7	*F*(1,6) = .478, *MSE*=.044, η^2_p= .074, *p* = .515	*F*(5,30) = 2.19, *MSE*=.024, η^2_p= .267, *p* = .082	*F*(5,30) = 1.60, *MSE*=.022, η^2_p= .210, *p* = .191
8 *N* = 7	*F*(1,6) = .075, *MSE*=.060, η^2_p= .012, *p* = .793	*F*(6,36) = 2.27, *MSE*=.047, η^2_p= .275, *p* = .058	*F*(6,36) = .522, *MSE*=.030, η^2_p= .080, *p* = .788
10 *N* = 3	*F*(1,2) = 1.23, *MSE*= .060, η^2_p=.381, *p* = .383	*F*(8,16) = 1.68, *MSE*= .058, η^2_p=.457, *p* = .179	*F*(8,16) = .187, *MSE*= .117, η^2_p=.086, *p* = .989
12 *N* = 2	*F*(1,1) = 9.00, *MSE*=.006, η^2_p= .900, *p* = .205	*F*(10,10) = 2.19, *MSE*=.031, η^2_p= .686, *p* = .117	*F*(10,10) = .324, *MSE*=.081, η^2_p= .245, *p* = .955
15 *N* = 3	*F*(1,2) = 1.00, *MSE*=.003, η^2_p= .333, *p* = .423	*F*(13,26) = 1.00, *MSE*=.003, η^2_p= .333, *p* = .479	*F*(13,26) = 1.00, *MSE*=.003, η^2_p= .333, *p* = .479

Note: significant main effects and interactions are presented in bold. *N* refers to the number of participants contributing to the ANOVA.

Appendix 2.12

Experiment 3: Table C4. Analyses of the IFR serial position curves from Experiment 4, shown in Figures 2.15 and Figure 2.16 (Panels A and B, for the No AS and AS trials respectively) using only data from trials starting with one of the last 4 serial positions with FR scoring. At each list length, the free recall data were subjected to a 2 (group: AS and No AS) x $n - 1$ (serial position: SP, 2, …,n) mixed ANOVA. This was done separately for both the verbal and visuo-spatial group. Note that there were relatively few participants included in the analysis at shorter list lengths.

List length	Main Effects		Interaction
	Articulatory suppression	Serial position	
Verbal Data			
3 $N = 2$	$F(1,2) = 1.00$, $MSE=.083$, $\eta^2_p = .500$, $p = .500$	$F(1,2) = 1.00$, $MSE=.083$, $\eta^2_p = .500$, $p = .500$	$F(1,2) = 1.00$, $MSE=.083$, $\eta^2_p = .500$, $p = .500$
4 $N = 7$	$F(1,6) = 3.74$, $MSE=.144$, $\eta^2_p = .384$, $p = .101$	$F(3,18) = 1.35$, $MSE=.165$, $\eta^2_p = .184$, $p = .290$	**$F(3,18) = 3.69$, $MSE=.165$, $\eta^2_p = .381$, $p = .031$**
5 $N = 11$	**$F(1,10) = 9.77$, $MSE=.164$, $\eta^2_p = .494$, $p = .011$**	**$F(4,40) = 3.8$, $MSE=.079$, $\eta^2_p = .279$, $p = .009$**	**$F(4,40) = 3.38$, $MSE=.069$, $\eta^2_p = .253$, $p = .018$**
6 $N = 15$	**$F(1,14) = 25.1$, $MSE=.067$, $\eta^2_p = .632$, $p < .001$**	**$F(5,70) = 15.8$, $MSE=.084$, $\eta^2_p = .530$, $p < .001$**	**$F(5,70) = 3.80$, $MSE=.063$, $\eta^2_p = .213$, $p = .004$**
7 $N = 14$	**$F(1,13) = 18.7$, $MSE=.054$, $\eta^2_p = .590$, $p < .001$**	**$F(6,78) = 18.4$, $MSE=.068$, $\eta^2_p = .585$, $p < .001$**	**$F(6,78) = 2.77$, $MSE=.098$, $\eta^2_p = .176$, $p = .017$**
8 $N = 16$	**$F(1,15) = 34.7$, $MSE=.039$, $\eta^2_p = .698$, $p < .001$**	**$F(7,105) = 14.2$, $MSE=.091$, $\eta^2_p = .486$, $p < .001$**	$F(7,105) = 1.24$, $MSE=.101$, $\eta^2_p = .076$, $p = .286$
10 $N = 15$	**$F(1,14) = 21.7$, $MSE= .038$, $\eta^2_p =.608$, $p < .001$**	**$F(9,126) = 23.1$, $MSE= .069$, $\eta^2_p =.622$, $p < .001$**	$F(9,126) = .709$, $MSE= .078$, $\eta^2_p =.048$, $p = .700$
12 $N = 16$	**$F(1,15) = 37.8$, $MSE=.034$, $\eta^2_p = .716$, $p < .001$**	**$F(11,165) = 20.0$, $MSE=.074$, $\eta^2_p = .571$, $p < .001$**	**$F(11,165) = 2.04$, $MSE=.060$, $\eta^2_p = .119$, $p = .028$**
15 $N = 18$	**$F(1,17) = 17.8$, $MSE=.073$, $\eta^2_p = .512$, $p < .001$**	**$F(14,238) = 23.3$, $MSE=.065$, $\eta^2_p = .578$, $p < .001$**	**$F(14,238) = 2.26$, $MSE=.053$, $\eta^2_p = .117$, $p = .007$**

Visuo-Spatial data			
3 $N = 4$	$F(1,3) = .086$, MSE=.122, η^2_p= .028, $p = .798$	**$F(2,6) = 9.38$, MSE=.092, η^2_p= .758, $p = .014$**	$F(2,6) = .326$, MSE=.130, η^2_p= .098, $p = .734$
4 $N = 8$	**$F(1,7) = 6.60$, MSE=.052, η^2_p= .485, $p = .037$**	**$F(3,21) = 5.50$, MSE=.214, η^2_p= .391, $p = .014$**	$F(3,21) = .311$, MSE=.127, η^2_p= .043, $p = .817$
5 $N = 9$	$F(1,8) = 1.97$, MSE=.160, η^2_p= .198, $p = .198$	**$F(4,32) = 8.00$, MSE=.127, η^2_p= .500, $p < .001$**	$F(4,32) = 2.62$, MSE=.140, η^2_p= .246, $p = .054$
6 $N = 9$	$F(1,8) = .327$, MSE=.106, η^2_p= .039, $p = .583$	**$F(5,40) = 17.8$, MSE=.087, η^2_p= .689, $p < .001$**	$F(5,40) = .220$, MSE=.094, η^2_p= .027, $p = .952$
7 $N = 10$	**$F(1,9) = 6.25$, MSE=.039, η^2_p= .410, $p = .034$**	**$F(6,54) = 4.33$, MSE=.140, η^2_p= .325, $p = .001$**	$F(6,54) = .636$, MSE=.161, η^2_p= .066, $p = .701$
8 $N = 10$	$F(1,9) = 1.75$, MSE=.074, η^2_p= .162, $p = .219$	**$F(7,63) = 16.7$, MSE=.084, η^2_p= .650, $p < .001$**	$F(7,63) = .377$, MSE=.098, η^2_p= .040, $p = .913$
10 $N = 13$	$F(1,12) = .866$, MSE= .074, η^2_p=.067, $p = .371$	**$F(9,108) = 14.9$, MSE= .098, η^2_p=.554, $p < .001$**	$F(9,108) = .869$, MSE= .107, η^2_p=.068, $p = .555$
12 $N = 10$	$F(1,9) = 2.18$, MSE=.077, η^2_p= .195, $p = .174$	**$F(11,99) = 12.4$, MSE=.075, η^2_p= .579, $p < .001$**	$F(11,99) = 1.64$, MSE=.048, η^2_p= .154, $p = .100$
15 $N = 14$	**$F(1,13) = 7.57$, MSE=.048, η^2_p= .368, $p = .016$**	**$F(14,182) = 9.72$, MSE=.096, η^2_p= .428, $p < .001$**	$F(14,182) = 1.05$, MSE=.086, η^2_p= .075, $p = .405$

Note: significant main effects and interactions are presented in bold. *N* refers to the number of participants contributing to the ANOVA.

Appendix 3.1

Analyses of the IFR SPCs from Experiment 4, shown in Figure 3.3, using all the data with FR scoring. The performance of each of the single-modality groups (auditory-verbal and visuo-spatial) was compared to the verbal and visuo-spatial performance of the parallel presentation group respectively. At each list length, the IFR data were subjected to a 2(group: either auditory-verbal and parallel presentation or visuo-spatial and parallel presentation) x *n* (serial position 1…*n*) mixed ANOVA where *n* is the list length.

List Length	Main Effects		Interaction
	Group	Serial Position	
Verbal			
2	$F(1,38) = .159$, $MSE = .003$, $\eta^2_p = .004$, $p = .692$	$F(1,38) = .734$, $MSE = .003$, $\eta^2_p = .019$, $p = .397$	$F(1,38) = 1.65$, $MSE = .003$, $\eta^2_p = .042$, $p = .206$
4	$F(1,38) = .007$, $MSE = .036$, $\eta^2_p < .001$, $p = .934$	**$F(3,114) = 6.60$, $MSE = .010$, $\eta^2_p = .148$, $p = .001$**	$F(3,114) = .558$, $MSE = .010$, $\eta^2_p = .014$, $p = .664$
8	$F(1,38) = .775$, $MSE = .052$, $\eta^2_p = .020$, $p = .384$	**$F(7,266) = 24.4$, $MSE = .040$, $\eta^2_p = .391$, $p < .001$**	**$F(7,266) = 2.05$, $MSE = .040$, $\eta^2_p = .051$, $p = .049$**
16	$F(1,38) = 3.65$, $MSE = .024$, $\eta^2_p = .088$, $p = .064$	**$F(15,266) = 85.5$, $MSE = .021$, $\eta^2_p = .692$, $p < .001$**	**$F(15,266) = 2.09$, $MSE = .021$, $\eta^2_p = .052$, $p = .009$**
Visuo-Spatial			
2	$F(1,38) = .127$, $MSE = .048$, $\eta^2_p = .003$, $p = .723$	$F(1,38) = .639$, $MSE = .024$, $\eta^2_p = .017$, $p = .429$	$F(1,38) = .005$, $MSE = .024$, $\eta^2_p < .001$, $p = .942$
4	$F(1,38) = 1.55$, $MSE = .071$, $\eta^2_p = .039$, $p = .221$	$F(3,114) = 1.97$, $MSE = .031$, $\eta^2_p = .049$, $p = .123$	$F(3,114) = .153$, $MSE = .031$, $\eta^2_p = .004$, $p = .928$
8	$F(1,38) = 3.74$, $MSE = .056$, $\eta^2_p = .090$, $p = .061$	**$F(7,266) = 7.94$, $MSE = .025$, $\eta^2_p = .173$, $p < .001$**	$F(7,266) = .960$, $MSE = .025$, $\eta^2_p = .025$, $p = .461$
16	**$F(1,38) = 14.1$, $MSE = .060$, $\eta^2_p = .271$, $p = .001$**	**$F(15,266) = 14.7$, $MSE = .019$, $\eta^2_p = .279$, $p < .001$**	$F(15,266) = 1.32$, $MSE = .019$, $\eta^2_p = .034$, $p = .182$

Note: significant main effects and interactions are presented in bold

Appendix 3.2

Analyses of the resultant SPCs of Experiment 4 using trials starting with SP1 in FR Scoring, shown in Figure 3.5 (panels A and B). This was done separately for the verbal and visuo-spatial stimuli in the dual-modality group, whereby the performance of each of the single-modality groups (auditory-verbal and visuo-spatial) was compared to the verbal and visuo-spatial performance of the parallel presentation group. The data were subjected to a 2(group: either auditory-verbal and parallel presentation or visuo-spatial and parallel presentation) x *n* (serial positions 2…*n*) mixed ANOVA, where *n* is the list length. Here, SP1 was excluded since it was, by definition, always recalled.

List Length	Main effects		Interaction
	Group	Serial Position	
Verbal			
4 AV = 20; PP = 20	$F(1,38) = .013$, $MSE = .027$, $\eta^2_p < .001$, $p = .910$	$\mathbf{F(2,76) = 6.85}$, $\mathbf{MSE = .011}$, $\boldsymbol{\eta^2_p = .153}$, $\mathbf{p = .002}$	$F(2,76) = .745$, $MSE = .011$, $\eta^2_p = .019$, $p = .478$
8 AV = 17; PP = 18	$F(1,33) = .641$, $MSE = .068$, $\eta^2_p = .019$, $p = .429$	$\mathbf{F(6,198) = 8.84}$, $\mathbf{MSE = .094}$, $\boldsymbol{\eta^2_p = .211}$, $\mathbf{p < .001}$	$F(6,198) = 1.76$, $MSE = .094$, $\eta^2_p = .051$, $p = .109$
16 AV = 13; PP = 10	$F(1,21) = 1.12$, $MSE = .061$, $\eta^2_p = .051$, $p = .302$	$\mathbf{F(14,294) = 8.71}$, $\mathbf{MSE = .080}$, $\boldsymbol{\eta^2_p = .293}$, $\mathbf{p < .001}$	$F(14,294) = .686$, $MSE = .080$, $\eta^2_p = .032$, $p = .788$
Visuo-spatial			
4 VS = 19; PP = 20	$F(1,37) = 2.49$, $MSE = .076$, $\eta^2_p = .063$, $p = .123$	$F(2,74) = 1.86$, $MSE = .088$, $\eta^2_p = .048$, $p = .164$	$F(2,74) = .713$, $MSE = .088$, $\eta^2_p = .019$, $p = .493$
8 VS = 19; PP = 14	$\mathbf{F(1,31) = 7.21}$, $\mathbf{MSE = .079}$, $\boldsymbol{\eta^2_p = .189}$, $\mathbf{p = .012}$	$\mathbf{F(6,186) = 3.59}$, $\mathbf{MSE = .072}$, $\boldsymbol{\eta^2_p = .104}$, $\mathbf{p = .002}$	$F(6,186) = .635$, $MSE = .072$, $\eta^2_p = .020$, $p = .702$
16 VS = 10; PP = 5	$F(1,13) = .749$, $MSE = .150$, $\eta^2_p = .054$, $p = .403$	$F(14,182) = .891$, $MSE = .086$, $\eta^2_p = .064$, $p = .570$	$F(14,182) = 1.63$, $MSE = .086$, $\eta^2_p = .111$, $p = .076$

Note: all significant main effects and interactions are presented in bold. AV, VS, and PP stand for the number of participants contributing to the ANOVA from the auditory-verbal, visuo-spatial and parallel presentation groups respectively.

Appendix 3.3

Analyses of the resultant SPCs of Experiment 4 using trials starting with SP1 in SR Scoring, shown in Figure 3.5 (panels C and D). This was done separately for the verbal and visuo-spatial stimuli in the dual-modality groups, whereby the performance of each of the single-modality groups (auditory-verbal and visuo-spatial) was compared to the verbal and visuo-spatial performance of the parallel presentation groups. The data were subjected to a 2(group: either auditory-verbal and parallel presentation or visuo-spatial and parallel presentation) x *n* (serial positions 2…*n*) mixed ANOVA, where *n* is the list length. Here, SP1 was excluded since it was, by definition, always recalled.

List Length	Main effects		Interaction
	Group	Serial Position	
Verbal			
4 AV = 20; PP = 20	$F(1,38) = .001$, $MSE = .109$, $\eta^2_p < .001$, $p = .928$	$\mathbf{F(2,76) = 20.3}$, $\mathbf{MSE = .012}$, $\mathbf{\eta^2_p = .348}$, $\mathbf{p < .001}$	$F(2,76) = .014$, $MSE = .012$, $\eta^2_p < .001$, $p = .986$
8 AV = 17; PP = 18	$F(1,33) = .532$, $MSE = .067$, $\eta^2_p = .016$, $p = .471$	$\mathbf{F(6,198) = 53.8}$, $\mathbf{MSE = .034}$, $\mathbf{\eta^2_p = .620}$, $\mathbf{p < .001}$	$F(6,198) = .437$, $MSE = .034$, $\eta^2_p = .013$, $p = .854$
16 AV = 13; PP = 10	$F(1,21) = 1.58$, $MSE = .025$, $\eta^2_p = .070$, $p = .223$	$\mathbf{F(14,294) = 18.1}$, $\mathbf{MSE = .019}$, $\mathbf{\eta^2_p = .464}$, $\mathbf{p < .001}$	$F(14,294) = .785$, $MSE = .019$, $\eta^2_p = .036$, $p = .686$
Visuo-spatial			
4 VS = 19; PP = 20	$F(1,37) = 1.11$, $MSE = .109$, $\eta^2_p = .029$, $p = .300$	$\mathbf{F(2,74) = 3.16}$, $\mathbf{MSE = .073}$, $\mathbf{\eta^2_p = .079}$, $\mathbf{p = .048}$	$F(2,74) = 1.30$, $MSE = .073$, $\eta^2_p = .034$, $p = .278$
8 VS = 19; PP = 14	$F(1,31) = 3.52$, $MSE = .050$, $\eta^2_p = .102$, $p = .070$	$\mathbf{F(6,186) = 10.6}$, $\mathbf{MSE = .031}$, $\mathbf{\eta^2_p = .255}$, $\mathbf{p < .001}$	$F(6,186) = .341$, $MSE = .031$, $\eta^2_p = .011$, $p = .914$
16 VS = 10; PP = 5	$F(1,13) = .304$, $MSE = .019$, $\eta^2_p = .028$, $p = .591$	$\mathbf{F(14,182) = 3.17}$, $\mathbf{MSE = .013}$, $\mathbf{\eta^2_p = .196}$, $\mathbf{p < .001}$	$F(14,182) = .304$, $MSE = .013$, $\eta^2_p = .023$, $p = .993$

Note: all significant main effects and interactions are presented in bold. AV, VS, and PP stand for the number of participants contributing to the ANOVA from the auditory-verbal, visuo-spatial and parallel presentation groups respectively.

Appendix 3.4

Analyses of the resultant Serial Position curves of Experiment 4 using trials starting with one of the Last 4 items with FR Scoring, shown in Figure 3.5 (panels E and F). This was done separately for the verbal and visuo-spatial stimuli in the dual-modality group, whereby the performance of each of the single-modality groups (auditory-verbal and visuo-spatial) was compared to the verbal and visuo-spatial performance of the parallel presentation group. The data were subjected to a 2(group: either auditory-verbal, parallel presentation or visuo-spatial and parallel presentation) x *n* (serial position) mixed ANOVA, where *n* is the list length.

List Length	Main effects		Interaction
	Group	Serial Position	
Verbal			
4 AV = 8; PP = 8	$F(1,14) = 1.02$, $MSE = .143$, $\eta^2_p = .068$, $p = .330$	**$F(3,42) = 3.17$, $MSE = .133$, $\eta^2_p = .185$, $p = .034$**	$F(3,42) = 2.17$, $MSE = .133$, $\eta^2_p = .134$, $p = .106$
8 AV = 17; PP = 18	$F(1,33) = .145$, $MSE = .067$, $\eta^2_p = .004$, $p = .706$	**$F(7,231) = 50.2$, $MSE = .056$, $\eta^2_p = .603$, $p < .001$**	$F(7,231) = 1.50$, $MSE = .056$, $\eta^2_p = .043$, $p = .169$
16 AV = 20; PP = 19	$F(1,37) = .589$, $MSE = .046$, $\eta^2_p = .016$, $p = .448$	**$F(15,555) = 82.1$, $MSE = .036$, $\eta^2_p = .689$, $p < .001$**	$F(15,555) = .734$, $MSE = .036$, $\eta^2_p = .019$, $p = .751$
Visuo-spatial			
4 VS = 9; PP = 9	$F(1,16) = 1.13$, $MSE = .082$, $\eta^2_p = .066$, $p = .304$	**$F(3,48) = 6.36$, $MSE = .159$, $\eta^2_p = .284$, $p = .001$**	$F(3,48) = .891$, $MSE = .159$, $\eta^2_p = .053$, $p = .453$
8 VS = 10; PP = 16	$F(1,24) = 3.73$, $MSE = .058$, $\eta^2_p = .134$, $p = .065$	**$F(7,168) = 13.9$, $MSE = .077$, $\eta^2_p = .366$, $p < .001$**	$F(7,168) = .405$, $MSE = .077$, $\eta^2_p = .017$, $p = .898$
16 VS = 17; PP = 19	**$F(1,34) = 16.0$, $MSE = .095$, $\eta^2_p = .321$, $p < .001$**	**$F(15,510) = 21.9$, $MSE = .056$, $\eta^2_p = .392$, $p < .001$**	$F(15,510) = .790$, $MSE = .056$, $\eta^2_p = .023$, $p = .689$

Note: all significant main effects and interactions are presented in bold. AV, VS, and PP stand for the number of participants contributing to the ANOVA from the auditory-verbal, visuo-spatial and parallel presentation groups respectively.

Appendix 3.5

Experiment 4: The average number of auditory-words and visuo-spatial dots recalled for each of the eight possible output strategies for the first three outputs of the parallel presentation group

Auditory-words

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
List Length								
4		2.00	2.00	1.94	1.88	1.96	2.00	
8	3.00		3.27	3.53	3.14	3.56	4.00	3.85
16	4.50	3.00	4.55	3.56	3.27	3.78	3.00	4.05
32	4.00	3.00	4.33	4.15	3.91	4.10	3.00	4.56
Average	3.86	2.67	3.39	3.33	2.75	3.32	2.67	4.26

Visuo-spatial Dots

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
List Length								
4		2.00	1.28	1.65	1.33	1.37	1.00	
8	2.00		1.73	1.67	1.00	1.87	1.00	1.46
16	3.50	1.00	2.09	1.83	1.64	1.98	2.00	1.10
32	4.00	3.00	3.07	2.15	3.91	2.79	2.00	1.35
Average	3.29	2.00	2.00	1.84	1.89	1.97	1.33	1.29

Note: W stands for word; D stands for dot. List length 2 was eliminated because there were only two options of outputs: DW or WD

Appendix 3.6

Experiment 4. The frequency by which a specific item in a specific serial position (*n*) was outputted and followed by another outputted item (*n* + 1)

	Output *n* +1															
n	1D	1W	2D	2W	3D	3W	4D	4W	5D	5W	6D	6W	7D	7W	8D	8W
1D		101	15	174	1	10	1	6		3	2	2		1	1	2
1W	326		21	54	3	3	1	1	3	3	3	2	2			
2D	4	4		35	8	49	2	12	1	3	1	4		1		5
2W	10	5	178		14	18	1	6		2	1	2	1	1	2	1
3D		2	2	2		15	5	51		4			1	5		4
3W	2	2	13	4	57		10	15	1					1		1
4D	1	5	1	6		5		12	1	4	1			5		3
4W	2	1	2	1	10	3	63			1	2	2		1	1	3
5D	2		1	1	2	1		1		5	1	8	1	4	1	2
5W	7				1		1	1	8		3	6	3	4	2	5
6D		3		3		3		1	1	1		4	2	9		4
6W	3	1	2	1	1	1	2		2	3	14		6	5	2	1
7D		1	4	1				1		4	2	8		11	1	12
7W	1	1	3		1	4	1	1	3	3	5	5	25		4	11
8D		3		2	1	1	2	4	1	6	1	7	1	19		9
7W	4		3	1	1		2	5	2	3	4	6	5	6	56	
9D				1		1							2			
9W			1									1	1			
10D				1			1							1		
10W		1		1						1			1	1		
11D			1											1		
11W			1				1					1				
12D										1						
12W	1		1		1	1			2				1	1	1	1
13D				1		1						1				

13W	1	2	1				1		1	1	1		1		1	1
14D		1			1									2	2	1
14W		2			1				1				2	1		1
15D									1	1				1		1
15W	1			1	2			1							1	
16D		3		3		1			2	1	1					
16W		2	1						2	1	1	1			4	
Blank	6633	9	17	12	25	11	12	10	23	14	32	7	35	11	40	34
Total	6998	149	268	305	130	128	106	128	55	65	75	67	90	92	119	102

	Output *n* +1																
n	9D	9W	10D	10W	11D	11W	12D	12W	13D	13W	14D	14W	15D	15W	16D	16W	Blank
1D		1	1	1		1						2				2	174
1W		1			1	2		1	2	1			1				295
2D	1			1										1			161
2W			1				1				1						239
3D			1		1	1	1	1				1					43
3W			1			1											130
4D			1														81
4W									1						1		154
5D					2	1		1				1		1	1		27
5W	1		1								1			2		2	58
6D			1							2				1			26
6W	1	1					1			1							74
7D		1		1						2	1	1					30
7W	1					1	1										75
8D		2						1		2		1	2		1	1	37
7W		2												3			92
9D			1	1					1			3	1			3	14
9W	1			1	1			1				1	1				23
10D	1			2			1			1	1			1			14

10W	1				2			1	1	1					1	1	22
11D	1					2			1	1						1	20
11W	1				3		2	2	1		2	2		1		1	27
12D				1	1	1		4	2	3	1	2	1	1		1	10
12W	3		1	1	1		3		1	3	1					3	16
13D	1			1		1		2		1		3	1	1			13
13W	1	2			1		3	2	4		2	2		2		2	41
14D	2		1	1	1			2	1			3	2	3		2	17
14W		4	1	2			1	1	1	5	10		5	11	1	3	46
15D		1		1	1	1		1		4	1	6		7		10	15
15W	1		1	1		1	2	1	1	4	6	7	24		5	11	60
16D	1	1		2		2	1	2		5		12	2	26		10	19
16W			2	1			1	3		8		10	2	14	63		53
Blank	77	38	176	34	110	31	111	29	41	15	43	25	50	16	70	10	13
Total	95	54	190	52	125	46	129	55	58	59	70	82	92	91	143	63	2119

Note: 'Blank' refers to those instances where participants made an error or a non-response

Appendix 3.7
Experiment 4: The number of occurrences of each of the four types of possible transitions at each possible lag transition

Overall Transitions

		D	W
from	D	125	868
	W	1123	364

0 lag		D	W
from	D		221
	W	835	

+ 1 lag		D	W
from	D	38	329
	W	75	142

- 1 lag		D	W
from	D	16	75
	W	60	55

+ 2 lag		D	W
from	D	9	41
	W	17	22

- 2 lag		D	W
from	D	7	41
	W	20	28

+ 3 lag		D	W
from	D	4	19
	W	7	16

- 3 lag		D	W
from	D	4	24
	W	12	17

+ 4 lag		D	W
from	D	5	17
	W	6	14

- 4 lag		D	W
from	D	8	12
	W	16	19

+ 5 lag		D	W
from	D	2	14
	W	6	6

- 5 lag		D	W
from	D	7	8
	W	10	10

+ 6 lag		D	W
from	D	4	10
	W	7	2

- 6 lag		D	W
from	D	3	8
	W	8	4

+ 7 lag		D	W
from	D	6	9
	W	1	4

- 7 lag		D	W
from	D	1	10
	W	12	1

+ 8 lag		D	W
from	D	2	4
	W	1	2

- 8 lag		D	W
from	D	0	2
	W	5	2

+ 9 lag		D	W
from	D	2	4

- 9 lag		D	W
from	D	1	0

	W	2	0

	W	4	2

+ 10 lag		D	W
from	D	0	2
	W	2	4

- 10 lag		D	W
from	D	2	2
	W	2	1

+ 11 lag		D	W
from	D	1	1
	W	0	3

- 11 lag		D	W
from	D	3	2
	W	5	2

+ 12 lag		D	W
From	D	0	0
	W	4	1

- 12 lag		D	W
from	D	0	0
	W	3	2

+ 13 lag		D	W
From	D	0	3
	W	0	0

- 13 lag		D	W
from	D	0	2
	W	0	3

+ 14 lag		D	W
From	D	0	0
	W	1	0

- 14 lag		D	W
from	D	0	3
	W	2	0

+ 15 lag		D	W
From	D	0	2
	W	0	0

- 15 lag		D	W
from	D	0	3
	W	0	2

Appendix 3.8

Experiment 5: Analyses of the resultant SPCs, shown in Figure 3.15, using trials starting with SP1 with FR Scoring, SP1 with SR scoring and one of the last 4 items with FR scoring respectively. In those trials starting with SP1, the free recall data were subjected to a 3(group: either auditory-verbal, parallel presentation, alternating presentation or visuo-spatial, parallel presentation, alternating presentation) x 5 (serial positions 2-6) mixed ANOVA. Here, SP1 was excluded since it was, by definition, always recalled. In those trials starting with one of the last 4, the free recall data were subjected to a 3 (group: see above) x 6 (serial position) mixed ANOVA. This was done separately for the verbal and visuo-spatial stimuli in the dual-modality groups.

	Main effects		Interaction
	Group	Serial Position	
Verbal			
SP1 (FR)	$F(2,57) = .410$, $MSE = .066$, $\eta^2_p = .014$, $p = .665$	**$F(4,228) = 8.21$, $MSE = .034$, $\eta^2_p = .126$, $p < .001$**	$F(8,228) = .840$, $MSE = .034$, $\eta^2_p = .029$, $p = .568$
AV = 20; PP = 20; AP = 20			
SP1 (SR)	$F(2,57) = .485$, $MSE = .098$, $\eta^2_p = .017$, $p = .618$	**$F(4,228) = 175$, $MSE = .014$, $\eta^2_p = .755$, $p < .001$**	$F(8,228) = .900$, $MSE = .014$, $\eta^2_p = .031$, $p = .518$
AV = 20; PP = 20; AP = 20			
Last 4	$F(2,54) = 1.38$, $MSE = .060$, $\eta^2_p = .049$, $p = .260$	**$F(5,270) = 67.6$, $MSE = .035$, $\eta^2_p = .556$, $p < .001$**	$F(10,270) = .937$, $MSE = .035$, $\eta^2_p = .034$, $p = .499$
AV = 20; PP = 19; AP = 18			
Visuo-Spatial			
SP1 (FR)	**$F(2,57) = 4.59$, $MSE = .059$, $\eta^2_p = .139$, $p = .014$**	**$F(4,228) = 4.48$, $MSE = .036$, $\eta^2_p = .073$, $p = .002$**	$F(8,228) = 1.70$, $MSE = .036$, $\eta^2_p = .056$, $p = .100$
VS = 20; PP = 20; AP = 20			
SP1 (SR)	$F(2,57) = 1.65$, $MSE = .040$, $\eta^2_p = .055$, $p = .200$	**$F(4,228) = 31.4$, $MSE = .016$, $\eta^2_p = .355$, $p < .001$**	**$F(8,228) = 2.92$, $MSE = .016$, $\eta^2_p = .093$, $p = .004$**
VS = 20; PP = 20; AP = 20			
Last 4	**$F(2,54) = 5.05$, $MSE = .043$, $\eta^2_p = .157$, $p = .010$**	**$F(5,270) = 53.5$, $MSE = .045$, $\eta^2_p = .498$, $p < .001$**	$F(10,270) = .839$, $MSE = .045$, $\eta^2_p = .030$, $p = .591$
VS = 19; PP = 19; AP = 19			

Note: all significant main effects and interactions are presented in bold. AV, VS, PP and AP stand for the number of participants contributing to the ANOVA from the auditory-verbal, visuo-spatial, parallel presentation and alternating presentation groups respectively.

Appendix 3.9

Experiment 5: The average number of auditory-words and visuo-spatial dots recalled for each of the eight possible output strategies for the first three outputs of the parallel presentation group

Auditory-words

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
PP Group	1.67	3.75	3.27	3.74	3.37	3.71	3.19	4.12
AP Group								
SP1 = D	0.50		3.77	3.88	3.70	3.92	2.71	3.98
SP1 = W	1.50	2.00	3.90	3.67	3.70	3.91	2.62	3.62
Average	1.17	2.00	3.82	3.77	3.70	3.91	2.67	3.81

Visuo-Spatial Dots

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
PP Group	2.00	1.75	1.97	2.16	1.90	1.94	1.62	1.42
AP Group								
SP1 = D	1.50		1.75	1.47	1.61	1.67	1.64	1.27
SP1 = W	2.50	3.00	1.67	2.02	1.59	1.71	1.85	1.36
Average	2.17	3.00	1.72	1.75	1.60	1.69	1.74	1.31

Note: W stands for word; D stands for dot

Appendix 3.10A

Experiment 5. The frequency by which a specific item in a specific serial position (*n*) was outputted and followed by another outputted item (*n* + 1) in the parallel presentation group

	Output *n* +1												
n	1D	1W	2D	2W	3D	3W	4D	4W	5D	5W	6D	6W	Blank
1D		36	19	80	6	14	2	16		8		5	105
1W	136		18	81	13	25	9	10	5	10	5	6	296
2D	3	11		21	13	51	4	23	2	19	1	10	109
2W	15	6	108		17	43	14	25	7	8	6	9	274
3D	3	4	7	8		22	4	42	3	13	1	12	119
3W	15	6	23	22	74		22	31	8	15	4	12	306
4D	4	15	2	10	5	19		16	10	38	3	20	122
4W	15	4	16	6	17	10	94		21	39	12	16	319
5D	1	22	4	28	4	31	6	64		27	4	64	98
5W	13	8	8	6	10	9	27	14	201		25	41	314
6D	1	31	4	13	3	21	3	43	16	177		54	103
6W	21	10	5	9	3	13	6	24	28	31	331		311
Blank	30	141	53	209	72	245	71	233	46	203	41	200	4853
Total	257	294	267	493	237	503	262	541	347	588	433	449	7329

Appendix 3.10B

Experiment 5. The frequency by which a specific item in a specific serial position (*n*) was outputted and followed by another outputted item (*n* + 1) in the alternating presentation group

	Output *n* +1												
n	1D	1W	2D	2W	3D	3W	4D	4W	5D	5W	6D	6W	Blank
1D		57	6	120	1	23		16	1	13	1	11	76
1W	182		24	79	20	17	6	8	8	6	10	7	357
2D	1	7		42	9	85	3	30		22	2	19	83
2W	12	1	138		39	33	10	16	6	7	3	3	356
3D	2	7	2	24		33	8	46	6	40	1	12	91
3W	11	3	29	10	69		19	28	12	7	10	7	371
4D	5	7	2	10	3	15		32	4	27	5	32	68
4W	8	6	22	3	30	12	41		30	28	11	16	354
5D	2	9	3	11	1	14	7	14		30	15	49	85
5W	14	9	11	3	12	7	30	26	86		38	36	357
6D		24	3	17	4	15	2	16	7	34		59	135
6W	6	8	8	5	16	15	13	15	23	66	140		380
Blank	24	128	48	273	61	275	65	284	45	270	48	316	4688
Total	267	266	296	597	265	544	204	531	228	550	284	567	7401

Appendix 3.11

Experiment 5. The frequency by which a specific item in a specific serial position (*n*) was outputted and followed by another outputted item (*n* + 1) for the alternating presentation group using overall serial positions and output orders.

	Output *n* +1																								
n	1D	1W	2D	2W	3D	3W	4D	4W	5D	5W	6D	6W	7D	7W	8D	8W	9D	9W	10D	10W	11D	11W	12D	12W	Blank
1D				29	3			51				8				6				4	1			8	39
1W			110			33	7			9	7			5	3			4	3			4	6		164
2D		28				69	3			15	1			10				9	1			3			37
2W	72				17			46	13			8	3			3	5			2	4			3	193
3D	1			3				17	4			45	2			14				5	2			8	43
3W			7				69			14	20			7	8			3	4				1		180
4D		4				25				40	5			16	1			17				11			40
4W	5			1	69				19			19	2			9	2			4	2			3	176
5D	1			7	1			14				13	3			20	1			22				3	48
5W		2	6			5	19				36			5	6			1	9			6	5		181
6D			1			10	1			20				26	5			18	5			9	1		43
6W	5			1	10			5	33				13			23	3			6	5			1	190
7D	3			4	1			6	1			8				19	2			19	5			12	36
7W		4	3			2	16			5	15				18			11	15			7	4		173
8D		3	2			4	1			7	2			13				8	2			20			32
7W	5			2	6			1	15			7	23				15			17	7			9	181
9D	2			4	2			4	1			5	3			6				12	4			22	41
9W		4	3			3	6			4	9			11	18				51			17	15		161
10D		5				7	1			9				8	4			18				27	11		44
10W	11			5	5				3			3	12			15	35				23			19	196
11D				14	3			5	1			7	1			9	3			19				24	71
11W		5	3			3	6			7	10			7	5			38	12				69		200
12D		10				12				8	3			7	1			15	4			35			64
12W	3			3	2			2	6			8	8			8	11			28	71				180
Blank	13	54	11	74	22	128	26	145	32	127	29	148	42	143	23	141	24	123	21	147	20	159	28	157	4688
Total	121	119	146	147	141	301	155	296	128	265	137	279	112	258	92	273	101	265	127	285	144	298	140	269	7401

Note: 'Blank' refers to those instances where participants made an error or a non-response

Appendix 3.12A

Experiment 5: The number of occurrences of each of the four types of possible transitions at each possible lag transition for the parallel presentation group

Overall Transitions

		D	W
from	D	138	1088
	W	1352	549

0 lag		D	W
from	D		176
	W	944	

+ 1 lag		D	W
from	D	50	275
	W	103	235

- 1 lag		D	W
from	D	37	279
	W	110	83

+ 2 lag		D	W
from	D	16	70
	W	47	81

- 2 lag		D	W
from	D	12	88
	W	47	45

+ 3 lag		D	W
from	D	5	47
	W	20	30

- 3 lag		D	W
from	D	11	64
	W	26	23

+ 4 lag		D	W
from	D	1	18
	W	11	19

- 4 lag		D	W
from	D	5	35
	W	18	17

+ 5 lag		D	W
from	D	0	5
	W	5	6

- 5 lag		D	W
from	D	1	31
	W	21	10

Appendix 3.12B

Experiment 5: The number of occurrences of each of the four types of possible transitions at each possible lag transition for the alternating presentation group

Overall Transitions

		D	W
from	D	106	1022
	W	1147	487

0 lag		D	W
from	D		253
	W	656	

+ 1 lag		D	W
from	D	42	327
	W	150	204

- 1 lag		D	W
from	D	20	94
	W	124	115

+ 2 lag		D	W
from	D	15	125
	W	53	56

- 2 lag		D	W
from	D	7	47
	W	58	28

+ 3 lag		D	W
from	D	1	50
	W	22	22

- 3 lag		D	W
from	D	12	33
	W	35	24

+ 4 lag		D	W
from	D	3	32
	W	11	9

- 4 lag		D	W
from	D	5	26
	W	22	14

+ 5 lag		D	W
from	D	1	11
	W	10	7

- 5 lag		D	W
from	D	0	24
	W	6	8

Appendix 3.12C

Experiment 5: The number of occurrences of each of the four types of possible transitions at each possible lag transition for the alternating presentation group using overall serial position

Overall Transitions

		D	W
from	D	106	1022
	W	1147	487

+ 1 lag		D	W
from	D		284
	W	440	

- 1 lag		D	W
from	D		189
	W	374	

+ 2 lag		D	W
from	D	42	
	W		204

- 2 lag		D	W
from	D	20	
	W		115

+ 3 lag		D	W
from	D		226
	W	88	

- 3 lag		D	W
from	D		71
	W	89	

+ 4 lag		D	W
from	D	15	
	W		56

- 4 lag		D	W
from	D	7	
	W		28

+ 5 lag		D	W
from	D		92
	W	38	

- 5 lag		D	W
from	D		35
	W	41	

+ 6 lag		D	W
from	D	1	
	W		22

- 6 lag		D	W
from	D	12	
	W		24

+ 7 lag		D	W
from	D		34
	W	19	

- 7 lag		D	W
from	D		27
	W	25	

+ 8 lag		D	W
from	D	3	
	W		9

- 8 lag		D	W
from	D	5	
	W		14

+ 9 lag		D	W
from	D		15
	W	8	

- 9 lag		D	W
from	D		31
	W	16	

+ 10 lag		D	W
from	D	1	
	W		7

- 10 lag		D	W
from	D	0	
	W		8

+ 11 lag		D	W
from	D		8
	W	6	

- 11 lag		D	W
from	D		10
	W	3	

Appendix 4.1

Experiment 6: Analyses of the resultant Serial Position curves of Experiment 6 using trials starting with SP1 in FR scoring, SP1 in SR scoring and one of the Last 4 items using FR Scoring respectively (see Figure 4.5). This was done separately for the verbal and visuo-spatial stimuli in the dual-modality groups, whereby the performance of each of the single-modality groups (auditory-verbal and visuo-spatial) was compared to the verbal and visuo-spatial performance of the randomised presentation groups. In those trials starting with SP1, the free recall data were subjected to a 2 (group: either auditory-verbal, randomised presentation or visuo-spatial and randomised presentation) x 5 (serial position 2-6) mixed ANOVA. SP1 was excluded since it was, by definition, always recalled. In those trials were recall was initiated with one of the last four items, the data were subjected to a 2 (group: see above) x 6 (serial position) mixed ANOVA.

	Main effects		Interaction
	Group	Serial Position	
Verbal Data			
SP1 (FR) AV = 20; RP = 20	$F(1,38) = .082$, $MSE = .065$, $\eta^2_p = .002$, $p = .776$	**$F(4,152) = 24.2$, $MSE = .019$, $\eta^2_p = .389$, $p < .001$**	$F(4,152) = 2.20$, $MSE = .019$, $\eta^2_p = .055$, $p = .071$
SP1 (SR) AV = 20; RP = 20	$F(1,38) = .003$, $MSE = .080$, $\eta^2_p < .001$, $p = .959$	**$F(4,152) = 195.5$, $MSE = .010$, $\eta^2_p = .837$, $p < .001$**	$F(4,152) = .184$, $MSE = .010$, $\eta^2_p = .005$, $p = .947$
Last 4 AV = 19; RP = 20	$F(1,37) = .037$, $MSE = .059$, $\eta^2_p = .001$, $p = .848$	**$F(5,185) = 57.8$, $MSE = .028$, $\eta^2_p = .610$, $p < .001$**	**$F(5,185) = 2.65$, $MSE = .028$, $\eta^2_p = .067$, $p = .024$**
Visuo-spatial Data			
SP1 (FR) VS = 20; RP = 20	**$F(1,38) = 4.42$, $MSE = .039$, $\eta^2_p = .104$, $p = .042$**	**$F(4,152) = 8.16$, $MSE = .020$, $\eta^2_p = .177$, $p < .001$**	$F(4,152) = 1.75$, $MSE = .020$, $\eta^2_p = .044$, $p = .142$
SP1 (SR) VS = 20; RP = 20	**$F(1,38) = 6.63$, $MSE = .028$, $\eta^2_p = .149$, $p = .014$**	**$F(4,152) = 40.8$, $MSE = .009$, $\eta^2_p = .518$, $p < .001$**	$F(4,152) = 2.36$, $MSE = .009$, $\eta^2_p = .058$, $p = .046$
Last 4 VS = 18; RP = 20	$F(1,36) = 2.03$, $MSE = .039$, $\eta^2_p = .053$, $p = .163$	**$F(5,180) = 26.5$, $MSE = .044$, $\eta^2_p = .424$, $p < .001$**	$F(5,180) = 1.34$, $MSE = .044$, $\eta^2_p = .036$, $p = .252$

Note: all significant main effects and interactions are presented in bold. AV, VS, and RP stand for the number of participants contributing to the ANOVA from the auditory-verbal, visuo-spatial and ransomised presentation groups respectively.

Appendix 4.2

Experiment 6: The average number of auditory-words and visuo-spatial dots recalled for each of the eight possible output strategies for the first three outputs of the randomised presentation group.

Auditory-words

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
First three items								
DDD	3.40	4.00	3.29	3.29	3.29	4.17	4.15	4.21
DDW	3.00	2.50	3.70	3.44	4.00	4.13	3.33	4.15
DWD	3.00		3.42	3.80	4.00	3.86	3.60	3.79
DWW	3.00	2.83	3.06	3.57	3.80	4.07	3.77	3.83
WDD	2.67	3.71	3.51	3.13	3.16	3.74	3.77	3.85
WDW	1.00	3.00	3.38	3.55	3.91	3.65	3.40	4.28
WWD	3.25	2.75	3.76	3.45	3.21	3.90	3.42	4.24
WWW	3.00	4.00	3.73	3.67	4.22	4.05	3.00	4.29
Average	2.90	3.38	3.52	3.50	3.63	3.94	3.64	4.07

Visuo-spatial Dots

	First three outputs							
	DDD	DDW	DWD	DWW	WDD	WDW	WWD	WWW
First three items								
DDD	2.00	1.50	2.14	1.86	1.86	1.96	1.31	1.26
DDW	1.00	1.50	1.67	1.33	2.17	1.46	1.00	1.48
DWD	2.00		1.63	1.60	1.83	1.81	1.40	1.32
DWW	2.00	0.83	1.06	1.21	1.20	1.71	1.46	1.10
WDD	2.00	2.43	1.74	0.63	1.58	1.53	1.08	1.27
WDW	1.50	1.00	1.88	1.18	1.82	1.59	1.50	0.80
WWD	2.50	2.50	2.12	1.55	1.50	1.59	1.50	0.82
WWW	3.50	1.60	1.87	1.67	1.56	2.00	1.33	0.88
Average	2.14	1.72	1.75	1.36	1.65	1.67	1.33	1.12

Note: W stands for word; D stands for dot

Appendix 4.3

Experiment 6. The frequency by which a specific item in a specific serial position (*n*) was outputted and followed by another outputted item (*n* + 1)

	Output *n* +1																								
n	1D	1W	2D	2W	3D	3W	4D	4W	5D	5W	6D	6W	7D	7W	8D	8W	9D	9W	10D	10W	11D	11W	12D	12W	Blank
1D			2	20	4	22		20	2	14		6	1	6		10	1	2		3	2	4		4	50
1W			31	41	18	23	13	14	5	11	4	3	5	4	6	5	6	4	4	5	7	2	6	3	146
2D		17			9	8		6	1	12	6	5		6	1	5	2	7		5		4		6	44
2W	27	1			7	42	9	19	15	12	7	14	5	4	4	6	2	2	6	4	1	7	9	3	149
3D		13		13			2	10	4	9	2	10	2	6		6		4	1	6	1	6	1	6	61
3W	13	2	6	4			14	27	9	20	4	12	3	4	6	3	5	2	2	1	3	6	5	3	162
4D		7	2	8		6			5	7		5	1	7	1	4	1	7	1	9	1	7		2	58
4W	7	4	12	2	12				9	27	7	10	7	8	3	5	5	5	4	6	6	6	4	6	136
5D		3		5	1	6	4	8			2	1	1	11		10		10		7	1	6		5	50
5W	4		3	1	8	2	6	1			3	13	7	8	4	9	8	6	3	5	7	9	5	10	160
6D		4		4	1	4	1	3	1	4			5	4	4	1		4		4	2	6		4	42
6W	11		8	1	5		6	2	9	2			4	14	3	8	3	2	3	4	8	11	4	2	144
7D		1	1	6	2	2	2	4		4	1	5			3	9	1	2	1	5		6		4	45
7W	5	4	5	2	9	3	3		9	1	7	3			1	13	4	12	6	8	2	1	6	7	143
8D	2	2		4		3	1	4		3	1	4	2	2			2	2	1	3	1	3		7	47
7W	6	1	3	2	7	2	6	2	8	1	3	5	3	2			7	17	2	7	2	13	13	8	145
9D	1	3		5				2				8	2	5	1	5				9	1	9		11	54
9W	6	4	4	4	7	2	6	1	6	1	7	1	5	1	3	1			1	17	8	12	7	14	165
10D	1			5	1	4	2	2		4		5		1	1	1	4	5				4	1	6	38
10W	5	5	7	3	6	2	8	2	3	3	6	3	3	5	7	4	4	4			10	18	6	25	185
11D	1	3	1	3		2		2	1	6	1	6	2	4	2	6	1	7	2	11			6	13	44
11W	8	4	6	1	7	5	4	3	3	1	6	3	7	6	3	5	8	9	6	10			14	35	224
12D	1	6	1	12	1	6		4	1	7	2	4		7		9		9	2	13	2	10			49
12W	15	14	2	4	7	4	6	3	8	2	7	5	5	7	6	9	8	7	7	12	11	11			249
Blank	23	75	28	78	35	95	37	124	30	108	20	105	30	116	31	110	37	132	25	130	32	158	29	153	4965
Total	136	173	122	228	147	243	130	263	129	259	96	236	100	238	90	244	109	261	77	284	108	319	116	337	7555

Note: 'Blank' refers to those instances where participants made an error or a non-response

Appendix 4.4
Experiment 6: The number of occurrences of each of the four types of possible transitions at each possible lag transition

Overall Transitions

		D	W
from	D	142	793
	W	861	908

+ 1 lag		D	W
from	D	36	87
	W	101	264

- 1 lag		D	W
from	D	17	86
	W	94	39

+ 2 lag		D	W
from	D	17	74
	W	73	144

- 2 lag		D	W
from	D	11	64
	W	78	40

+ 3 lag		D	W
from	D	6	82
	W	61	92

- 3 lag		D	W
from	D	5	47
	W	47	24

+ 4 lag		D	W
from	D	11	56
	W	44	53

- 4 lag		D	W
from	D	5	31
	W	52	25

+ 5 lag		D	W
from	D	3	42
	W	37	38

- 5 lag		D	W
from	D	2	32
	W	43	18

+ 6 lag		D	W
from	D	4	34
	W	29	29

- 6 lag		D	W
from	D	5	17
	W	33	16

+ 7 lag		D	W
from	D	4	35
	W	21	24

- 7 lag		D	W
from	D	4	20
	W	28	12

+ 8 lag		D	W
from	D	2	15
	W	19	20

- 8 lag		D	W
from	D	1	14
	W	26	15

+ 9 lag		D	W
from	D	1	13
	W	10	15

- 9 lag		D	W
from	D	3	9
	W	18	10

+ 10 lag		D	W
from	D	2	10
	W	16	5

- 10 lag		D	W
from	D	2	15
	W	10	8

+ 11 lag		D	W
from	D	0	4
	W	6	3

- 11 lag		D	W
from	D	1	6
	W	15	14

Appendix 4.5

Experiment 7: Analyses of the resultant Serial Position curves of Experiment 7 using trials starting with SP1 in FR scoring, SP1 in SR scoring and one of the Last 4 items using FR Scoring respectively (see Figure 4.15). This was done separately for the verbal and visuo-spatial stimuli in the dual-modality groups, whereby the performance of each of the single-modality groups (auditory-verbal and visuo-spatial) was compared to the verbal and visuo-spatial performance of the randomised presentation groups. In those trials starting with SP1, the free recall data were subjected to a 2 (group: either auditory-verbal, randomised presentation or visuo-spatial and randomised presentation) x 5 (serial position 2-6) mixed ANOVA. SP1 was excluded since it was, by definition, always recalled. In those trials were recall was initiated with one of the last four items, the data were subjected to a 2 (group: see above) x 6 (serial position) mixed ANOVA.

	Main effects		Interaction
	Group	Serial Position	
Verbal Data			
SP1 (FR) Pre = 19; Post = 20; RP = 20	$F(2,56) = .405$, $MSE = .053$, $\eta^2_p = .014$, $p = .669$	**$F(4,224) = 18.9$, $MSE = .029$, $\eta^2_p = .252$, $p < .001$**	$F(8,224) = .970$, $MSE = .029$, $\eta^2_p = .033$, $p = .460$
SP1 (SR) Pre = 19; Post = 20; RP = 20	$F(2,56) = 2.56$, $MSE = .100$, $\eta^2_p = .084$, $p = .087$	**$F(4,224) = 200.3$, $MSE = .013$, $\eta^2_p = .782$, $p < .001$**	$F(8,224) = .320$, $MSE = .013$, $\eta^2_p = .011$, $p = .958$
Last 4 Pre = 18; Post = 20; RP = 20	**$F(2,55) = 4.41$, $MSE = .070$, $\eta^2_p = .138$, $p = .017$**	**$F(5,275) = 85.7$, $MSE = .036$, $\eta^2_p = .609$, $p < .001$**	**$F(10,275) = 2.05$, $MSE = .036$, $\eta^2_p = .069$, $p = .028$**
Visuo-spatial Data			
SP1 (FR) Pre = 20; Post = 19; RP = 20	**$F(2,56) = 11.4$, $MSE = .087$, $\eta^2_p = .288$, $p < .001$**	**$F(4,224) = 24.9$, $MSE = .020$, $\eta^2_p = .308$, $p < .001$**	$F(8,224) = 1.86$, $MSE = .020$, $\eta^2_p = .062$, $p = .067$
SP1 (SR) Pre = 20; Post = 19; RP = 20	**$F(2,56) = 3.94$, $MSE = .049$, $\eta^2_p = .123$, $p = .025$**	**$F(4,224) = 123.8$, $MSE = .010$, $\eta^2_p = .689$, $p < .001$**	$F(8,224) = 1.21$, $MSE = .010$, $\eta^2_p = .041$, $p = .294$
Last 4 Pre = 20; Post = 20; RP = 20	**$F(2,57) = 14.8$, $MSE = .090$, $\eta^2_p = .342$, $p < .001$**	**$F(5,285) = 25.6$, $MSE = .031$, $\eta^2_p = .310$, $p < .001$**	$F(10,285) = 1.08$, $MSE = .031$, $\eta^2_p = .037$, $p = .377$

Note: all significant main effects and interactions are presented in bold. Pre, Post and RP stand for the number of participants contributing to the ANOVA from the precued, postcued and randomised presentation groups respectively.

Appendix 4.6

Experiment 7: The average number of auditory-words and visuo-spatial locations recalled for each of the eight possible output strategies for the first three outputs of the randomised presentation group.

Auditory-words

	First three outputs							
	RRR	RRW	RWR	RWW	WRR	WRW	WWR	WWW
First three items								
RRR	3.50	3.00	3.89	4.07	2.88	4.11	3.31	3.98
RRW	3.25		3.65	3.88	4.50	4.00	4.19	3.97
RWR	2.89	3.67	3.65	3.81	4.10	3.79	3.78	3.82
RWW	3.33	4.00	3.78	4.00	3.29	4.06	3.96	3.87
WRR	3.00	3.00	4.00	3.33	3.85	4.08	3.58	3.99
WRW	3.00	3.00	4.14	3.88	4.33	3.97	4.00	3.85
WWR	3.80	2.00	3.43	4.13	4.00	4.02	4.16	3.80
WWW	3.00	3.00	3.25	3.86	3.50	4.16	4.18	3.91
Average	3.20	3.20	3.74	3.93	3.83	4.01	3.93	3.90

Visuo-spatial Rectangles

	First three outputs							
	SSS	SSW	SWS	SWW	WSS	WSW	WWS	WWW
First three items								
RRR	3.13	5.00	3.56	3.13	2.63	3.46	3.44	2.91
RRW	2.33		3.06	3.59	4.75	3.76	3.48	2.90
RWR	3.17	4.67	4.00	3.50	3.80	3.57	3.26	2.92
RWW	2.24	4.00	4.00	3.17	3.57	3.34	3.78	2.66
WRR	2.58	4.00	3.80	3.33	3.54	3.29	3.21	2.84
WRW	2.95	3.00	4.00	3.41	3.87	3.57	3.65	2.89
WWR	3.20	1.00	3.43	3.53	3.75	3.46	4.16	2.42
WWW	3.22	5.00	2.25	3.00	3.88	3.45	3.50	2.60
Average	2.80	3.87	3.64	3.39	3.67	3.49	3.58	2.76

Note: W stands for word; R stands for rectangle

Appendix 4.7

Experiment 7. The frequency by which a specific item in a specific serial position (*n*) was outputted and followed by another outputted item (*n* + 1)

	Output *n* +1																								
n	1R	1W	2R	2W	3R	3W	4R	4W	5R	5W	6R	6W	7R	7W	8R	8W	9R	9W	10R	10W	11R	11W	12R	12W	Blank
1R			28	30	28	35	23	31	12	20	9	19	11	21	6	21	5	15	9	18	2	17	8	18	118
1W			76	85	47	45	28	37	15	17	14	13	7	8	14	15	9	10	8	13	13	7	12	4	77
2R	10	27			37	26	28	20	17	18	10	22	13	18	5	20	5	21	8	19	9	17	8	22	132
2W	70	4			23	83	23	39	28	39	16	25	14	17	12	9	9	10	13	8	9	7	16	4	87
3R	12	17	12	27			34	22	30	20	16	20	13	25	9	23	7	14	6	19	11	18	10	15	135
3W	37	5	15	1			28	69	30	32	19	28	17	17	10	10	10	20	17	23	20	9	10	9	98
4R	7	8	11	17	10	25			17	21	13	19	18	23	16	15	7	18	6	17	11	17	9	15	155
4W	28	3	27	5	31	5			13	43	22	29	16	13	19	17	18	18	14	11	16	9	9	18	96
5R	6	17	5	12	8	17	7	31			24	10	12	19	13	14	9	14	7	18	9	9	5	13	172
5W	19	4	27	7	24	11	21	5			20	41	7	22	17	24	16	21	13	10	16	8	15	9	89
6R	5	6	7	12	9	8	7	15	17	21			18	7	20	9	7	13	9	12	12	20	6	23	150
6W	18	3	17	3	19	5	20	5	20	6			20	32	13	23	17	21	18	17	13	12	31	13	103
7R	6	7	3	6	2	6	5	11	15	10	8	8			11	9	11	22	9	19	9	15	14	21	138
7W	18	5	17	4	17	4	23	5	16	10	13	11			16	32	16	17	25	14	18	24	8	14	118
8R	5	5	6	17	5	14	8	11	11	9	6	18	2	13			12	12	16	17	6	13	7	20	139
7W	25	7	15	2	14	3	27	6	17	2	19	4	20	12			20	31	25	40	23	18	15	15	88
9R	5	8	5	5	1	11	10	13	5	13	7	9	5	8	14	14			12	17	14	26	11	17	147
9W	21	7	21	4	25	9	21	7	16	5	26	11	19	4	19	8			15	39	19	28	22	26	131
10R	3	8	3	5	8	9	6	10	8	8	11	17	3	19	7	16	15	21			15	14	13	12	131
10W	25	2	25	5	23	9	23	2	28	3	26	9	22	9	12	17	19	22			28	60	24	39	126
11R	5	8	7	12	3	13	5	12	9	6	11	18	14	20	10	15	7	19	19	12			17	21	127
11W	23	2	26	14	25	13	17	8	15	6	17	13	18	16	26	9	28	14	19	16			30	60	162
12R	4	5	11	15	5	21	7	3	2	17	7	10	6	20	4	5	10	18	7	15	14	16			146
12W	27	9	26	6	25	7	26	5	27	13	19	9	13	14	23	17	31	24	24	21	25	21			209
Blank	36	45	61	57	95	50	64	64	69	59	71	51	69	56	68	64	82	68	59	89	59	79	53	113	6315
Total	415	212	451	351	484	429	461	431	437	398	404	414	357	413	364	406	370	463	359	484	371	464	353	5210	9389

Note: 'Blank' refers to those instances where participants made an error or a non-response

Appendix 4.8

Experiment 7: The number of occurrences of each of the four types of possible transitions at each possible lag transition

Overall Transitions

		R	W
from	R	1340	2074
	W	2699	2117

+ 1 lag		R	W
from	R	225	189
	W	289	575

- 1 lag		R	W
from	R	128	215
	W	272	111

+ 2 lag		R	W
from	R	185	199
	W	226	314

- 2 lag		R	W
from	R	85	152
	W	226	96

+ 3 lag		R	W
from	R	120	168
	W	195	220

- 3 lag		R	W
from	R	67	109
	W	219	75

+ 4 lag		R	W
from	R	85	143
	W	134	153

- 4 lag		R	W
from	R	57	101
	W	163	64

+ 5 lag		R	W
from	R	71	137
	W	90	94

- 5 lag		R	W
from	R	48	85
	W	128	47

+ 6 lag		R	W
from	R	44	104
	W	90	69

- 6 lag		R	W
from	R	35	61
	W	115	33

+ 7 lag		R	W
from	R	33	91
	W	71	66

- 7 lag		R	W
from	R	25	48
	W	113	41

+ 8 lag		R	W
from	R	33	67
	W	51	45

- 8 lag		R	W
from	R	18	29
	W	97	30

+ 9 lag		R	W
from	R	28	50
	W	27	29

- 9 lag		R	W
from	R	15	41
	W	76	23

+ 10 lag		R	W
from	R	10	39
	W	29	11

- 10 lag		R	W
from	R	16	23
	W	49	8

+ 11 lag		R	W
from	R	8	18
	W	12	4

- 11 lag		R	W
from	R	4	5
	W	27	9